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- **A multi-criteria model** for maintenance job scheduling
- Application of FT-NIR spectroscopy to the measurement of fruit firmness of "Fuji" apples
- Biological indices for classification of water quality around *Mae Moh* power plant, Thailand

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Texts:

2. A. I. Vogel, "A Textbook of Practical Organic Chemistry", 3rd Edn., Longmans, London, 1956.

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Thesis / Dissertation:

4. W. phutdhawong, "Isolation of glycosides by electrolytic decolourisation and synthesis of pentinomycin", *PhD. Thesis*, **2002**, Chiang Mai University, Thailand.

Patents:

5. K. Miwa, S. Maeda, and Y. Murata, " Purification of Stevioside by Electrolysis", *Jpn. Kokai Tokkyo Koho 79 89,066* (1979).

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Editor's note

Since its launching a year ago, the reception for this journal from contributors has been unexpectedly overwhelming. Our first concern over the journal's potential doom due to scanty support has thus been turned the other way round. Our main problem is now how to turn out published articles quickly enough to ensure that our claim of 'rapid' publication is real. We have had to apologise many authors for an unusual delay in publication due to our own undermanned and underfinanced editorial team.

In this regard, the contributors can help us to a great extent by adjusting their articles exactly as per the journal's format, especially in the reference section. Most important of all, however, is the need for their manuscripts to be properly edited for English and style in order that they can be much more rapidly processed.

Duang Buddhasukh
Editor-in-Chief

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Full Paper

A multi-criteria model for maintenance job scheduling

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Abstract: This paper presents a multi-criteria maintenance job scheduling model, which is formulated using a weighted multi-criteria integer linear programming maintenance scheduling framework. Three criteria, which have direct relationship with the primary objectives of a typical production setting, were used. These criteria are namely minimization of equipment idle time, manpower idle time and lateness of job with unit parity. The mathematical model constrained by available equipment, manpower and job available time within planning horizon was tested with a 10-job, 8-hour time horizon problem with declared equipment and manpower available as against the required. The results, analysis and illustrations justify multi-criteria consideration. Thus, maintenance managers are equipped with a tool for adequate decision making that guides against error in the accumulated data which may lead to wrong decision making. The idea presented is new since it provides an approach that has not been documented previously in the literature.

Keywords: multi-criteria analysis, decision-making, maintenance-scheduling, optimisation, truck plant

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Introduction

Contemporary industrial systems strive for both quality and cost-effectiveness as a result of the challenges of optimally managing their processes and facilities through effective and efficient maintenance schemes [1-7]. Thus, a properly planned and implemented maintenance scheduling programme would guarantee efficient utilisation of machines, rapid response to demands and the achievement of specific deadlines [8]. However, maintenance could be linked with the multi-facet objective of industrial systems. Hence, modelling, simulating, and analysing industrial system problems with multi-objective formulations are more realistic than formulating models and solving them through a single objective of system. Consequently, when such multi-objective frameworks have unit-parity, a single multi-criteria objective formulation may be used in place of the inherently multi-objective formulation with unit disparity. These arguments inform the methods used in this work.

In the maintenance scheduling literature, a number of approaches have been used in tackling the problem [9-12]. In addition, Jarvis [13] developed a heuristic computerised maintenance system for planning and scheduling. This model includes a scheme that allocates manpower to jobs based on First In First Out (FIFO) queue discipline. Roberts and Escudero [14] proposed a deterministic integer linear programming model in which personnel availability is given. The model is not multi-criteria. Roberts and Escudero [15] further revised the earlier work to obtain a minimum size model. Worrall and Mert [16] proposed dynamic heuristic and deterministic rules for maintenance planning and scheduling which does not address a multi-criteria concern. Duffuaa and Al-Sultan [17,18] proposed a stochastic formulation of the maintenance scheduling problem as an extension of Roberts and Escudero's [14] work. This again did not address a multi-criteria or multi-objective proposition. Based on the obvious gaps identifiable in the literature, this work addresses the multi-criteria concern. The approach is similar to the framework presented by Ogunwolu and Popoola [19].

The paper consists of four sections. The introduction provides the motivation for the study, the definition of the problem, the research objective, a literature review and the expected contributions. The methodology employed for the maintenance job scheduling is presented in section two. This shows the framework of the multi-criteria integer linear programming (MILP) problem formulated and solved. Section three presents the results obtained in running the model and its variants. It also shows a number of deductions made in line with the method of analysis. Discussions are also made on the optimal values and other values of importance. In section four, conclusions are made to justify the current approach and future directions given.

Methodology

Preamble

The maintenance job scheduling problem was modeled as a multi-criteria integer linear programming problem with three criteria. The three criteria used run parallel to the three major goals of typical manufacturing system. They are based on minimisation of equipment idle times, personnel idle times and delay in scheduling and presented in the next sub-section. These criteria have time-parity and are hence integrated as a single objective problem with integrated criteria. The problem space is constrained by specified jobs arrival (due routine maintenance) times, job-specific and unique time commencement of maintenance, as well as the need for the required personnel and equipment to be met by the available personnel and equipment at any time point within the schedule time-horizon. The schedule time-horizon is discretised at one-hour intervals of time. Job arrivals and maintenance, durations also have integral values.

The main model

The maintenance problem on hand is modeled as

$$\text{Minimize}\left\{\sum_{\ell}\sum_{k}\left(TE_{\ell k(\ell)}-\sum_{i}\sum_{j}x_{ij}t_i n^{e}_{i\ell k(\ell)}\right)+\sum_{p}\left(TM_p-\sum_{i}\sum_{j}x_{ij}t_i n^{m}_{ip}\right)+\sum_{i}\sum_{j}x_{ij}\left(j-a_i\right)\right\}$$

subject to:

$$\sum_{i}x_{ij}\left(j-a_i-1\right)\geq 0 \text{ for each } j \qquad (1)$$

$$\sum_{j}x_{ij}\leq 1 \text{ for each job } i \qquad (2)$$

$$\sum_{i}x_{ij}\geq 0 \text{ for each } j \qquad (3)$$

$$\sum_{r}x_{ir}n^{e}_{i\ell k(\ell)}\leq E_{\ell k(\ell)} \text{ for each } i,\ell,k\ . \qquad (4)$$

$$\sum_{r}x_{ir}n^{m}_{ip}\leq M_p \text{ for each } i,p \qquad (5)$$

$$x_{ij}=\begin{cases}1 & \text{if job i is scheduled at time j}\\ 0 & \text{otherwise}\end{cases} \qquad (6)$$

$$j\leq T \qquad (7)$$

$$a_i+2\leq r\leq j-1 \qquad (8)$$

T = scheduling time-horizon
$E_{\ell k(\ell)}$ = the maximum available number of Equipment of group ℓ type $k(\ell)$
M_p = the maximum available number of manpower of category p available
t_i = duration of job i
$n^{e}_{i\ell k(\ell)}$ = number of equipment group ℓ type $k(\ell)$ needed for job i
n^{m}_{ip} = number manpower category p needed for job i
a_i = due time for routine maintenance of job i within schedule time-horizon

Model Criteria

Criterion 1 measures the idle time of equipment. It constitutes the first term in the objective function and is expressed as a difference of the total time of availability of all equipment (i.e. $TE_{\ell k(\ell)}$) and the time the equipment are in use (i.e. $\sum_{i}\sum_{j}x_{ij}t_i n^{e}_{i\ell k(\ell)}$) over the schedule horizon. *Criterion 2* measures personnel idle time. It constitutes the second term in the objective function and is expressed as a difference of the total time of availability of all personnel of different trades, (i.e TM_p) and the time they are engaged, (i.e. $\sum_{i}\sum_{j}x_{ij}t_i n^{m}_{ip}$) within the schedule horizon. *Criterion 3* measures the job delay. It constitutes the third term in the objective function and is expressed as the difference between the actual schedule time, j and the job arrival time, a_i over all jobs and the schedule horizon.

The three criteria that result in downtime for the system considered here are idle time of equipment, personnel idle time, and job delays. This downtime can be classified as avoidable and unavoidable. Avoidable idle time relates to those created artificially by the system due to non-provision of resources needed for the maintenance job when needed. Unavoidable idle time relates to those due to naturally uncontrollable situations such as unplanned absence of key maintenance staff at work, thereby creating a job implementation vacuum. In general, other causes of idle time/downtime include (i) inefficient material ordering system, which leads to delay in the receipt of materials; (ii) untimely release of funds to execute projects by the accounts department; and (iii) unexpected damage to funding equipment or its non-functionality.

Model Constraints

Constraint 1 stipulates the earliest time a job can be scheduled. *Constraint 2* constrains the model to schedule a job once or not schedule at all. *Constraint 3* allows none or more than one job to be scheduled at any discrete time point, j. *Constraint 4* stipulates that the maximum number of individual equipment group tools in use at any time j cannot exceed the maximum available. *Constraint 5* stipulates that the maximum number engaged of an individual personnel group at any time j cannot exceed the maximum available. *Constraint 6* is the binary integer decision variable for determining schedule time points that optimises the objective function. *Constraint 7* constrains all schedule time points to be within the stipulated time-horizon T. *Constraint 8* specifies a range of value of discrete time point based on maintenance duration of individual jobs during which relevant equipment and personnel are kept in use.

Model Variants

From the above, variants of the main model for different combinations of criteria are obtainable (Table 1). For all variants, constraints (1), (2), (3), (6) and (7) govern. Here, for each variant the governing criteria are marked (√) and additional constraints (apart from the common ones) marked as (†).

Table 1. Variants of the model with criteria combinations and variable constraints

Variant	Criteria Combinations			Constraints		
	1	2	3	4	5	8
Main	√	√	√	†	†	†
1	√			†		†
2		√			†	†
3			√			
4	√	√		†	†	†
5	√		√	†		†
6		√	√		†	†

Case study

In order to verify the model in a case study, hypothetical data is used to illustrate the working of the model through the generation of a test problem. The data mimics that of a truck manufacturing company (Dynamics) located in Lagos, Nigeria. This company mostly engages skilled electricians, mechanical technicians, and labourers in the maintenance of its equipment. It is assumed that as soon as an equipment breaks down, it is ready for maintenance. Maintenance scheduling in Dynamics is typically an iterative process, which involves various steps with the aim of achieving cost effective maintenance. In Dynamics, a planned maintenance schedule is a properly organised report that would effectively handle the maintenance activities performed on the various equipment in the plant. It takes into consideration the frequency of activities that would be performed on equipment and facilities. It also optimally allots man-hours to activities based on the availability of manpower. Other concerns include safety precautions to be observed, the tools, materials and test equipment that should be made available. Each division in the organisation will submit request for a planned maintenance event. A planning group will be tasked with the responsibility of coordinating the entire maintenance request to produce a "least-cost" maintenance schedule observing reliability constraints. This schedule will be passed to the generation division, which will review the schedule in terms of resource constraints (e.g. availability of personnel and equipment) and suggest revision. The planning group incorporates these decisions in order to produce a revised maintenance schedule. Typically, there are multiple iterations between the planning group and the generation division before a maintenance schedule is approved.

The multi-criteria model was tested with a short term 10-job scheduling problem with time horizon of 8 hours (one day) with deterministic arrival times (due time for routine maintenance). The job parameter specifications giving the available time, ideally the routine maintenance due times that fall within the schedule time-horizon, and the estimated duration of time required for maintenance of individual jobs are given in Table 2.

Table 2. Job parameter specifications

Job i	Arrival time, a_i	Maintenance Duration t_i
1	0	2
2	4	3
3	3	2
4	2	2
5	5	2
6	4	3
7	3	1
8	7	2
9	6	1
10	5	3

It should be noted that constraint 1 of the Mathematical model above constrains the earliest schedule time of a job as 1 hour after the due time for its routine maintenance. This is ideal for practical considerations. Table 3 gives the schedule of needed and available (maximum number of) equipment. The equipment is classified as tool groups for simplicity with three mechanical tool groups and two for electrical.

Table 3. Job equipment needs and availability

Job	Equipment					
	Mechanical			Electrical		
	1	*2*	*3*	*1*	*2*	
i	4	5	4	4	6	Max.
1	1	2	2	1	2	Required
2	2	2	1	1	2	
3	2	2	2	1	2	
4	1	1	2	1	2	
5	2	1	2	2	1	
6	2	2	1	1	2	
7	2	1	2	1	2	
8	1	2	2	2	2	
9	2	2	1	1	2	
10	1	2	2	1	1	

Personnel available (maximum number) and those required for the individual jobs are specified in Table 4. Three classes of manpower: mechanical, electrical and supporting labour force, are specified.

Table 4. Job manpower needs and availability

Job	Manpower			
	Mechanical	Electrical	Labour	
i	7	6	7	Max
1	2	3	2	Required
2	3	2	3	
3	3	2	2	
4	1	2	1	
5	2	1	1	
6	3	2	3	
7	2	2	3	
8	2	1	1	
9	2	2	2	
10	1	1	2	

Method of solution

The test problem was run with the Integer Linear Programming module of the Quantitative Systems for Business Plus (QSB+) software for the solution of the main model formulated and its variants.

Methods of analysis

Apart from the optimal objective values realised, five other approaches are used in this paper to compare the results obtained and make necessary deductions:

1. *The number of jobs scheduled.* The model by Constraint (2) allows a job to be scheduled or unscheduled within the given time-horizon. The measure of the number of jobs scheduled or unscheduled is a measure of satisfactoriness of the model variant.
2. *The number of uncompleted jobs.* There are possibilities of jobs scheduled which cannot be completed within the time-horizon. This is a backlog which the next horizon schedule has to start with. The number of jobs completed together with the time duration left for completion can also serve as a basis of comparison of variants of the model.
3. *Equipment utilisation indices.* Hourly equipment utilisation index (HEUI) for each variant h of the model can be defined as
$$\lambda^{e}_{hj} = \sum_{k}\sum_{\ell}\left[\frac{\sum_{i}\left(x_{ij}+x_{ir}\right)n^{e}_{\ell k(\ell)}}{E_{\ell k(\ell)}}\right] \text{ for each } j \text{ and } x_{ij}=1 .$$
Thus, the total equipment utilisation index for each variant h within the time horizon T is
$$\eta^{e}_{h} = \frac{1}{T}\sum_{j=1}^{T}\lambda^{e}_{hj} .$$
4. *Manpower utilisation indices.* Hourly manpower utilisation index (HMUI) for each variant λ^{m}_{hj} is defined similar to HEUI as
$$\lambda^{m}_{hj} = \sum_{p}\left[\frac{\sum_{i}\left(x_{ij}+x_{ir}\right)n^{m}_{p}}{M_{p}}\right] \text{ for each } j \text{ and } x_{ij}=1 .$$
The total manpower utilisation index for a variant h is also defined as
$$\eta^{m}_{h} = \frac{1}{T}\sum_{j=1}^{T}\lambda^{m}_{hj} .$$
5. *Number of branch and bound iterations required.* The QSB+ solution procedure used zero integer tolerance and newest branching schemes. The number of iterations for the model and its variant is thus a level ground for their comparison.

Results and Discussion

The schedules obtained from running the model and its variants are as in Table 5. A number of deductions can be made in line with the methods of analysis enumerated in the previous section. These are summarised in Tables 6, 7 and 8. Other analyses emerged as in Tables 9 and 10. Statistical tests using t-Test were administered on the results obtained in Tables 7 and 8. These analyses are shown in Tables 9 and 10 respectively. The aim of this analysis is to find out whether or not there are significant differences between the main model and one of its variants. In using statistical test for the problem, the first step taken is to formulate the null hypothesis and alternative hypothesis also. If the mean of the main model is represented by μ_1, and that of the first variant (and for any of the variants in subsequent analysis) is μ_2, then the null hypothesis is stated as: μ_1-μ_2 = 0. The alternative hypothesis is stated as: μ_1-$\mu_2 \neq 0$. The level of significance, α, equals 0.05.

Table 5. Job schedules for model and its variants

Model/ Variant	Time Point, j (hourly)							
	1	2	3	4	5	6	7	8
Main	*1*		*4*	*3*	*7*	*5, 6*	*9*	*2, 8*
1	*1*		*4*	*3*	*7*	*5,6*		*2, 10*
2	*1*		*4*	*3,7*	*6*	*5*	*9*	*2,8,10*
3*	*1*		*4*	*3,7*	*2,6*	*5,10*	*9*	*8*
4	*1*		*4*	*3*	*7*	*5,6*		*2,8*
5	*1*		*4*	*3*	*7*	*5,6*		*2,10*
6	*1*		*4*	*3,7*	*2*	*5*	*9*	*6,8,10*

* Constraint 2 relaxed as an equality constraint

The criterion is that the null hypothesis should be rejected if t <-1.89 or t >1.89, where 1.89 is the value of $t_{0.05}$ for 7 degrees of freedom. Since the means and variances of the two samples are 0.59 and 0.09 for sample 1, and 0.61 and 0.06 for sample 2, t equals -0.23. Then, since t = -0.23 does not exceed 1.89, the null hypothesis must be accepted. We conclude that the values from the two methods are the same, hence, significant difference does no exist between them. This analysis is only for data in Table 7, between the main method and variant 1. Similar analysis is then performed for the main method and other variants. This is also extended to the data in Table 8. The decisions are stated in Tables 9 and 10.

Table 6. Deductions from optimal schedules

Model / variant	Optimal value (hrs)	No. of iterations	No. of jobs un-scheduled	Jobs un-completed	
				No.	Hours
Main	37	11	1	1	3
1	43	17	2	2	4
2	43	16	0	3	5
3	11	1	0	1	1
4	99	25	2	2	3
5	58	13	2	2	4
6	58	27	0	3	5

Optimal values

Apart from variant 3, a single criterion variant with trivial solution, the other non-single criteria variants have comparably better optima. For virtually all the measures of analysis identified, the non-single criteria variants and the main model have equally good or better comparative measures.

Table 7. Variants' equipment utilisation indices

Model/ Variant	Hourly Equipment Utilisation Index								Total
	1	2	3	4	5	6	7	8	
Main	0.35	0.35	0.20	0.55	0.70	0.60	1.00	1.00	0.60
1	0.35	0.35	0.30	0.70	0.74	0.70	0.70	1.00	0.60
2†	0.35	0.35	0.30	1.00	0.40	0.70	1.04	1.00	0.68
3†	0.35	0.35	0.30	1.00	1.09	1.04	1.04	1.43	0.83
4	0.35	0.35	0.30	0.70	0.74	0.70	0.70	1.00	0.60
5	0.35	0.35	0.30	0.70	0.74	0.70	0.70	1.00	0.60
6	0.35	0.35	0.30	1.00	0.74	0.74	1.04	1.04	0.68

†Some indices are greater than 1 since the measure is not reckoned within the variants.

Table 8. Variants' manpower utilisation indices

Model/ Variant	Hourly Manpower Utilisation Index								Total
	1	2	3	4	5	6	7	8	
Main	0.35	0.35	0.20	0.70	0.74	0.70	0.90	1.00	0.63
1	0.35	0.35	0.20	0.55	0.70	0.60	0.60	1.00	0.54
2	0.35	0.35	0.20	0.90	0.75	0.60	0.90	0.90	0.62
3†	0.35	0.35	0.20	0.90	1.15	0.80	1.20	1.20	0.77
4	0.35	0.35	0.20	0.55	0.70	0.60	0.60	1.00	0.54
5	0.35	0.35	0.20	0.55	0.70	0.60	0.60	1.00	0.54
6	0.35	0.35	0.20	0.90	0.75	0.60	0.90	0.80	0.62

†Some indices are greater than 1 since the measure is not reckoned within the variants.

Table 9. t-Test paired two samples for means (analysis of data from Table 7)

Description	Main	Variant 1	Main	Variant 2	Main	Variant 3	Main	Variant 4	Main	Variant 5	Main	Variant 6
Mean	0.59	0.61	0.59	0.64	0.59	0.83	0.59	0.61	0.59	0.61	0.59	0.70
Variance	0.09	0.06	0.09	0.11	0.09	0.18	0.09	0.06	0.09	0.06	0.09	0.10
Correlation	0.89		0.79		0.89		0.89		0.89		0.89	
Hypothesised mean	0		0		0		0		0		0	
Df	7		7		7		7		7		7	
t Stat	-0.23		-0.67		-3.07		-0.23		-0.23		-1.93	
P(T≤ t) one tail	0.41		0.26		0.01		0.41		0.41		0.05	
t Critical one tail	1.89		1.89		1.89		1.89		1.89		1.89	
P(T≤ t) two tail	0.82		0.52		0.02		0.82		0.82		0.10	
t Critical two tail	2.36		2.36		2.36		2.36		2.36		2.36	
Decision	Not significant		Not significant		Significant		Not significant		Not significant		Significant	

Table 10. t-Test paired two samples for means (analysis of data from Table 8)

Description	Main	Variant 1	Main	Variant 2	Main	Variant 3	Main	Variant 4	Main	Variant 5	Main	Variant 6
Mean	0.62	0.54	0.62	0.62	0.62	0.77	0.62	0.54	0.62	0.54	0.62	0.61
Variance	0.08	0.06	0.08	0.08	0.08	0.17	0.08	0.06	0.08	0.06	0.08	0.08
Correlation	0.93		0.95		0.97		0.93		0.93		0.92	
Hypothesised mean	0		0		0		0		0		0	
Df	7		7		7		7		7		7	
t Stat	1.94		-0.04		-2.79		1.94		1.94		0.28	
P(T≤ t) one tail	0.05		0.49		0.01		0.05		0.05		0.39	
t Critical one tail	1.89		1.89		1.89		1.89		1.89		1.89	
P(T≤ t) two tail	0.09		0.97		0.03		0.09		0.09		0.79	
t Critical two tail	2.36		2.36		2.36		2.36		2.36		2.39	
Decision	Significant		Not significant		Significant		Significant		Significant		Not significant	

Conclusion

Professionals in the industry, particularly maintenance managers are facing many challenges in the rapidly changing modern world. The stiff competition in the global international business is forcing decision makers and researchers to review maintenance practices towards a more efficient maintenance organisation. In this paper an attempt has been made to demonstrate the development and application of the multi-criteria approach to maintenance job scheduling in order to generate more robust maintenance job schedules than with single criterion. From the literature, no prior research seems to have been documented in this regard. Thus, this appears to be an important contribution to knowledge. An important benefit of the present work to the maintenance scheduling community is the ability to capture holistic information of the system being studied. From the case study considered we have shown that it is feasible to implement the model in a particular instance. Further applications in different environments are possible with slight modifications in model parameters. Future studies may consider extension to the model by incorporating fuzziness, stochastic elements, and genetic optimisation techniques in order to have a wide range of data capture and analysis.

References

1. W. C. Lee and C. C. Wu, "Multi-machine scheduling with deteriorating jobs and scheduled maintenance", *Appl. Math. Modelling*, **2008**, *32*, 362-373.
2. D. L. Yang, C. J. Hsu, and W. H. Kuo, "A two-machine flowshop scheduling problem with a separated maintenance constraint", *Comput. Oper. Res.*, **2008**, *35*, 876-883.
3. S. A. Oke, "Maintenance scheduling: description, status, and future directions", *South African J. Ind. Eng.,* **2004**, *15*, 101-117.
4. S. A. Oke and O. E. Charles-Owaba, "An inflation-based maintenance scheduling model", *South African J. Ind. Eng.*, **2005**, *16*, 123-142.
5. S. A. Oke and O. E. Charles-Owaba, "A sensitivity analysis of an optimal Gantt charting maintenance scheduling model", *Int. J. Quality & Reliability Management*, **2006**, *23*, 197-229.
6. S. A. Oke and O. E. Charles-Owaba, "Application of fuzzy logic control model to Gantt charting preventive maintenance scheduling", *Int. J. Quality & Reliability Management*, **2006**, *23*, 441-459.
7. S. A. Oke and O. E. Charles-Owaba, "An approach for evaluating preventive maintenance scheduling cost", *Int. J. Quality & Reliability Management*, **2006**, *23*, 847-879.
8. A. B. Badiru, "Project management in manufacturing and high technology operations", 2nd Ed., John Wiley and Sons, New York, **1996**.
9. D. Xu, K. Sun, and H. Li, "Parallel machine scheduling with almost periodic maintenance and non-preemptive jobs to minimize makespan", *Comput. Oper. Res.*, **2008**, *35*, 1344-1349.
10. M. Ji, Y. He, and T. C. E. Cheng, "Single-machine scheduling with periodic maintenance to minimize makespan", *Comput. Oper. Res.*, **2007**, *34*, 1764-1770.
11. X. Qi, "A note on worst-case performance of heuristics for maintenance scheduling problems", *Discrete Appl. Math.*, **2007**, *155*, 416-422.

12. G. Mosheiov and D. Oron, “Due-date assignment and maintenance activity scheduling problem”, *Math. Comput. Modelling*, **2006**, *44*, 1053-1057.
13. W. J. Jarvis, “Maintenance planning and scheduling in petrochemical manufacturing environment”, *National Petroleum Refineries Association*, Wash. DC, **1980**, MC 80: 2, p. 1-12.
14. S. M. Roberts and L. F. Escudero, “Scheduling of plant maintenance personnel”, *J. Optimization Theory and Application*, **1983**, *39*, 323-343.
15. S. M. Roberts and L. F. Escudero, “Minimum problem-size formulation for the scheduling of plant maintenance personnel”, *J. Optimization Theory and Application*, **1983**, *39*, 345-362.
16. B. M. Worrall and B. Mert, “Applications of dynamic scheduling rules in maintenance planning and scheduling”, *Int. J. Production Res.*, **1980**, *18*, 57-71.
17. S. O. Duffuaa and K. S. Al-Sultan, “A mathematical model for effective maintenance planning and scheduling”, Proceedings of the 2nd Scientific Symposium on Maintenance Planning and Operations, Riyadh, **1993**, p.184-193.
18. S. O. Duffuaa and K. S. Al-Sultan, “Mathematical programming for the management of maintenance planning and scheduling”, *J. Qual. Mainten. Eng.*, **1997**, *3*, 163-176.
19. L. Ogunwolu and O. P. Popoola, “A stochastic multi-criteria model for maintenance job scheduling”, Accepted for the 2nd University of Lagos Research Fair, **2006**, Lagos, Nigeria.

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Full Paper

Application of FT-NIR spectroscopy to the measurement of fruit firmness of "Fuji" apples

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Abstract: This paper indicates the possibility of using near infrared (NIR) spectroscopy as a rapid method of predicting quantitatively fruit firmness of apple. A hundred "Fuji" apples were used as the study target in the experiment. A partial least square (PLS) algorithm was used to perform the calibration. To decide upon the number of PLS factors included in the PLS model, the model was chosen according to the lowest root mean square error of cross-validation (RMSECV) in training. The correlation coefficient R between the NIR predicted and the reference results for the test set were used as an evaluation parameter for the models. The best experimental results were obtained as follows: the PLS calibration model in fruit firmness determination was achieved with 12 PLS factors under MSC preprocessing method. The correlation coefficient between the NIR spectroscopy prediction results and reference measurement result was R = 0.74893. The study demonstrates that NIR spectroscopy technology with multivariate calibration analysis could be successfully applied as a rapid method to predict fruit firmness of apples.

Keywords: FT-NIR spectroscopy, apple, fruit firmness, PLS, RMSECV

Introduction

Apples are one of the most popular fruits across the world. "Fuji" apples are one of the most cultivated commercial apple cultivars in global production. With a raised consumption, quality control of apples is becoming increasingly important. Fruit firmness is one of the important quality parameters used for assessing apple quality [1-6]. Currently, fruit firmness is commonly measured with the Magness–Taylor (MT) firmness tester or similar testing devices. Yet, this quality measurement method is often destructive, inefficient or time consuming, and prone to operational error. Thus, a nondestructive sensing technique that is capable of measuring quality parameters of apple including fruit firmness would be of great value in ensuring consistently high quality fruits for the consumer.

Abundant literature exists on nondestructive sensing techniques for determining fruit firmness. For example, multispectral imaging based on light scattering principle was attempted to measure the internal quality of fruits including firmness [7-10]. First, the absorption and scattering properties of apple tissue over the visible and near infrared regions were acquired by multispectral imaging system, then a curve fitting algorithm for a steady-state diffusion theory model was proposed to determine absorption and reduced scattering coefficients from the spatially-resolved multispectral reflectance profiles. Finally, predictive model for measuring apple fruit firmness and soluble solid content (SSC) were calibrated by simple multi-regression analysis. Although, multispectral imaging is simple, fast and easily applied to measuring fruit firmness, precision of measuring results is not satisfying, especially in measuring fruit firmness; the correlative coefficient is often less than 0.7.

Additionally, in measuring fruit firmness, past research was largely focused on using mechanical methods, such as quasi-static compression, vibration, impact, and sonic or ultrasonic sensing [11-13]. These mechanical techniques have shown potential for measuring fruit firmness, but they are often difficult to implement or too slow for online sorting application. Therefore, it is necessary to replace time-consuming methods with a fast, accurate and nondestructive technique.

Near-infrared (NIR) spectroscopy has been proven to be a powerful analytical tool used in the agricultural, nutritional, petrochemical, textile and pharmaceutical industries [14-22]. It is a fast, accurate and non-destructive technique that can be used as a replacement of time-consuming chemical method. Near-infrared (NIR) spectroscopy has also proven to be effective for quantitatively analysing internal quality of fruits. Many studies on measuring fruit firmness of apple with NIR spectroscopy were cited [23-24].

In order to apply FT-NIR to predict quantitatively fruit firmness of apple, it is necessary to build a reliable calibration model. The objective of this research is to develop and prove the applicability of multivariate calibration to NIR data. The different steps that have to be undertaken in multivariate calibration were systematically studied. The partial least square (PLS) model was used and the study focused on the effect of the number of PLS factors and the method of spectral preprocessing. The robustness of the final PLS model was evaluated according to the root mean square error of cross-validation (RMSECV), the root mean square error of prediction (RMSEP), and the correlation coefficient (R).

Materials and Methods

Apple fruit samples

For this research, 100 “Fuji” apples were purchased from the local market in Zhenjiang City, Jiangsu Province of China. All of the apples were sent to the laboratory and non-destructively analysed by diffuse reflectance FT-NIR spectroscopy between 10,000-4,000 cm^{-1}, and also destructively analysed by a texture analyser for fruit firmness.

The apples were divided into two groups. The first group consisted of 60 apples used for developing the calibration model. The second group consisted of 40 apples used for prediction models. Each apple was measured at four equally spaced positions along the equator. For the reference measurement using a texture analyser, the measurement was conducted on peeled apples.

Spectral data acquisition

The reflectance NIR spectra of intact apples were measured by a FT-NIR spectrometer (Antaris™ II analyser, Thermo Electron Corporation, USA) with integrating sphere sampling module. The FT-NIR spectrometer had a spectral range of 10,000-4,000 cm^{-1} (1,000-2,500 nm) and the resolution was set at 8.0 cm^{-1} with 3.856 cm^{-1} data intervals, each spectrum having thus 1,557 data points. The number of the spectral scans was 32 in this experiment.

Figure 1 shows a schematic diagram of NIR diffuse reflectance measurement set-up. Diffuse reflectance measurement is simplified by using an integrating sphere. The light beam is directed into the sphere and travels directly through the center of the sphere and the optical window into the apple sample. The beam scatters off the sample and the reflected light beams re-enter the sphere. The inside of the sphere is coated with diffuse gold, which collects the light beams and directs them to the detector [25].

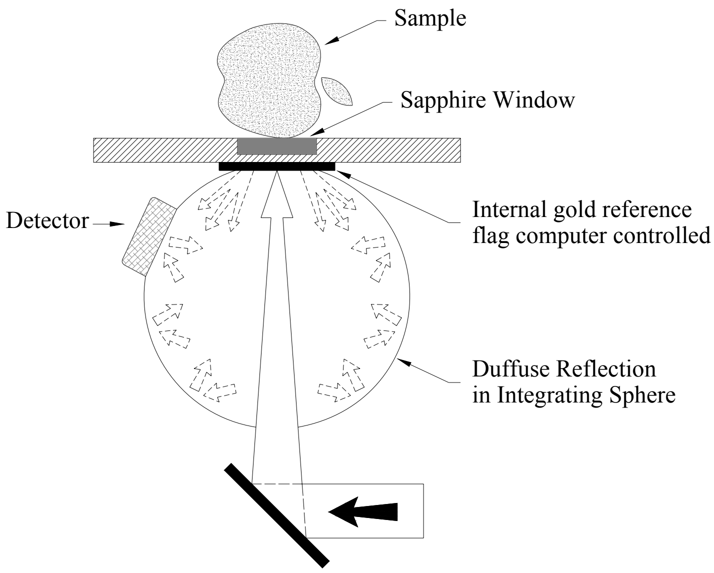

Figure 1. Schematic diagram of NIR diffuse reflectance measurement set-up

Each spectrum was recorded as log (1/R) where R was fractional reflectance, by averaging 32 scans of spectra. Four reflectance spectra were measured at 4 positions on each apple around the equator. After that the four reflectance spectra were averaged to provide a mean spectrum for calibration and validation set.

The original reflectance spectral data of 100 apple samples is shown in Figure 2. Partial least square (PLS) algorithm of multivariate calibration was attempted several times to determine the optimal spectral range for building calibration model. It was found that the optimal spectral range of fruit firmness of apples was 9,391-6,886 cm^{-1}.

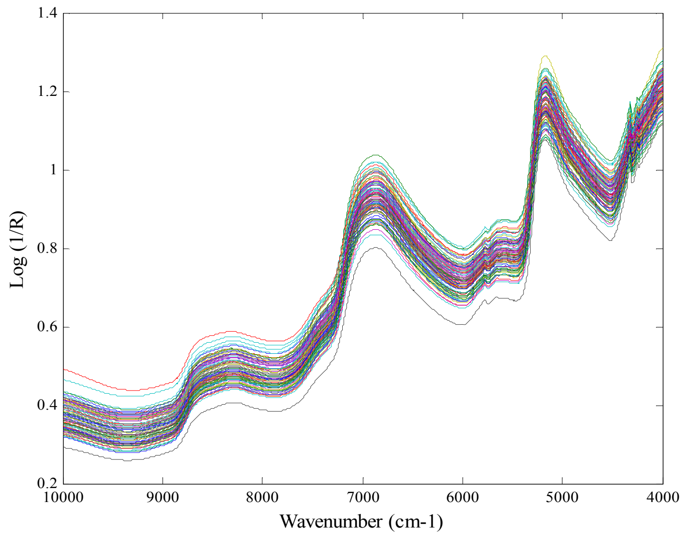

Figure 2. Original reflectance spectra as log (1/R) for 100 apple samples

Reference measurements

The destructive measurement on the apples in this research was conducted to determine the fruit firmness. It was measured with a texture analyser (Model TA-XT2i, Stable Microsystem, Ltd., England). This measurement was carried out exclusively on peeled apples, thus applying only to apple flesh. Fruit firmness parameters in this experiment included 1.0 mm/s test speed, 10.0 mm penetration distance and 100 g force setting with 3-mm diameter stainless cylinder probe. Maximum flesh rupture force was analysed in this research.

The measuring procedure was similar to that for FT-NIR. Each apple was measured at the same four positions around the equator. The mean value of firmness was the average of 4 measurements for the calibration and validation sets.

Spectral preprocessing methods

In this study, the spectral data were analysed using PLS regression with preprocessing. Four spectral preprocessing methods were applied comparatively; these were standard normal variate (SNV), mean centering, multiplicative scatter correction (MSC) and min/max normalisation method, respectively. First, SNV, a mathematical transformation method of the spectra, was used to remove slope variation and to correct for scatter effects. Each spectrum was corrected individually by first centering the spectral values, then the centred spectrum was scaled by the standard deviation calculated from the individual spectral values. Second, mean centering method process was used to calculate the average spectrum of the data set and subtract that average from each spectrum. Third, MSC was used for the correction of scattered light on the basis of different particle sizes. The technique was used to correct for additive and multiplicative effects in the spectra. Finally, min/max normalisation, a type of normalisation, was utilised to transform the data into a desired range by subtracting the minimum value of an attribute from each value of the attribute and then dividing the difference by the range of the attribute [26]. Generally, the range of the spectral value after min/max normalization spectral preprocessing is set [0 1]. Figure 3 shows the results of different methods after preprocessing.

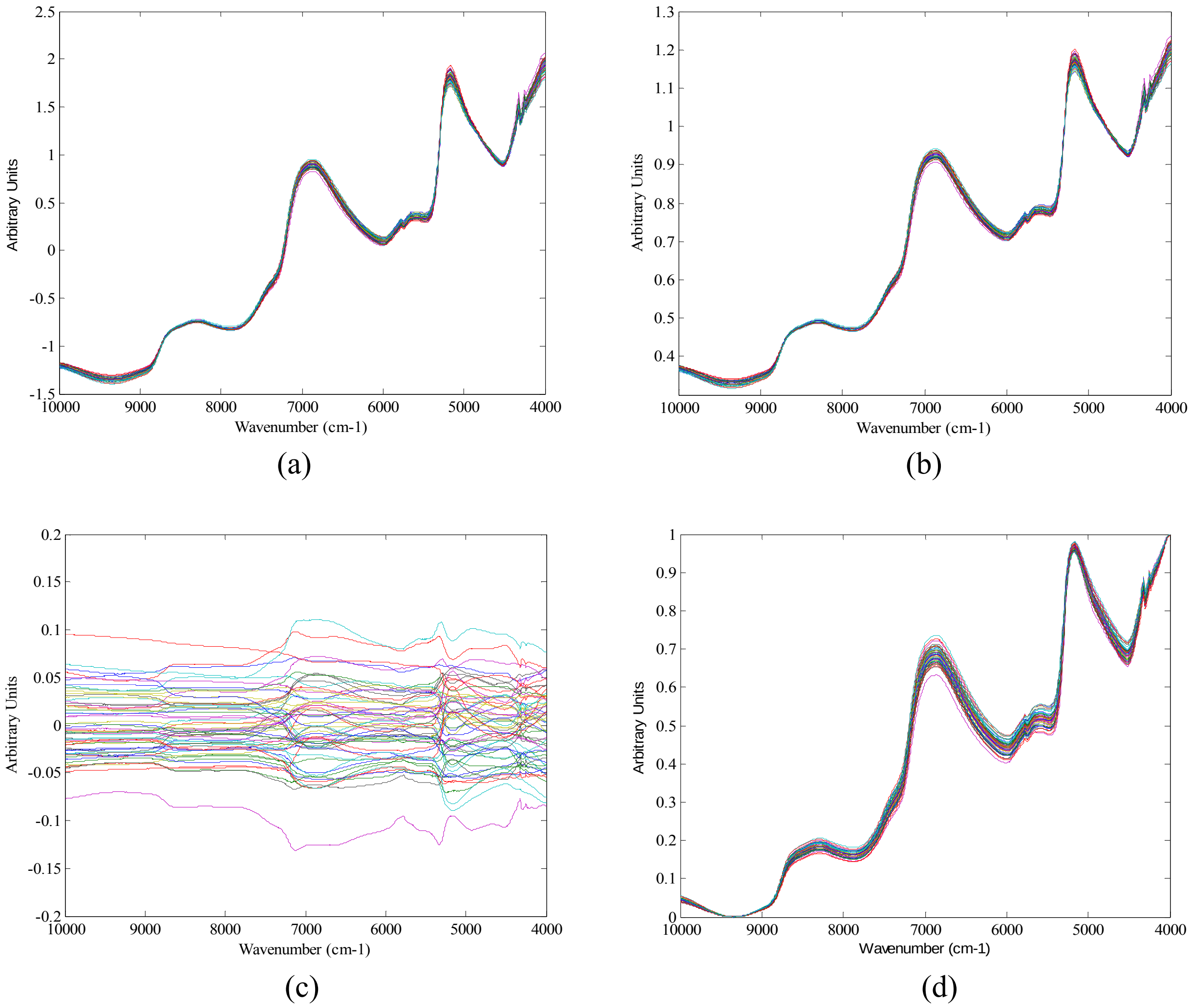

Figure 3. Preprocessed reflectance spectra of apple: (a) SNV (b) MSC (c) mean centering (d) min/max normalisation

Software

All methods were performed in Matlab V.7.1 (Mathworks, Natick, USA) for Windows XP. For the spectral acquisition, Result Integrating Program (Thermo Electron Result Integration and Result Operation Software, Thermo Electron Corporation, USA) was used.

Results and Discussion

Quantitative analysis of the PLS models

One hundred "Fuji" apple samples were selected to build the PLS model in this experiment. All 100 spectra were divided into a training set and a test set. To avoid bias in subset selection, this division was arranged as follows: all samples were sorted according to their respective y-value (viz. the reference measurement value of fruit firmness). In order to come to a 3/2 division of training/test spectra, three spectra from every five samples were selected for the training set, and two spectra from every five samples were selected for the test set, so that finally the training set contained 60 spectra (see Table 1) and the remaining 40 spectra constituted the test set (see Table 2). As seen in Tables 1 and 2, the range of y values in the training set covers the range in the test set, therefore the distribution of the samples was appropriate in training and test sets.

Table 1. Reference measurement and sample number in training set

Component	Unit	S.N.	Range	Mean	S.D.
Fruit Firmness	gf	60	133.28-817.00	446.77	148.91

(S.N., sample number; S.D., standard deviation; gf, gram force unit)

Table 2. Reference measurement and sample number in test set

Component	Unit	S.N.	Range	Mean	S.D.
Fruit Firmness	gf	40	151.45-811.02	446.39	149.37

(S.N., sample number; S.D., standard deviation; gf, gram force unit)

The performance of the final PLS model was evaluated in terms root mean square error of cross-validation (RMSECV), the root mean square error of prediction (RMSEP), and the correlation coefficient (R). For RMSECV, a leave-one-sample out cross-validation was performed: the spectrum of one sample of the training set was deleted from this set and a PLS model was built with the remaining spectra of the training set. The left-out sample was predicted with this model and the procedure was repeated by leaving out each of the samples of the training set. RMSECV was calculated by Eq.1 as shown:

$$RMSECV = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{y}_{\backslash i} - y_i\right)^2}{n}} \tag{1}$$

where n was the number of samples in the training set, y_i was the reference measurement result for sample i, and $\hat{y}_i$ was the estimated result for sample i when the model was constructed with sample i removed. The number of PLS factors included in the model was chosen according to the lowest

RMSECV. This procedure was repeated for each of the preprocessed spectra. For the test set, the root mean square error of prediction (RMSEP) was calculated by Eq. 2 as follows:

$$RMSEP = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{n}} \tag{2}$$

where n was the number of apple samples in the test set, y_i was the reference measurement result for test set sample i, and $\hat{y}_i$ was the estimated result of the model for test sample i. Finally, the model with the overall lowest RMSECV was selected as the final model. Correlation coefficients between the predicted and the measured value were calculated for both the training and the test set, which were calculated as follows (Eq. 3):

$$R = \sqrt{1 - \frac{\sum_{i=1}^{n}\left(\hat{y}_i - y_i\right)^2}{\sum_{i=1}^{n}\left(y_i - \bar{y}_i\right)^2}} \tag{3}$$

Fruit firmness

The model with the overall lowest RMSECV was selected as the final model. Figure 4 shows RMSECV plots as a function of PLS factors for determining fruit firmness by different spectral preprocessing methods. The RMSECV values decreased sharply with increasing numbers of PLS factors, which are shown in Figure 4. The optimal PLS numbers of SNV, MSC, mean centering and min/max normalisation spectral preprocessing methods were equal to 12, 12, 14 and 12, respectively.

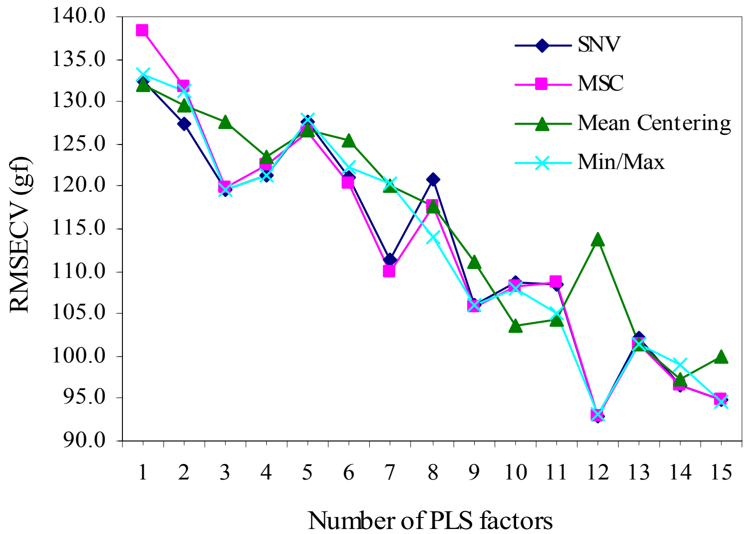

Figure 4. Effect of number of PLS factors on RMSECV for fruit firmness calibration model

Table 3 shows the best results of the models by different spectral preprocessing methods for determining the prediction of the fruit firmness. As seen in Table 3, the difference of RMSCEV was slight for SNV, MSC and min/max normalisation spectral preprocessing methods. The optimal PLS number of these three spectral preprocessing methods was equal to 12, while that of the mean centering spectral preprocessing method was equal to 14. However, in this application MSC spectral

Table 3. Best results for each of the processing methods for the models of fruit firmness

Preprocessing method	PLS factors	RMSECV (gf)	RMSEP (gf)	R (train)	R (test)
SNV	12	92.930	99.371	0.69682	0.74661
MSC	**12**	**92.910**	**98.980**	**0.69698**	**0.74893**
Mean centering	14	97.254	100.890	0.66074	0.73741
Min/max normalization	12	93.173	95.409	0.69489	0.76942

(gf = gram force unit)

preprocessing method was optimal and selected to build the calibration model, due to its lowest RMSECV value. Therefore, the best predictive model was achieved with 12 PLS factors after MSC spectral preprocessing method, in which the values of RMSECV and RMSEP were 92.910 gf and 98.980 gf, respectively. The correlation coefficients for training and test set were 0.69698 and 0.74893, respectively, and Figure 5 shows the scatter plots of the model for determining fruit firmness by MSC spectral preprocessing method, which was selected in this study.

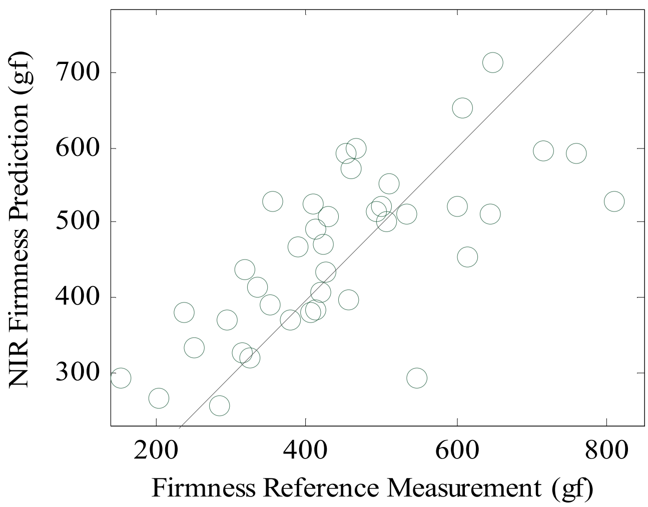

Figure 5. Reference determination versus NIR prediction for fruit firmness of training set data

Conclusion

The overall results in this research sufficiently indicate that it is possible to use this non-destructive technique for measuring fruit firmness in "Fuji" apples and that fruit firmness can be determined by FT-NIR spectroscopy using the spectral range of 10,000-4,000 cm^{-1}. The PLS method has the potential to estimate the calibration and prediction model from their near infrared spectra. The PLS calibration model in fruit firmness determination was achieved with 12 PLS factors under MSC preprocessing method. The correlation coefficient between the NIR spectroscopy prediction results and reference measurement results was R = 0.74893. It could be concluded that the fruit firmness of apple could be analysed quickly and simultaneously by NIR spectroscopy coupled with the appropriate chemometric methods, and this real-time, on-site measurement would significantly improve the efficiency of quality control and assurance.

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References

1. H. G. Antihus, Y. He, and A. G. Pereira, "Non-destructive measurement of acidity, soluble solids and firmness of Satsuma mandarin using VIS/NIR-spectroscopy techniques", *J. Food Eng*., **2006**, *77*, 313-319.
2. E. Mehinagic, G. Royer, R. Symoneaux, D. Bertrand, and F. Jourjon, "Prediction of the sensory quality of apples by physical measurements", *Postharvest Biol. Technol*., **2004**, *34*, 257-269.
3. J. Lammertyn, B. M. Nicolai, K. Ooms, V. De Smedt, and J. De Baerdemaeker, "Non-destructive measurement of acidity, soluble solids, and firmness of Jonagold apples using NIR-spectroscopy", *Postharvest Biol. Technol*., **1998**, *41*, 1089-1094.
4. V. A. McGlone, R. B. Jordan, and P. J. Martinsen, "VIS/NIR estimation at harvest of pre- and post-storage quality indices for 'Royal Gala' apple", *Postharvest Biol. Technol*., **2002**, *25*, 135-144.
5. R. F. Lu, "Nondestructive measurement of firmness and soluble solids content for apple fruit using hyperspectral scattering images", *Sens. Instru. Food Qual*., **2007**, *1*, 19-27.
6. X. B. Zou, J. W. Zhao, and Y. X. Li, "Use of FT-NIR spectrometry in non-invasive measurements of soluble solid contents (SSC) of 'Fuji' apple based on different PLS models", *Chemom. Intell. Lab. Syst*., **2007**, *87*, 43-51.
7. R. F. Lu and Y. K. Peng, "Hyperspectral scattering for assessing peach fruit firmness", *Biosystem. Eng*., **2006**, *93*, 161-171.
8. R. F. Lu, "Imaging spectroscopy for assessing internal quality of apple fruit", *ASAE Ann. Int*., **2003**, No.036012.

9. Y. K. Peng, and R. F. Lu, "Prediction of apple fruit firmness and soluble solids content using characteristics of multispectral scattering images", *J. Food Eng.*, **2007**, *82*, 142-152.
10. Y. K. Peng, and R. F. Lu, "Improving apple fruit firmness predictions by effective correction of multispectral scattering images", *Postharvest Biol. Technol.*, **2006**, *41*, 266-274.
11. J. A. Abbott, "Quality measurement of fruits and vegetables", *Postharvest Biol. Technol.*, **1998**, *15*, 207-225.
12. J. A. Abbott, R. F. Lu, B. L. Upchurch, and R. L. Stroshine, "Technologies for nondestructive quality evaluation of fruits and vegetables", in *Horticultural Reviews*, Vol. 20 (Ed. J. Janick), John Wiley and Sons Inc., New York, **1997**, p. 1-120.
13. Kavdir, R. F. Lu, D. Ariana, and M. Ngouajio, "Visible and near-infrared spectroscopy for nondestructive quality assessment of pickling cucumber", *Postharvest Biol. Technol.*, **2007**, *44*, 165-174.
14. J. M. Esteban-Diez, C. Gonzalez-saiz, and Pizarro, "An evaluation of orthogonal signal correction methods for the characterization of Arabica and robusta coffee varieties by NIRS", *Anal. Chim. Acta.*, **2004**, *514*, 57-67.
15. K. Kachrimanis, V. Karamyan, and S. Malamataris, "Artificial neural networks (ANN) and modeling of powder flow", *Int. J. Pharm.*, **2003**, *250*, 13 - 23.
16. Y. A. Woo, H. J. Kim, K. R. Ze, and H. Chung, "Near-infrared (NIR) spectroscopy for the non-destructive and fast determination of geographical origin of Angelicae gigantis Radix", *J. Pharmaceut. Biomed. Anal.*, **2005**, *36*, 955-959.
17. Y. Dou, Y. Sun, Y. Q. Ren, P. Ju, and Y. L. Ren, "Simultaneous non-destructive determination of two components of combined paracetamol and amantadine hydrochloride in tablets and powder by NIR spectroscopy and artificial neural networks", *J. Pharmaceut. Biomed. Anal.*, **2005**, *37*, 543-549.
18. C. W. Huck, W. Guggenbichler, and G. K. Bonn, "Analysis of caffeine, theobromine and theophylline in coffee by near infrared spectroscopy compared to high-performance liquid chromatography (HPLC) coupled to mass spectrometry", *J. Pharmaceut. Biomed. Anal.*, **2005**, *538*, 195-203.
19. R. De Maesschalck and T. V. Kerkhof, "Implementation of a simple semi-quantitative near-infrared method for the classification of clinical trial tablets", *J. Pharmaceut. Biomed. Anal.*, **2005**, *37*, 109-114.
20. C. J. Clark, V. A. McGlone, and R. B. Jordan, "Detection of Brownheart in 'Braeburn' apple by transmission NIR spectroscopy", *Postharvest Biol. Technol.*, **2005**, *28*, 87-96.
21. Y. A. Woo, H. R. Lim, H. J. Kim, and H. Chung, "Determination of hydrogen peroxide concentration in antiseptic solutions using portable near-infrared system", *J. Pharmaceut. Biomed. Anal.*, **2003**, *33*, 1049-1057.
22. V. A. McGlone, R. B. Jordan, R. Seelye, and P. J. Martinsen, "Comparing density and NIR methods for measurement of Kiwifruit dry matter and soluble solids content", *Postharvest Biol. Technol.*, **2002**, *26*, 191-198.
23. B. M. Nicolai, E. V. Bert, D. Michele, S. Stijn, S. Wouter, T. Karen, C. Rinaldo, P. Antonio, and T. Alessandro, "Time-resolved and continuous wave NIR reflectance spectroscopy to

predict soluble solids content and firmness of pear", *Postharvest Biol. Technol.*, **2008**, *47*, 68-74.

24. V. A. McGlone and S. Kawano, "Firmness, dry-matter and soluble-solids assessment of postharvest kiwifruit by NIR spectroscopy", *Postharvest Biol. Technol.*, **1998**, *13*, 131-141.
25. H. Y. Cen and Y. He, "Theory and application of near infrared reflectance spectroscopy", *Food Sci. Technol.*, **2007**, *18*, 72-83.
26. Q. S. Chen, J. W. Zhao, X. Y. Huang, H. D. Zhang, and M. H. Liu, "Simultaneous determination of total polyphenols and caffeine contents of green tea by near-infrared reflectance spectroscopy", *Microchem. J.*, **2006**, *83*, 42-47.

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Full Paper

Biological indices for classification of water quality around Mae Moh power plant, Thailand

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Abstract: The algal communities and water quality were monitored at eight sampling sites around Mae Moh power plant during January-December 2003. Three biological indices, viz. algal genus pollution index, saprobic index, and Shannon-Weaver index, were adopted to classify the water quality around the power plant in comparison with the measured physico-chemical water quality. The result shows that the Shannon-Weaver diversity index appears to be much more applicable and interpretable for the classification of water quality around the Mae Moh power plant than the algal genus pollution index and the saprobic index.

Keywords: algae, algal genus pollution index, biological indices, Mae Moh power plant, saprobic index, Shannon-Weaver index, water quality

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Introduction

Biological methods of assessing aquatic ecosystem have long been used in many countries. Algae as a component of aquatic ecosystem are an indicator of water quality which is determined by their species composition and diversity. Algae have been pointed out as a useful tool for estimation of the environmental impact on the aquatic ecosystem due to its quick response to changes in the environmental condition thus enabling a quick assessment of water quality [1-4]. A reduction in the number of species and an increase in the number of individuals that characterise polluted areas result in significant decrease in the value of diversity [5-6]. In contrast, high diversity (few individuals but many species) and low biomass indicate a healthy area [5]. The biological indices have been used to monitor the impact of disturbance and pollution on aquatic ecosystems and discussed by many researchers [6-9].

Mae Moh power plant is a thermal electricity unit, operated by the Electricity Generating Authority of Thailand (EGAT). It consists of 13 units, which can be operated continually to produce about 2,625 megawatts at full capacity. All the power plant units employ lignite fuel to heat water in boilers producing hot steam for operating the generators. The drainage water and effluent from the activities of the power plant are treated by both physical and biological processes in the wastewater treatment system. This research was undertaken to determine the species composition of algae and to test the utility and suitability of some biological indices as indicator of water quality around the power plant.

Materials and Methods

Studied area

The Mae Moh power plant is located in Mae Moh district, Lampang province, approximately 650 kilometers north of Bangkok (99º 46' E, 18º 18'N). The power plant requires about 46,000,000 m^3 of water per year for its cooling system and other activities. This amount of water comes from the Mae Kham and Mae Chang reservoirs which are the main natural water supplies. About 25,640 m^3 of industrial wastewater and 200 m^3 of domestic wastewater pass through the physical and biological wastewater treatment system of the power plant. The wastewater treatment system is composed of 4 ponds in series: settleable solid and oxidation pond, bio-treatment pond, diversion pond and south wetland pond. Eight sites selected for water sampling around the power plant are as follows (Figure 1): site 1 - Mae Kham reservoir (capacity 36,979,000 m^3), site 2 - Mae Chang reservoir (capacity 105,780,000 m^3), site 3 - main drain 1, site 4 - main drain 2, site 5 - settleable solid and oxidation pond (capacity 20,000 m^3), site 6 - bio-treatment pond (capacity 100,000 m^3), site 7 - diversion pond (capacity 100,000 m^3), and site 8 - south wetland pond (capacity 192,600 m^3).

Physico-chemical water quality analysis

Water samples were collected monthly from the eight sampling sites during January-December 2003. Some variables including temperature, pH and conductivity were measured in situ by using portable electronic measuring instruments (pH meter: Horibra, model D21, and conductivity meter: Jenway, model 4200). Water samples were collected near the outlet points and from water surface (0.3 m), middle depth and bottom for sites 1 and 2. However, water samples of sites 3–8 were collected only at the depth of 0.3 m and preserved in an ice-box until further processing. Analysis of dissolved oxygen (DO) and biochemical oxygen demand (BOD) was carried out using azide modification method whereas chemical oxygen demand (COD) was determined by closed reflux method [10-11]. Suspended solids (SS) and hardness were determined by hot air oven (105 ºC) and EDTA titrimetric method, respectively. Silica (SiO_2), ammonia nitrogen (NH_3-N) and orthophosphate phosphorus (PO_4-P) were analysed by heteropoly blue methods, nesslerisation method and stannous chloride method, respectively. Chlorophyll-a was determined by cold acetone method [10-11].

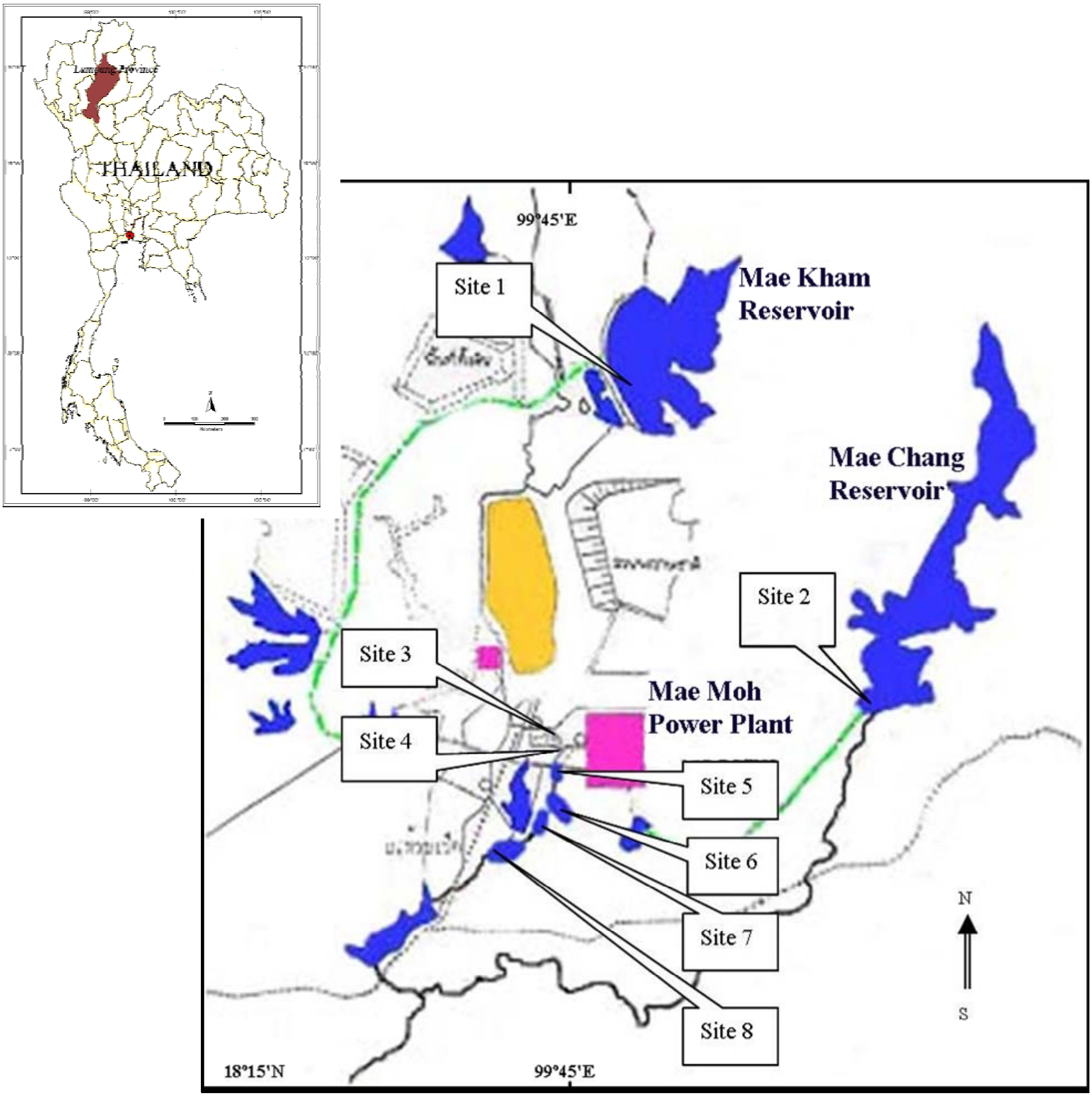

Figure 1. Map of Thailand and location of sampling sites around the Mae Moh power plant:
sites 1, 2 - natural water supplies for power plant activities
sites 3, 4 - effluents from power plant activities
sites 5-8 - wastewater treatment system

Algal analysis

Water sample for algal counting was transfered to a 500 ml cylinder and fixed with Lugol's iodine solution (5 ml). The preserved sample was left to stand in the dark for 10 days to allow concentration by decantation. Then the lower layer (20-25 ml) containing the sedimented algae was transfered to a 50 ml cylinder. The second decantation was conducted after 7 days, and the lower layer (10 ml) containing sedimented algae was put in a plastic vial and stored in a dark box. The concentrated sample containing the sedimented algae was used for identification and counting of algae under a compound light microscope [11].

Three biological indices were calculated as follows:

1) Algal genus pollution index [12], as shown in Table 1. In making a microscopic analysis of a sample, all of the 20 algae observed were recorded (providing 5 or more individuals per slide of a particular kind were present). The index factors of the algae present were then totalled.

2) Saprobic index (*S*) [9],

$$S = \sum (rh) / \sum (h)$$

where *r* is the taxon saprobic rating (1 = oligosaprobic organism, 2 = β-mesosaprobic organism, and 3 = α-mesosaprobic organism), and *h* is the taxon occurrence rating (1 = occurring incidentally with < 100 cells ml^{-1}, 2 = occurring frequently with 100-200 cells ml^{-1}, and 3 = occurring abundantly with > 200 cells ml^{-1}).

3) Shannon-Weaver diversity index (*H'*) [6],

$$H' = -\sum_{I=1}^{n} Pi \ \ln Pi$$

where *Pi* is proportion of species i in the community and n is number of species.

Table 1. Algal genus pollution index [12]

Genus	Pollution index	Genus	Pollution index
Anacystis	1	*Micractinium*	1
Ankistrodesmus	2	*Navicula*	3
Chlamydomonas	4	*Nitzschia*	3
Chlorella	3	*Oscillatoria*	5
Closterium	1	*Pandorina*	1
Cyclotella	1	*Phacus*	2
Euglena	5	*Phormidium*	1
Gomphonema	1	*Scenedesmus*	4
Lepocinclis	1	*Stigeoclonium*	2
Melosira	1	*Synedra*	2

Note: Larger number indicates more pollution.

Results and Discussion

Assessment of water quality from eight sampling sites around Mae Moh power plant was conducted during January-December 2003. The water quality based on measurements of physico-chemical and biological parameters from all sampling sites (Table 2) was investigated.

Classification of Algae

The algae from 8 sampling sites of Mae Moh power plant consisted of 107 species distributed in 6 divisions. The species belong to 42 Chlorophyta, 25 Cyanophyta, 23 Chrysophyta, 11 Euglenophyta, 3 Cryptophyta, and 3 Pyrrophyta (Table 3). The higher numbers of algal taxa in each site were found in Cyanophyta, Chlorophyta and Chrysophyta. A total of 7 dominant species was reported, viz. *Cylindrospermopsis raciborskii*, *Oscillatoria* sp.3, *Raphidiopsis curvata,* *Synechococcus* sp., *Gomphosphaeria* sp., *Chlamydomonas* sp., and *Platymonas* sp. The common algae of all sampling sites were *Coelomoron* sp., *Cylindrospermopsis raciborskii*, *Dactylococcopsis* sp., *Merismopedia* sp.2, *Oscillatoria* spp., *Raphidiopsis curvata*, *Spirilina laxiscina,* *Crucigenia* sp., *Scenedesmus* sp.1, *Cyclotella* sp., *Gomphonema* sp., *Mallomonas* sp., *Nitzschia palea*, and *Cryptomonas* sp.

Table 2. Means and standard deviations of selected physico-chemical and biological characteristics of water around Mae Moh power plant

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Temperature (^oC)	29.32± 2.26	26.82± 2.95	28.73± 2.54	34.29± 3.75	32.11±3.30	32.01± 3.45	31.49±2.68	30.12± 3.60
SS (mg L^{-1})	7.58± 7.39	8.58±9.70	15.75±8.80	573.42±358.63	246.08±257.33	19.92±19.56	14.17±8.84	15.33±20.37
pH	7.88±0.39	7.77±0.49	7.23±0.47	9.01±0.53	8.69±0.50	7.62±0.50	7.66±0.68	7.09±0.48
Conductivity (µS cm^{-1})	268±44.14	218±37.24	330±70.20	683±114.14	846±137.23	997±366.93	1072±410.89	1198±354.70
Hardness (mg L^{-1}as $CaCO_3$)	145±22.10	123±22.60	120±26.89	343±103.30	464±116.90	555±111.50	596±163.03	702±185.68
DO (mg L^{-1})	3.83±1.24	4.84±1.40	4.12±1.57	4.02±2.13	4.68±1.90	4.07±1.03	6.48±3.33	3.17±1.55
BOD (mg L^{-1})	1.98±0.87	1.50±0.81	7.70±3.79	5.03±3.01	3.68±2.53	2.38±1.57	3.10±2.04	2.49±1.32
COD (mg L^{-1})	2.07±0.81	1.85±1.04	12.30±7.50	6.32±11.16	7.10±2.98	3.51±1.43	3.07±1.46	3.56±1.85
NH_3-N (mg L^{-1})	0.188±0.21	0.124±0.12	2.649±1.80	0.246±0.22	0.225±0.21	0.134±0.13	0.208±0.23	0.268±0.36
PO_4-P (mg L^{-1})	0.008±0.01	0.006±0.01	0.417±0.36	0.050±0.05	0.030±0.03	0.039±0.04	0.034±0.03	0.044±0.05
SiO_2 (mg L^{-1})	14.07±2.13	11.88±3.43	10.38±2.50	23.36±3.80	20.96±4.70	21.36±4.84	22.00±4.63	21.66±4.46
Chlorophyll-a (mg m^{-3})	7.52±4.13	3.66±1.44	4.21±2.28	1.63±1.17	2.83±1.61	2.96±1.91	10.27±10.01	3.73±2.22

Table 3. Diversity and classification of algae around Mae Moh power plant

Algae	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
DIVISION CYANOPHYTA								
Anabaena sp.	+	+	-	+	+	-	+	+
Chroococcus sp.	+	+	-	+	+	+	+	+
Coelomoron sp.	+	+	+	+	+	+	+	+
Cylindrospermopsis raciborskii	+++	+	+	++	++	+	+	+
C. curvispora	+	-	-	-	+	-	+	-
Dactylococcopsis sp.	++	+	+	+	++	+	+	+
Gomphosphaeria sp.	+	+++	-	+	+	+	+	+
Lemmermanniella sp.	+	++	-	-	+	+	-	-
Lyngbya sp.	-	-	-	+	-	-	-	-
Merismopedia sp.1	-	+	+	+	+	++	+	+
Merismopedia sp. 2	+	++	+	+	+	+	+	+
Merismopedia sp. 3	+	+	-	-	-	+	-	-
Microcystis sp.	+	-	-	-	-	+	-	-
Oscillatoria sp.1	+	+	+	+	+	+	+	+
Oscillatoria sp.2	+	+	+	+	+	+	+	+
Oscillatoria sp.3	+++	+	++	++	++	++	++	++
Oscillatoria sp.4	++	+	+++	++	+	+	+	+
Romeria sp.	+	-	-	-	-	+	-	-
Plectonema sp.	-	-	+++	-	+	+	+	-
Pseudanabaena sp.	+	+	+	+	+	+	+	+
Raphidiopsis curvata	+++	+++	++	++	++	++	+	+
Spirulina laxissima	+	+	+	+	+	+	+	+
S. subsalsa	-	-	-	-	-	-	+	-
Synechocystis sp.	+	+	+	+	+	+	+	+
Synechococcus sp.	+++	-	+++	++	++	++	++	+
DIVISION CHLOROPHYTA								
Actinastrum sp.	+	+	-	-	+	+	+	+
Ankyra sp.	-	+	-	-	-	+	+	+
Ankistrodesmus braunii	+	+	-	+	+	+	+	+
Ankistrodesmus falcatus	+	+	+	+	+	+	+	+
Ankistrodesmus sp.	+	+	-	-	-	-	-	-
Acanthosphaera sp.	+	-	-	-	-	-	-	-
Chlamydomonas sp.	+	+	+	-	+	++	+++	+
Chlorella sp.	+	+	-	-	-	+	+	+
Chlorogonium sp.	-	+	-	-	-	+	+	+
Closterium sp.	+	+	-	-	-	-	+	-
Coelastrum sp.	+	+	-	+	+	-	+	+

Notes: - (not found), + (1-100 unit ml^{-1}), ++ (101-1000 unit ml^{-1}), +++ (> 1000 unit ml^{-1})

Table 3 (continued). Diversity and classification of algae around Mae Moh power plant

Algae	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Cosmarium sp.	+	+	-	-	+	-	-	-
Crucigenia sp.	+	+	+	+	+	+	+	+
Chodatella sp.	+	+	-	-	-	+	+	-
Dictyosphaerium sp.	+	+	-	+	-	+	+	-
Dimorphococcus sp.	-	+	-	-	-	-	+	-
Gloeocystis sp.	+	-	-	-	+	-	-	-
Golenkinia sp.	+	+	-	-	-	-	+	-
Gonium sp.	-	-	-	-	-	-	-	-
Halosphaera sp.	+	-	-	-	-	-	+	+
Interfilum paradoxum	+	+	-	-	+	-	-	-
Micractinium sp.	-	-	-	-	+	-	+	-
Oocystis sp.	+	-	-	-	-	+	+	+
Pandorina sp.	-	+	-	-	-	-	+	+
Pediastrum sp.	+	-	-	+	-	+	-	-
Platymonas sp.	-	++	-	-	+	+	+++	++
Pteromonas sp.	-	-	-	-	-	-	-	-
Scenedesmus sp. 1	+	+	+	+	+	+	+	+
Scenedesmus sp. 2	+	-	-	+	-	-	+	+
Scenedesmus sp. 3	+	-	-	+	+	+	+	+
Scenedesmus sp. 4	+	-	-	-	-	+	+	+
Scenedesmus sp. 5	+	+	-	-	-	+	+	+
Scenedesmus sp. 6	-	-	-	+	-	-	+	-
Spermatozopsis erultans	+	+	-	-	-	+	+	+
Staurastrum longbrachiatum	+	+	-	-	+	-	-	-
Staurastrum gracile	-	+	-	-	-	-	-	-
Staurodesmus sp.	+	+	-	-	-	+	-	-
Tetraedon caudatum	+	+	-	-	-	+	+	-
T. gracile	-	+	-	-	+	-	-	-
T. trigonum	+	-	-	-	-	-	-	-
T. minimum	+	-	+	+	-	+	+	+
Treubaria sp.	-	-	-	-	-	-	-	-
DIVISION CRYSOPHYTA								
Achnanthes sp.	+	+	+	+	+	+	-	+
Cyclotella sp.	++	++	+	+	+	+	++	+
Cymbella sp.	+	+	-	-	+	+	+	+
Centritractus sp.	-	+	-	-	-	-	+	+
Cocconeis sp.	-	+	-	+	+	-	+	+
Dinobryon sp. 1	+	+	-	+	+	+	-	-

Notes: - (not found), + (1-100 unit ml^{-1}), ++ (101-1000 unit ml^{-1}), +++ (> 1000 unit ml^{-1})

Table 3 (continued). Diversity and classification of algae around the Mae Moh power plant

Algae	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Dinobryon sp. 2	+	+	+	+	-	-	-	-
Fragilaria sp.	+	-	-	+	+	+	+	+
Gomphonema sp.	+	+	+	+	+	+	+	+
Gyrosigma sp.	-	-	-	-	+	+	+	-
Mallomonas sp.	+	+	+	+	+	+	+	+
Merosila sp.	+	+	-	-	-	-	-	-
Navicula sp. 1	+	+	+	+	+	+	-	+
Navicula sp. 2	++	+	-	+	+	+	+	+
Nitzschia sp. 1	+	+	-	-	+	+	+	+
Nitzschia sp. 2	+	+	-	+	+	+	+	+
N.reversa	-	-	-	-	+	+	+	+
N. palea	+	+	+	+	+	+	+	+
N. sigma	-	-	+	+	+	+	-	+
Pinnularia sp.	-	-	+	+	+	+	+	+
Surirella sp.	-	-	-	-	-	-	-	+
Stauroneis sp.	-	-	-	-	-	-	-	+
Synedra sp.	-	-	-	+	-	+	-	+
DIVISION EUGLENOPHYTA								
Euglena acus	-	-	-	-	+	-	+	+
E. fusca	-	-	-	-	-	-	+	+
E. caudate	-	-	-	+	+	+	+	+
Euglena ehrenbergii	+	+	-	-	+	-	+	+
Phacus curvicauda	+	+	+	-	+	+	+	+
P. longicauda	+	+	-	-	-	-	+	+
P. helikoides	+	-	-	-	-	-	+	+
Trachelomonas sp. 1	+	-	+	-	+	+	+	+
Trachelomonas sp. 2	+	+	-	-	-	-	+	-
Strombomonas sp.	-	-	-	-	-	-	+	-
Lepocinclis sp.	+	+	-	-	-	+	+	+
DIVISION CRYPTOPHYTA								
Cryptomonas sp.	+	+	+	+	+	+	++	++
Chroomonas sp.	+	+	+	+	-	+	+	+
Hemiselmis sp.	-	+	-	-	-	-	+	+
DIVISION PYRROPHYTA								
Peridinium sp. 1[1]	+	+	+	+	-	+	+	+
Peridinium sp. 2[1]	+	+	-	+	+	-	+	+
Ceratium sp.	-	+	-	+	-	-	-	-

Notes: - (not found), + (1-100 unit ml^{-1}), ++ (101-1000 unit ml^{-1}), +++ (> 1000 unit ml^{-1})

Classification of water quality based on physico-chemical and biological indices

The water quality around the Mae Moh power plant is classified as shown in Table 4.

Table 4. Classification of water quality around Mae Moh power plant using both biological indices and surface water quality

Sampling site	Surface water quality index	Algal genus pollution index	Saprobic index	Shannon-Weaver index
Site 1	2-4	9-16	2.25-2.50	1.44-2.21
Site 2	2-4	12-16	2.25-2.75	1.61-2.46
Site 3	5	1-14	2.45-2.86	0.13-1.59
Site 4	5	0-18	2.40-3.00	0.06-2.37
Site 5	5	3-22	2.42-2.75	1.32-2.18
Site 6	3-5	1-21	2.00-2.60	0.96-2.67
Site 7	3-5	12-24	2.10-2.67	0.48-2.74
Site 8	3-5	8-27	2.13-2.55	1.14-3.13

Notes: (1) Surface water quality index was derived from comparing the measured physico-chemical water quality with the surface water quality standards set by the Pollution Control Department of Thailand [13].
(2) Larger value of surface water quality index, algal genus pollution index, and saprobic index indicates more pollution, while larger value of Shannon-Weaver index indicates less pollution.

Algal genus pollution index: According to the three quality classes (Table 5) defined for algal genus pollution index by Palmer and Adams [12], the water quality around the Mae Moh power plant is classified as clean water and moderately polluted water. The minimum value was recorded in site 3 (Table 4, Figure 2a), partially due to the reduction in the number of algal species. As can be seen, this index is apparently unapplicable and uninterpretable for the classification of water quality around the Mae Moh power plant, since it contradicts with the physico-chemical water quality or surface water quality index, especially for sites 3 and 4 (Table 4). Thus the algal genus pollution index is unsuitable for prediction of water quality around the Mae Moh power plant.

Table 5. Water quality classes according to algal genus pollution index [12]

Algal genus pollution index	Condition
≤14	low organic pollution
15 – 19	moderate organic pollution
≥20	high organic pollution

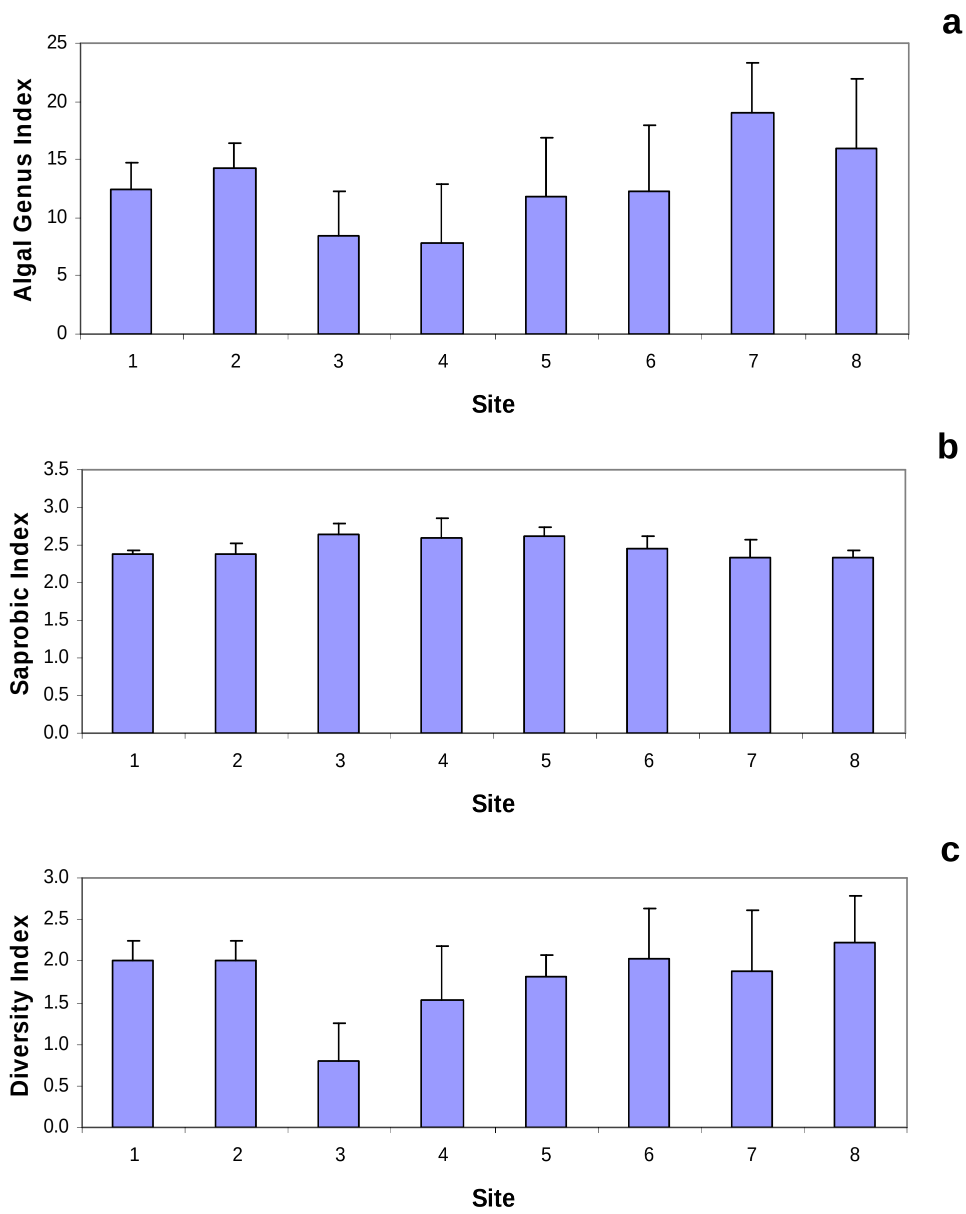

Figure 2. Changes in biological indices: (a) algal genus pollution index, (b) saprobic index, and (c) Shannon-Weaver index

Saprobic index: Four water quality classes are defined for saprobic condition index by Yap [9] as shown in Table 6. By this index, the water quality around the Mae Moh power plant ranged between 2.00-3.00, which is classified into class II and class III (moderate and high organic pollution). However, they were hardly different for all sampling sites (Figure 2b). This index is therefore not applicable to the differentiation of the water quality around the Mae Moh power plant.

Table 6. Water quality classes according to saprobic index [9]

Saprobic index	Class	Condition
1.0-1.5	I	very slight contamination
1.5-2.5	II	moderate contamination
2.5-3.5	III	heavy contamination
3.5-4.0	IV	very heavy contamination

The Shannon-Weaver index: Three water quality classes are defined for Shannon-Weaver diversity index by Wilhm [6] as shown in Table 7, which implies that the high *H'* value suggests the more healthy ecosystem (less pollution) while the low *H'* value suggests poor diversity in a community and a less healthy ecosystem (more pollution). The *H'* value of water around the Mae Moh power plant ranges between 0.06-3.13 (Table 4 and Figure 2c), 1.44-2.46 and 0.06-2.37 being for the reservoirs (sites 1 and 2) and the effluent from the power plant (sites 3 and 4), respectively. These two sources of water can only be classified into class II and class III (moderately and heavily polluted). However, as apparent from Table 4, the Shannon-Weaver index (*H'* value), compared with other indices, seems to be the best indicator of the water quality around the power plant. This is partly substantiated by the fact that the change in the *H'* value, which shows a trend declining sharply from site 1 to site 3 and increasing gradually from site 3 to site 8 (Figure 2c), can be positively correlated with water hardness and negatively correlated with BOD and NH_3-N, as shown in Figure 3.

Table 7. Water quality classes for Shannon-Weaver index [6]

Shannon-Weaver index	Class	Condition
> 3	I	clean water
1 – 3	II	moderately polluted
<1	III	heavily polluted

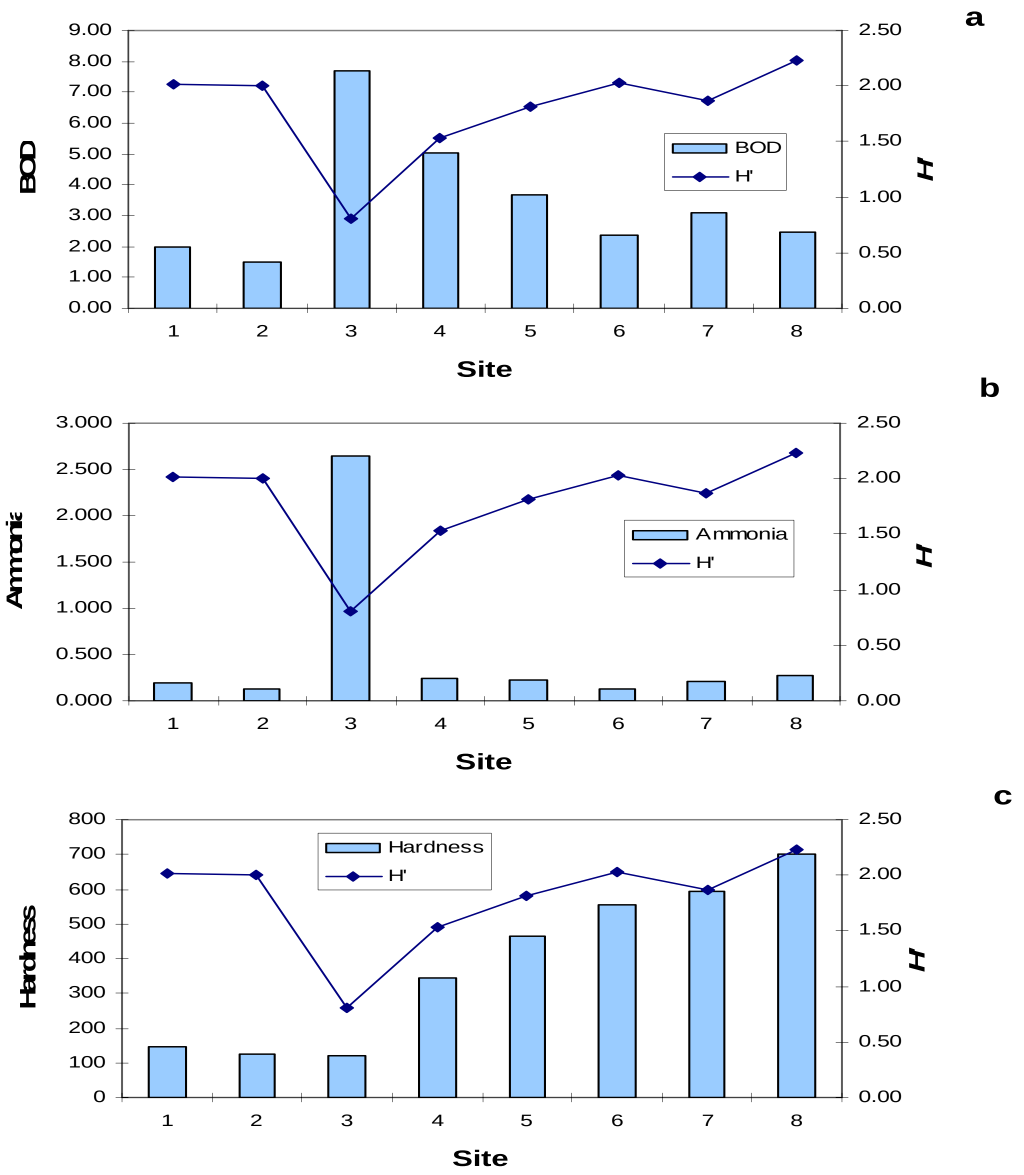

Figure 3. Changes in Shannon-Weaver index (*H'*) with (a) BOD (mg L^{-1}), (b) ammonia nitrogen (mg L^{-1}), and (c) hardness (mg L^{-1} as $CaCO_3$)

Conclusion

Diversity change of algal communities (*H'* value of the Shannon-Weaver index) can be used to compare and classify the water quality around Mae Moh power plant. This biological classification scheme depicts a difference in water quality between the clean upstream water, the polluted water (drainage from the power plant), and the remediated water. It is also in general agreement with the classification based on the traditional chemical water quality assessment. However, this preliminary attempt on biological classification is still in a developmental stage which can be recommended to serve as a guide for more intensive testing and application. This index may become a useful tool in assessing water quality around the Mae Moh power plant.

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References

1. A. A. Fathi, H. M. A. Abdelzaher, R. J. Flower, M. Ramdani, and H. M. Kraiem, "Phytoplankton communities of North African wetland lakes: the CASSARINA Project", *Aquatic Ecology*, **2001**, *35*, 303-18.
2. I. O'Farrell, R. Lombardo, P. P. Tezanos, and C. Loez "The assessment of water quality in the lower Lujan river (Buenos Aires, Argentina): phytoplankton and algal bioassays", *Environ. Pollution*, **2002**, *120*, 207-18.
3. M. I. Yarushina, V. P. Guseva, and M. Y. Chebotina, "Species composition and ecological characteristic of algae from the cooling reservoir of the Beloyarsk nuclear power plant", *Russian J. Ecology*, **2003**, *34*, 23-29.
4. H. Zeng, L. Song, Z. Yu, and H. Chen, "Distribution of phytoplankton in the Three-Gorge reservoir during rainy and dry seasons", *Sci. Total Environ.*, **2006**, *236*, 999-1009.
5. J. M. Hellawell, "Pollution monitoring series, biological indicators of freshwater pollution and environmental management", Elsevier, New York, **1986**.
6. J. L. Wilhm, "Biology indicators of pollution", in Whitton B.A. (Eds), "Studies in Ecology, Vol.2, River Ecology", Black Well Scientific Publications, London, **1975**, p. 375-402.
7. I. Izaguirre, I. O'Farrell, and G. Tell, "Variation in phytoplankton composition and limnological features in a water-water ecotone of the lower Paraná basin (Argentina)", *Freshwater Biology*, **2001**, *46*, 63-74.
8. W. O. W. Maznah and M. Mansor, "Aquatic pollution assessment based on attached diatom communities in the Pinang River Basin, Malaysia", *Hydrobiologia*, **2002**, *487*, 229-41.
9. S. Y. Yap, "Classification of a Malaysian river using biological indices: preliminary attempt", *Environmentalist*, **1997**, *17*, 79-86.
10. APHA, AWWA and WEA, "Standard methods for the examination of water and wastewater", 20^{th} Edn., United Book Press, Baltimore, **1998**.
11. S. Traichaiyaporn, "Water quality analysis" (Textbook in Thai), Department of Biology, Faculty of Science, Chiang Mai University, **2000**.
12. C. M. Palmer and S. Adams, "Algae and water pollution", Office of Research and Development, Ohio, **1977**.
13. Pollution Control Department, "Water quality standards", available online at http://www.pcd.go.th/ , **2001** (retrieved 10 August 2003).

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Addendum

Addendum to "Vegetation of Doi Tung, Chiang Rai Province, Northern Thailand" [*Mj. Int. J. Sci. Tech.*, 2007, *1*, 10-63]

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The plant list presented below includes species from the Doi Tung Project area as well as a granitic area in Teut Tai Subdistrict, *c*. 30 km west of the Royal Villa. This is the only area in the region with remaining forest (1000-1400 m) and includes Doi Bag Giah (with remnant pine on the summit, 1325 m) and Doi Bahng Mah Hahn. The vegetation on Doi Chang Moop must have been the same as on these two mountains.

The enumeration follows a basic Bentham & Hooker system as used in the CMU Herbarium. It is a morphological, taxonomic system which shows phyletic relationships between the families. Genera and species have been arranged alphabetically.

Since the database was published earlier this year, I have been able to visit Doi Tung again several times. The list has been updated, amended, and now includes 1013 species. It is presented in two forms, viz. alphabetically according to genus (Tables 1-3) and in a morphological (i.e. taxonomic) family order (Tables 4-6).

Notes

Habit:	t= tree	s= shrub	sc= scandent	l= treelet
	v= vine	cr= creeping	wc= woody climber	
Aped:	a= annual	pe= perennial evergreen	pd= perennial deciduous	ped= perennial evergreen+deciduous
Life mode:	aqu= aquatic	epl= epilithic	nat= naturalized	str= strangler
	car= carnivorous	gro= ground	par= parasite	wee= weed
	cul= cultivated	hyp= hyperparasite	rhe= rheophyte	
	epi= epiphyte	int= introduced/not native	sap= saprophyte	

Abundance:	0= Probably extirpated	3= Medium abundance
	1= Down to a few individuals, in danger of extirpation	4= Common, but not dominant
	2= Rare	5= Abundant
Habitat:	bb/df= bamboo+deciduous forest	eg/pine= evergreen with pine forest
	da= disturbed areas, roadsides	egf= evergreen forest
	do/pine= dipterocarp-oak+pine forest	mxf= mixed evergreen+deciduous forest
	dof= deciduous dipterocarp+oak forest	sg= secondary growth
	eg/bb= evergreen with bamboo forest	

Bedrock:	gr= granite	ls= limestone	ss= sandstone

Table 1. List of plant species (dicot) under phylum angiospermae surveyed at Doi Tung, Chiang Rai Province

								Lower	Upper	Flowering	Fruiting	Leafing	
Species	**Family**	**Habit**	**Aped**	**Life mode**	**Abundance**	**Habitat**	**Bedrock**	**Elevation (m)**		**Months**			**Collected**
Abelmoschus moschatus Medic. Ssp. *Moschatus* var. *moschatus*	Malvaceae	h	a	gro	2	da, sg	gr	1000	1200	oc		my-dc	
Acacia megaladena Desv. Var. *Garrettii* Niels.	Leguminosae, Mimosoideae	wc	pd	gro	3	rocks in mxf cliffs	ls	1300	1425	ap-jn	ja-fb	ap-ja	flowers , fruits
Acalypha kerrii Craib	Euphorbiaceae	s	pe	gro	3	rocks in mxf, eg/bb	ls	1200	1400	my-jn		ap-dc	flowers
Acer chiangdaoensis Santi.	Aceraceae	t	pd	gro, epl	3	rocks in mxf, egf cliffs	ls	1300	1425	my-jn	jl-fb	ja-nv	flowers, fruits
Achyranthes aspera L.	Amaranthaceae	h	a	gro, wee	3	eg/bb, da, sg	ls	400	1250	dc-fb	mr-ap	my-dc	flowers
Achyranthes bidentata Bl. Var. *bidentata*	Amaranthaceae	h	a	gro, wee	3	egf, eg/bb	ls	1200	1375	sp-oc	nv-dc	my-dc	flowers
Achyrospermum densiflorum Bl.	Labiatae	h	a	gro	2	eg/bb	gr	1100	1250		nv-dc	my-dc	fruits
Acrocarpus fraxinifolius Wight *ex* Arn.	Leguminosae, Caesalpinioideae	t	pd	gro	3	rocks in egf, cliffs	gr,ls	1000	1400	ja-fb	ap	ap-nv	
Actephila excelsa (Dalz.) M. A. var. *excelsa*	Euphorbiaceae	t	pe	epl	2	rocks in egf	ls	1300	1375	ag-sp	oc-nv	ja-dc	fruits
Actinodaphne henryi Gamb.	Lauraceae	t	pe	gro	3	egf, eg/bb	gr, ls	925	1400	ja	my	ja-dc	
Adenia penangiana (Wall. Ex G. Don) Wilde var. *Parvifolia* (Pierre *ex* Gagnep.) Wilde	Passifloraceae	v	a	gro	2	da, sg	gr	1000	1150			my-dc	
Adenosma ▯merica (Lour.) Merr.	Scrophulariaceae	h	a	gro	3	eg/pine	gr	1250	1325	sp-oc	nv-dc	my-dc	flowers
Aeginetia indica Roxb.	Orobanchaceae	h	pd	gro, par	3	rocks in mxf cliffs, egf	gr,ls	600	1500	sp	oc-dc	leafless	
Aerva sanguilonenta (L.) Bl.	Amaranthaceae	h	a	gro	3	rocks in egf cliffs	ls	1200	1400	ja-ap		ja-dc	flowers
Aeschynanthus hildebrandii Hemsl.	Gesneriaceae	h	pe	epi	2	egf, eg/bb	ls	1200	1400			ja-dc	
Aeschynanthus macranthus (Merr.) Pell.	Gesneriaceae	v	pe	epi	2	rocks in mxf, eg/bb	gr,ls	1300	1425	jl-sp	dc-mr	ja-dc	flowers, fruits
Aeschynomene ▯mericana L.	Leguminosae, Papilionoideae	h	a	gro, int, nat, wee	3	da, sg	gr	400	1000	sp-oc	dc	my-dc	flowers
Aesculus assamica Griff.	Hippocastanaceae	t	pd	gro, cul	3	eg/pine da	ls	1300	1350	ap		fb-dc	flowers
Afgekia fillipes (Dunn) Gees.	Leguminosae, Papilionoideae	wc	pd	gro	3	egf,eg/bb	gr	1000	1400	mr-ap	sp-oc	ap-ja	
Afzelia xylocarpa (Kurz) Craib	Leguminosae, Caesalpinioideae	t	pd	gro	2	bb/df	gr,ls	500	700			my-dc	

Table 1 (continued)

Agalia	Meliaceae	t	pe	gro	2	rocks in egf, cliffs	ls	1350	1375			ja-dc	
Agalia elliptica Bl.	Meliaceae	t	pe	gro	2	egf	ls	1200	1400		ja-fb, my-jn	ja-dc	fruits
Agapetes lobbii Cl.	Ericaceae	l	pe	epl , gro	3	rocks in mxf cliffs	ls	1375	1425	ja-fb		ja-dc	flowers
Agapetes megacarpa W.W. Sm.	Ericaceae	l	pe	epl	3	rocks in mxf cliffs	ls	1375	1425	oc-fb	ap	ja-dc	flowers
Ageratum conyzoides L.	Compositae	h	a	gro, wee	3	da, sg	gr,ls,ss	400	1525	jn-fb	ag-fb	my-fb	
Aglaia lawii (Wight) Sald. *ex* Rama.	Meliaceae	t, l	pe	gro	3	mxf, egf, eg/bb	ls	1200	1400	sp	ap-my	ja-dc	flowers, fruits
Aglaia spectabilis (Miq.) Jain & Benn.	Meliaceae	t	pe	gro	3	streams in egf, eg/bb	gr	1100	1300	jl-ag		ja-dc	flowers
Ajuga brateosa Wall. *ex* Bth.	Labiatae	h	a	gro	2	eg/bb, da		1100	1225	ja-fb	mr	ag-mr	flowers
Alangium barbatum (R.Br.) Baill. var. *barbatum*	Alangiaceae	l	pe	gro	2	egf	ls	1100	1400	ap	sp-oc	ja-dc	flowers, fruits
Alangium chinense (Lour.) Harms	Alangiaceae	t	pd	gro	3	eg/bb, da, sg	gr, ls	550	700		nv	my-fb	
Alangium kurzii Craib	Alangiaceae	t	pd	gro	3	egf, da	gr,ls	600	1500	ap-my		ap-dc	flowers
Albizia chinensis (Osb.) Merr.	Leguminosae, Mimosoideae	t	pd	gro	3	da, sg, eb/bb	gr	750	1525	ap-jn	dc-fb	mr-ja	flowers , fruits
Albizia crassiramea Lace	Leguminosae, Mimosoideae	t	pd	gro	3	da, sg	gr	800	1100	ag-sp		fb-dc	flowers
Albizia lucidor (Steud.) I. Niels.	Leguminosae, Mimosoideae	t	pe	gro	2	eg/bb	gr	1000	1250			ja-dc	
Albizia odoratissima (L. f.) Bth.	Leguminosae, Mimosoideae	t	pe	gro	3	egf ,da ,sg	gr	1000	1550	ap-my		ja-dc	Flowers
Alchornea rugosa (Lour.) M. A. var. *rugosa*	Euphorbiaceae	t	pe	gro	3	rocks in mxf, egf cliffs	ls	1200	1400	ja-fb		ja-dc	flowers♂,♀
Alectra avensis (Bth.) Merr.	Scrophulariaceae	h	a	gro	2	eg/pine, da	gr	1250	1500	oc-dc	dc-ja	my-dc	Flowers
Allophyllus cobbe (L.) Raeus.	Sapindaceae	t,l	pe	gro	3	rocks in mxf, egf, eg/bb	ls	1200	1400	jl-nv	oc-fb	ja-dc	flowers, fruits
Alseodaphne	Lauraceae	t	pe	gro	2	streams in egf, eg/bb	gr	1100	1300	nv-dc	jl-ag	ja-dc	flowers, fruits
Alstonia scholaris (L.) R.Br. var. *scholaris*	Apocynaceae	t	pd	gro	3	egf, da	gr	1000	1400	sp-oc		mr-dc	Flowers
Alternanthera sessilis (L.) DC. var. *sessilis*	Amaranthaceae	h	pe	aqu, gro	3	ponds, streams in egf, wet areas in eg/bb	gr	750	1100	my-jn	jn-jl	ja-dc	Flowers

Table 1 (continued)

Amalocalyx microlobus Pierre *ex* Spire	Apocynaceae	v,wc	pe	gro	3	egf, eg/pine, da	gr	1000	1400	my-jl		ja-dc	flowers
Amaranthus spinosus L.	Amaranthaceae	h	a	gro, wee	3	da	gr	400	1150	dc-fb	ja-mr	sp-mr	flowers
Amaranthus viridis L.	Amaranthaceae	h	a	gro, wee	3	da	gr	500	1500	ja-dc	ja-dc	ja-dc	
Anacolosa ilicoides Mast.	Olacaceae	t	pe	gro	2	egf	gr, ls	1100	1350	jn-sp	mr-my	ja-dc	
Anaphalis adnata DC.	Compositae	h	a	gro	3	eg/pine, da, eg/bb	gr	1100	1325	oc-dc	nv-ja	my-ja	flowers, fruits
Anaphalis margaritacea (L.) Bth.	Compositae	h	a	gro	3	eg/pine, da	gr	1200	1325	sp-fb	oc-fb	my-fb	flowers
Andrographis laxiflora (Bl.) Lindau	Acanthaceae	h	a	gro, epl	2	rocks, streams, wet areas in eg/bb, cliffs	gr,ls	1200	1375	ag-oc		my-dc	
Anneslea fragrans Wall.	Theaceae	t	pe	gro	3	egf, eg/pine	gr	1200	1450	nv-dc	ap*my	ja-dc	flowers
Anogeissus acuminata (Roxb. *ex* DC.) Guill.& Perr.	Combretaceae	t	pd	gro	3	bb/df, eg/bb	gr, ls	500	1200	ja-mr	ap-my	my-dc	
Antidesma acidum Retz.	Euphorbiaceae	l	pd	gro	3	eg/bb, da	gr	1000	1400	my-jn		my-dc	flowers♀
*Antidesma bunius (*L.) Spreng. var. *bunius*	Euphorbiaceae	t	pe	gro	3	egf, eg/bb	gr, ls	1200	1500		ag-sp	ja-dc	fruits
Antidesma montanum Bl. var. *montanum*	Euphorbiaceae	t	pe	gro	3	egf, eg/bb	ls	1200	1350	ap		ja-dc	flowers♂
Antidesma sootepense Craib	Euphorbiaceae	t,l	pe	gro	3	egf,eg/bb	gr,ls	800	1300	my-ag	jl-dc	ja-dc	flowers♂,♀, fruits
Aphanamixis polystachya (Wall.) R.Parker	Meliaceae	t	pe	gro	3	egf, eg/bb	gr	1000	1400		ap-jn	ja-dc	fruits
Aporosa octandra (B.-H. *ex* D.Don) Vick. var. *octandra*	Euphorbiaceae	t	pd	gro	3	eg/bb, da	gr, ls	1200	1375	ja-fb	my-jn	my-dc	fruits
Aporosa octandra (B.-H. *ex* D.Don) Vick. var. *yunnanensis* (Pax & Hoffm.) Schot	Euphorbiaceae	t	pd	gro	3	egf	gr	1100	1450	ja-fb	my-jn	ap-dc	fruits
Aporosa villosa (Lindl.) Baill.	Euphorbiaceae	t	pd	gro	3	eg/bb, da, sg	gr	1000	1200	ja-fb	my-jn	ap-ja	flowers♂
Aporosa yunnanensis (Pax & Hoff.) Metc.	Euphorbiaceae	t	pe	gro	3	egf, da, sg	gr	1100	1300	ja-fb	my-jn	ja-dc	flowers♂
Aquilaria crassna Pierre *ex* Lec.	Thymeleaceae	t	pd	gro	1	eg/bb	ls	1200	1250			fb-dc	
Arachis pintoi Krap. & Greg.	Leguminosae, Papilionoideae	h	pe	gro,cul,int	3	da	gr	400	1100	ja-dc		ja-dc	flowers
Aralia thomsonii Seem. *ex* Cl.	Araliaceae	l	pe	gro	3	egf, da, sg	gr, ls	1000	1450	my-jn	jl-ag	ja-dc	flowers, fruits
Archidendron clyperia (Jack) Niels. ssp. *clypearia* var. *clypearia*	Leguminosae, Mimosoideae	t	pe	gro	3	da, sg	gr, ls	1000	1400	fb-mr	ap-jn	ja-dc	
Ardisia attenuata Wall.*ex* A. DC.	Myrsinaceae	l	pe	gro	2	rocks in mxf, egf cliffs	ls	1400	1425	ja-dc		ja-dc	flowers

Table 1 (continued)

Ardisia corymbifera Mez var. *corymbifera*	Myrsinaceae	l	pe	gro	3	egf	gr,ls	1000	1375	my-jn	oc-dc	ja-dc	flowers, fruits
Ardisia quinquegona Bl.	Myrsinaceae	l	pe	gro	3	streams in egf	gr,ls	1100	1350	ap	my-jl	ja-dc	Fruits
Argostemma lobbii Hk. f.	Rubiaceae	h	a	epl	3	rocks in egf, eg/bb	ls	1200	1400	ja ag		my-dc	flowers
Argostemma verticillatum Wall.	Rubiaceae	h	pd	epl	3	rocks in mxf, eg/bb	ls	1200	1425	jn-jl	jl-ag	my-dc	flowers, fruits
Argyreia aggregata (Roxb.) Choisy	Convolvulaceae	wc	pd	gro	3	eg/bb, egf,da,sg	ls	1100	1500	oc-ja		my-dc	flowers
Argyreia capitiformis (Poir.) Oost.	Convolvulaceae	v	pe	gro	3	eg/bb, da, sg	gr	1000	1500	nv-dc	fb-mr	ja-dc	flowers
Argyreia henryi (Craib) Craib	Convolvulaceae	wc	pe	gro	3	da, sg	gr	1000	1200	oc-nv		ja-dc	flowers
Argyreia wallichii Choisy	Convolvulaceae	v	pd	gro	3	egf,da,sg	gr,ls	1000	1525	sp-oc	nv-dc	my-dc	flowers, fruits
Aristolochia tagala Cham.	Aristolochiaceae	v	pd	gro	3	da	ls	525	900			my-dc	
Artemisia indica Willd.	Compositae	h	pd	gro, wee	3	da, sg	gr,ls	1200	1525	sp-dc	nv-ja	my-dc	flowers
Artocarpus thailandicus C.C. Berg	Moraceae	t	pe	gro	3	egf, da	gr	950	1500	my-jn	my-jn	ja-dc	flowers, fruits
Aspidocarya uvifera Hk. f. & Th.	Menispermaceae	v	pe	gro	2	streams in eg/bb	gr	1200	1300	my-jn		ja-dc	flowers♂
Aspidopterys (aff. *thorelii* Dop)	Malpighiaceae	wc	pe	gro	3	rocks in mxf cliffs	ls	1375	1425	sp-oc	oc-nv	ja-dc	flowers
Aspidopterys nutans (Roxb. *ex* DC.) Juss.	Malpighiaceae	wc	pe	gro	2	da in mxf	gr	600	700	oc-nv	mr-ap	ja-dc	
Asystasiella neesiana (Wall.) Lindau	Acanthaceae	h	pe	gro	3	streams in egf	gr,ls	1200	1350	oc- nv		ja-dc	flowers
Baccaurea ramiflora Lour.	Euphorbiaceae	t	pe	gro	3	mxf	ls	600	1300	fb-mr	my-jn	ja-dc	flowers, fruits
Balakata baccata (Roxb.) Ess.	Euphorbiaceae	t	pe	gro	3	mxf, streams in egf	ss, gr,ls	500	1100	fb-mr	jl	ja-dc	flowers, fruits
Balanophora abbreviata Bl.	Balanophoraceae	h	pd	gro, par	2	streams in egf, eg/bb, da	gr,ls	1125	1350	oc-nv	nv-dc	leafless	flowers♀♂
Balanophora fungosa J.R. & G. Forst. ssp. *indica* (Arn.) B. Han. var. *indica*	Balanophoraceae	h	pe	gro	2	egf	ls	1000	1400	dc-fb		leafless	
Balanophora latisepala (Tiegh.) Lec.	Balanophoraceae	h	pd	gro,par	2	streams in eg/bb	gr	1150	1250	nv-dc		leafless	flowers♀
Baliospermum calycinum M. A.	Euphorbiaceae	l	pe	gro	2	egf, rocks in eg/bb	gr,ls	1200	1375	ag-sp	sp-oc	ja-dc	flowers♂,♀, fruits
Barleria strigosa Willd.	Acanthaceae	h	pd	gro	3	bb/df, eg/bb	gr,ls	500	900	oc-nv		my-dc	
Bauhinia ornata Kurz var. *kerrii* (Gagnep.) K. & S.S. Lar.	Leguminosae, Caesalpinioideae	wc	pe	gro	3	egf ,da	ss	900	1100	fb-mr		ja-dc	flowers
Bauhinia variegata L.	Leguminosae, Caesalpinioideae	t	pd	gro	3	eg/pine, eg/bb, bb/df	gr	650	1525	ja-fb		jn-fb	

Table 1 (continued)

Begonia acetosella Craib	Begoniaceae	h	pe	gro, rhe	3	streams in egf, wet areas	gr, ls	900	1500	mr-ap	mr-my	ja-dc	flowers, fruits
Begonia cathcartii Hk..f. *ex* Hk. f. & Th.	Begoniaceae	h	pe	gro, epl	3	mostly streams in egf,eg/bb, rarely cliffs in egf on ls	gr, ls	1200	1375	sp-dc	nv-ja	ja-dc	flowers, fruits
Begonia putii Craib	Begoniaceae	h	pd	epl	2	rocks in mxf, egf cliffs	ls	600	1425	oc		jn-dc	flowers
Begonia sect.Uniplacentales Cl.	Begoniaceae	h	pd	epl	3	rocks and cliffs in mxf	ls	550	1375	sp-nv	nv-dc	my-dc	flowers
Beilschmiedia aff. *intermedia* Allen	Lauraceae	t	pe	gro	2	egf, eg/bb	gr	1050	1200	my-jn		ja-dc	
Berchemia floribunda (Wall.) Wall. *ex* Brongn.	Rhamnaceae	wc	pe	gro	3	streams in egf, eb/bb	gr	1000	1300		fb-mr	ja-dc	fruits
Betula alnoides Ham. *ex* D.Don	Betulaceae	t	pd	gro	2	egf, eg/bb	gr	1100	1400	ja-fb	fb-mr	fb-dc	flowers♂
Bidens pilosa L.	Compositae	h	a	gro, wee	3	eg/pine, da, sg	gr	700	1525	my-oc	jn-nv	my-dc	
Bischofia javanica Bl.	Euphorbiaceae	t	pd	gro	2	streams in egf, eg/bb	gr	1000	1300	fb-mr	sp-nv	mr-fb	fruits
Blumea balsamifera (L.) DC.	Compositae	h	a	gro, wee	3	da, sg	gr	500	1500	ap-my	my-jn	ja-dc	flowers
Blumea lacera (Burm.f.) DC.	Compositae	h	a	gro	3	eg/bb	gr	1000	1500	ja-fb	fb-mr	jl-mr	flowers
Blumea napifolia DC.	Compositae	h	a	gro	3	eg/bb	gr	1000	1500	ja-fb	fb-mr	jn-mr	flowers
Blumeopsis flava (DC.) Gagnep.	Compositae	h	a	gro	3	egf,eg/bb da	gr	1000	1500	dc-ja	fb-mr	jn-mr	flowers
Boehmeria aff.*thailandica* Yaha.	Urticaceae	l,s	pe	gro	3	egf,da,sg	ls	1000	1100	oc-dc	ja-dc	ja-dc	fruits
Boehmeria clidemioides Miq. var. *clidemioides*	Urticaceae	s	pe	gro	3	mxf, da	ls	1300	1400	ag-sp		ja-dc	flowers♀♂
Boehmeria diffusa Wedd.	Urticaceae	s, l	pe	gro	3	egf, eg/pine, da, sg	gr	1000	1525	jn-oc		ja-dc	flowers♂
Boehmeria hamiltoniana Wall. *ex* Wedd.	Urticaceae	wc,s	pe	epl	3	streams in egf	gr	1100	1300	ja-dc		ja-dc	flowers
Boehmeria malabarica Wall. *ex* Wedd.	Urticaceae	s	pe	gro,epl	3	rocks in egf, mxf	ls	550	1400	sp	fb-mr	ja-dc	flowers♂, fruits
Boehmeria nivea (L.) Gaud. var. *tenacissima* (Roxb.) Miq.	Urticaceae	t	pe	gro	3	streams in mxf,da	ls	550	700		fb-mr	ja-dc	fruits
Boehmeria penduliflora Wedd. *ex* Long	Urticaceae	l	pe	gro	3	egf,da,sg	gr	600	900		oc-nv	ja-dc	fruits
Boehmeria pilosiuscula (Bl.) Hassk.	Urticaceae	h	pe	gro	3	egf,da,sg	gr,ls	1200	1425		sp-nv	ja-dc	fruits
Boehmeria platyphylla D.Don	Urticaceae	s,h	pe	gro	3	egf,eg/bb da	ls	600	1200	ag-oc	ja-dc	ja-dc	fruits
Boehmeria zollingeriana Wedd. var. *zollingeriana*	Urticaceae	s	pd	epl	3	eg/bb,da	ls	400	600	oc-nv		my-dc	flowers
Boeica glandulosa Burtt	Gesneriaceae	l	pe	gro	2	streams in egf	gr	1200	1350	sp	oc-nv	ja-dc	flowers, fruits

Table 1 (continued)

Boenninghauseana albiflora (Hk.) Roxb. *ex* Meissn.	Rutaceae	s	pd	epl	2	cliffs, rocks in egf	ls	1300	1400	oc	nv-dc	my-dc	flowers, fruits
Bombax anceps Pierre var. *anceps*	Bombacaceae	t	pd	gro	3	bb/df, eg/bb	gr	400	1000	ja-fb		my-dc	
Bombax insigne Wall.	Bombaceae	t	pd	gro	2	eg/bb, da, sg	gr	400	900	ja-fb	mr-ap	my-nv	
Borreria alata (Aubl.) DC.	Rubiaceae	h	a	gro, wee	3	da, sg	gr	900	1400	jn-sp	ag-oc	my-dc	flowers
Borreria laevis (Lmk.) Griesb.	Rubiaceae	h	a	gro, wee	3	da, sg	gr, ls	1000	1375	my-nv	jn-dc	my-dc	flowers
Borreria repens DC.	Rubiaceae	h	a	gro	3	da,sg	gr	1000	1400	oc-nv	nv-dc	my-dc	flowers, fruits
Brassiopsis hainla (B.-H. *ex* D. Don) Seem.	Araliaceae	t, l	pd	gro	3	rocks in mxf cliffs	ls	1375	1425	nv-dc	ap	my-dc	flowers, fruits
Breynia retusa (Denn.) Alst.	Euphorbiaceae	l	pe	gro	3	egf, eg/bb	gr	1000	1500	ap-jl	jl-sp	ja-dc	flowers♂
Bridelia glauca Bl.	Euphorbiaceae	t	pe	gro	3	egf	gr	1000	1550	ap-my		ja-dc	flowers
Bridelia stipularis (L.) Bl.	Euphorbiaceae	sc, wc	pd	gro	3	da, sg	gr	900	1200	sp-oc	ja-mr	my-mr	flowers♂, fruits
Bridelia tomentosa Bl.	Euphorbiaceae	t,l	pe	gro	3	egf,da,sg	gr	1000	1200	oc-nv	nv-dc	ja-dc	fruits♂
Broussonetia papyrifera Vent.	Moraceae	t,l	pe	gro	3	da, sg	gr	1000	1400	my	my-jn	ja-dc	flowers, fruits
Brucea javanica (L.) Merr.	Simaroubaceae	l	pd	gro	3	rocks in mxf cliffs	ls	1200	1425	fb-mr	sp-dc	mr-dc	flowers, fruits
Buddleja asiatica Lour.	Loganiaceae	l	pd	gro	3	da, sg	gr	500	1500	sp-fb		my-mr	flowers
Buxus	Buxaceae	t	pe	gro	3	rocks in mxf cliffs	ls	1400	1425		nv-dc	ja-dc	fruits
Byttneria aspera Colebr.	Sterculiaceae	wc	pe	gro	3	streams in mxf, da	gr, ls	500	1500	oc-nv		ja-dc	flowers
Cajanus goensis Dalz.	Leguminosae, Papilionoideae	v	a	gro	3	egf ,eg/pine sg	gr	600	1400	fb-mr		my-ap	flowers
Callerya atropurpurea (Wall.) Schot	Leguminosae, Papilionoideae	t	pe	gro	2	egf, eg/bb	gr	1200	1300		ag-sp	ja-dc	
Callicarpa arborea Roxb. var. *arborea*	Verbenaceae	t	pe,pd	gro	3	egf, da ,sg	gr	950	1500	mr-jn		ja-dc	flowers
Calophyllum polyanthum Wall *ex* Pl. & Tr.	Guttiferae	t	pe	gro	3	egf	gr	1100	1500			ja-dc	
Calopogonium mucunoides Desv.	Leguminosae, Papilionoideae	v	a	gro	3	da, sg	gr	900	1200	oc-nv	dc-ja	my-dc	fruits
Camellia sinensis (L.) O.K. var. *assamica* (Mast.) Kita.	Theaceae	l	pe	gro also cul	2	streams in egf	gr	1100	1400	oc		ja-dc	flowers
Cannvalia ensiformis (L.) A. DC.	Leguminosae, Papilionoideae	v	a	gro	3	da, sg	gr	1000	1200	oc-nv		my-ja	flowers
Canthium parviflorum Roxb.	Rubiaceae	l	pd	gro	3	egf, da, eg/bb,eg/pine	gr,ls	1000	1525	(nv)ap-my	jn-dc	fb-dc	flowers, fruits

Table 1 (continued)

Capparis assamica Hk.f. & Th.	Capparaceae	l	pe	gro	2	eg/bb	ls	1200	1300	ap		ja-dc	*flowers*
Capparis sabifolia Hk.f. & Th.	Capparaceae	l	pe	gro	3	rocks in mxf, cliffs	ls	1350	1400	ap		ja-dc	*flowers*
Carallia brachiata (Lour.) Merr.	Rhizophoraceae	t	pe	gro	3	egf	gr,ls	1000	1500		ap-my	ja-dc	*fruits*
Cardamine hirsuta L.	Cruciferae	h	a	gro, wee	2	da, sg	ls	1300	1375	oc	nv	my-dc	*flowers*
Careya arborea Roxb.	Lecythidaceae	t	pd	gro	2	bb/df, eg/bb	gr	400	1500	mr-ap	my-jn	my-dc	
Carlemannia tetragona Hk. f.	Caprifoliaceae	h	a	gro	2	streams in eg/bb, wet areas	gr	1200	1200	jl-ag	oc-nv	ap-dc	*flowers, fruits*
Casearia graveolens Dalz.	Flacourtiaceae	t	ped	gro	3	mxf, egf	gr,ls	1200	1400	my-jn	my-jn	ja-dc	*flowers, fruits*
Casearia grewiifolia Vent. var *gelonioides* (Bl.) Sleum.	Flacourtiaceae	t	pe	gro	3	egf	gr	1000	1550	mr-ap	jn-jl	ja-dc	*fruits*
Castanopsis acuminatissima (Bl.) A. DC.	Fagaceae	t	pe	gro	3	egf, eg/bb,eg/pine	gr	1200	1525	ja-fb	oc-nv	ja-dc	*flowers♂,♀, fruits*
Castanopsis argyrophylla King *ex* Hk. f.	Fagaceae	t	pe	gro	3	egf	gr	900	1200	fb-ap		ja-dc	*flowers*
Castanopsis armata (Roxb.) Spach	Fagaceae	t	pe	gro	3	egf eg/bb	gr	1000	1500	nv-dc	sp-oc	ja-dc	*flowers♂,♀*
Castanopsis calathiformis (Skan) Rehd. & Wils.	Fagaceae	t	pe	gro	2	eg/bb	gr	1100	1300		oc-nv	ja-dc	*fruits*
Castanopsis tribuloides (Sm.) A. DC.	Fagaceae	t	pe	gro	3	egf	gr, ls	1000	1525	ap-my	oc	ja-dc	*flowers♂,♀, fruits*
Castanposis diversifolia (Kurz) King *ex* Hk. f.	Fagaceae	t	pe	gro	3	egf, eg/pine	gr	1100	1300	ja-fb		ja-dc	*flowers♂*
Catunaregam spathulifolia Tirv.	Rubiaceae	l	pd	gro	3	bb/df, eg/bb	gr	600	1400	my-jn	nv-dc	my-dc	
Cayratia (*vide Cissus auriculata* (Roxb.) DC.)	Vitaceae	wc	pd	gro	3	da, sg	gr	1100	900		my-jn	my-dc	*fruits*
Cayratia japonica (Thunb.) Gagnep.	Vitaceae	v	pd	gro	3	mxf streams, egf	ls	500	1425	jl-nv		my-dc	*flowers*
Cayratia pedata (Lour.) Juss.	Vitaceae	v	a	gro	2	rocks in mxf, da, sg, eg/bb cliffs	ls	1200	1425	jl ag	sp-oc	my-dc	*flowers*
Celastrus hindisii Bth.	Celastraceae	wc	pe	gro	2	rocks in mxf cliffs	ls	1400	1425	my-jn	oc	ja-dc	*flowers, fruits*
Celosia argentea L.	Amaranthaceae	h	a	gro, wee	3	da, sg	gr	400	1000	ja-dc	ja-dc	ja-dc	
Centella asiatica (L.) Urb.	Umbelliferae	h,cr	pe	gro	3	egf, da, sg	gr	900	1500			ja-dc	
Chamaecrista leschenaultiana (DC.) Deg.	Leguminosae, Caesalpinioideae	h	a	gro	3	eg/pine, da	gr	1200	1500	sp-oc		my-dc	*flowers*
Chionanthus ramiflorus Roxb.	Oleaceae	t	pe	gro	3	egf	ss	900	1100	fb-mr		ja-dc	*flowers*
Chirita hamosa *Wall.* ex *R. Br.*	*Gesneriaceae*	*h*	*a*	*epl*	*4*	*rocks in bb/df, mxf cliffs*	*ls*	*400*	*700*	*sp-nv*	*oc-dc*	*my-dc*	*flowers*

Table 1 (continued)

Chisocheton cumingianus (C.DC.) Harms	Meliaceae	t	pe	gro	2	egf, eg/bb	gr	1000	1100	jl-ag		ja-dc	*flowers*
Chloranthus nervosus Coll. & Hemsl.	Chloranthaceae	h	pd	gro	2	egf, eg/bb	gr, ls	1300	1400	my-jn		my-dc	*flowers*
Choresthes lanceolata (T. And.) B.Han.	Acanthaceae	h	pe	gro	2	rocks in eg/bb	ls	1200	1300		ap	ja-dc	*fruits*
Cinnamomum	Lauraceae	t	pe	gro	2	streams in eg/bb	gr	1200	1250			ja-dc	
Cinnamomum caudatum Nees	Lauraceae	t	pe	gro	2	egf	gr, ls	1000	1300	my-jl		ja-dc	*flowers*
Cinnamomum iners Reinw. *ex* Bl.	Lauraceae	t	pe	gro	3	mxf, egf	gr,ss	500	1100	ja-fb		ja-dc	*flowers*
Cipadessa baccifera (Roth) Miq.	Meliaceae	t,l	ped	gro,epl	3	rocks and streams in mxf, eg/bb cliffs	ls	450	1425	ap-oc (dc)	fb-oc	ja-dc ap-dc	*flowers, fruits*
Cissus adnata (Wall. *ex* Wight & Arn.) Roxb.	Vitaceae	wc	pe	gro	3	egf, eg/pine, sg	gr	1000	1200	jl ag		ja-dc	*flowers*
Cissus convolvulacea Pl.	Vitaceae	v	ped	gro	3	streams in egf	ls	600	800		fb-mr	ja-dc	*fruits*
Cissus discolor Bl. var. *discolor*	Vitaceae	v	pe	gro	3	egf, da, eg/bb, mxf cliffs	gr, ls	550	1500	my-sp	oc-dc	ja-dc	*flowers, fruits*
Clarkella nana (Edgew.) Hk. f. var. *nana*	Rubiaceae	h	a	epl	2	rocks in mxf, egf, eg/bb cliffs	ls	1375	1425	jl-sp	sp-oc	jn-dc	*flowers, fruits*
Cleidion javanicum Bl.	Euphorbiaceae	t	pe	gro	2	mxf, egf	gr	500	900	fb-mr	jn	ja-dc	
Clematis eichleri (Tam.) Tam.	Ranunculaceae	v	pd	gro	2	da,sg	gr	1000	1100	nv-dc		my-dc	*flowers*
Clematis fulvicoma Rehd. & Wils.	Ranunculaceae	wc, v	pd	epl, gro	3	rocks in mxf cliffs	ls	1375	1425	sp-oc	oc-nv	my-dc	*flowers, fruits*
Clematis thaimontana Tam.	Ranunculaceae	v	pd	gro	2	streams in mxf da sg	ls	700	800	ja-dc	fb	jn-fb	*fruits*
Clerodendrum chinense (Osb.) Mabb. var. *chinense*	Verbenaceae	l	pe	gro	3	mxf, egf, da, sg	gr, ls	1000	1500	my-jn (oc)	oc-nv	ja-dc	*flowers*
Clerodendrum disparifoilum Bl.	Verbenaceae	l,s	pe	gro	3	rocks in mxf, egf, eg/bb	ls	500	1400	oc-nv		ja-dc	*flowers*
Clerodendrum glandulosum Colebr, *ex* Lindl.	Verbenaceae	l	pe	gro	3	da, sg	gr	1000	1400	sp-oc		ja-dc	
Clerodendrum paniculatum L.	Verbenaceae	l	pe	gro	2	da in egf	gr,ls	1000	1400	jn-sp	nv-dc	ja-dc	
Clerodendrum serratum (L.) Moon var. *wallichii* Cl.	Verbenaceae	l	pe	gro	3	bb/df, eg/bb, dg, sg	gr,ls	500	1525	sp-oc	jl-ag	ja-dc	*flowers*
Clerodendrum subscaposum Hemsl.	Verbenaceae	h	a	gro, epl	3	rocks in egf, mxf, eg/bb	ls	1375	1425	sp	oc-nv	my-dc	*flowers, fruits*
Codonopsis javanica (Bl.) Hk. f.	Campanulaceae	v	pe	gro	2	eg/pine, eg/bb	gr	1100	1350	sp-oc		ja-dc	*flowers*
Colebrookia oppositifolia *Sm.*	*Labiatae*	*s*	*pe*	*gro*	*3*	*mostly streams in mxf, egf eg/pine*	*gr,ls*	*500*	*1300*	*ja-fb*	*fb-mr*	*ja-dc*	*flowers, fruits*

Table 1 (continued)

Colona flagrocarpa (Cl.) Craib	Tiliaceae	t	pd	gro	3	eg/bb	gr	900	1400		ja fb	my-fb	*fruits*
Colona floribunda (Kurz) Craib	Tiliaceae	t	pd	gro	3	egf,da,sg	gr	600	1300	oc	nv-dc	my-dc	*fruits*
Colquhounia elegans Wall. var. *tenuiflora* Pr.	Labiatae	sc	pe	gro	2	rocks in mxf, egf cliffs	ls	1200	1400	ja-fb		ja-dc	*flowers*
Combretum griffithii Heur. & M. A.	Combretaceae	wc	pd	epl	3	rocks in bb/df cliffs	ls	400	800	fb	mr-ap	my-dc	
Combretum latifolium Bl.	Combretaceae	wc	pd	gro	3	mxf, eb/bb, sg	sh	500	800	dc-ja	my-jn	jn-fb	*flowers*
Congea rockii Mold.	Verbenaceae	wc	pe	gro	2	rocks in eg/bb	ls	1100	1300	fb-mr	ap-my	ja-dc	*fruits*
Congea tomentosa Roxb. var. *tomentosa*	Verbenaceae	wc	pe	gro	3	eg/bb, da	gr	1000	1400	ja-fb		ja-dc	*flowers*
Conyza sumatrensis (Retz.) Walk.	Compositae	h	a	gro,int,nat,wee	3	da, sg	gr,ls,ss	400	1500	ja-dc	ja-dc	ja-dc	
Cordia	Boraginaceae	t	pe	gro	2	da, sg	gr	1000	1100		oc-nv	ja-dc	*fruits*
Cordia grandis Roxb.	Boraginaceae	t	pe	gro	2	eg/pine,da, sg	gr	1200	1300		ja-mr	ja-dc	*fruits*
Coriandrum sativum L.	Umbelliferae	h	a	cul	3	da	gr	900	1100	oc-nv	nv-dc	my-dc	*flowers*
Craibiodendron stellatum (Pierre) W.W. Sm.	Ericaceae	t	pe	gro	3	eg/pine	gr	1200	1450			ja-dc	
Crassocephalum crepidioides (Bth.) S. Moore	Compositae	h	a	gro, wee	3	da, sg	gr, ls	900	1525	my-fb	jn-mr	my-mr	
Cratoxylum cochinchinense (Lour.) Bl.	Guttiferae, Hypericeae	t	pd	gro	3	egf,da,sg	gr	1000	1300	ap-my	oc-dc	my-dc	*flowers, fruits*
Cratoxylum formosum (Jack) Dyer ssp. *pruniflorum* (Kurz) Gog.	Guttiferae, Hypericeae	t	pd	gro	3	eg/bb, da, sg	gr	500	1100	ap		my-dc	
Crotalaria acicularis B.-H. *ex* Bth.	Leguminosae, Papilionoideae	h	a	gro, wee	3	eg/pine, eg/bb	gr	1100	1400	nv-dc	ja-fb	jn-mr	*flowers*
Crotalaria albida Hey. *ex* Roth	Leguminosae, Papilionoideae	h	a	gro	3	eg/pine, eg/bb	gr	900	1500	nv-dc	fb-mr	jn-mr	*flowers*
Crotalaria assamica Bth.	Leguminosae, Papilionoideae	h	a	gro	3	bb/df, da, sg	gr	500	800	oc-nv		my-fb	
Crotalaria bracteata Roxb. *ex* DC.	Leguminosae, Papilionoideae	h	a	gro, wee	3	eg/bb, da, sg	gr	900	1500	sp-oc		my-fb	
Crotalaria cytisoides Roxb. *ex* DC.	Leguminosae, Papilionoideae	l	pd	gro	3	eg/pine, eg/bb	gr	1200	1325		nv-ja	my-ja	*fruits*
Crotalaria dubia Grah. *ex* Bth.	Leguminosae, Papilionoideae	h	a	gro	3	eg/bb, da	gr	1000	1400	nv-dc	mr-ap	jn-mr	*flowers*
Crotalaria kurzii Baker *ex* Kurz	Leguminosae, Papilionoideae	h	a	gro	3	egf, eg/pine, eb/bb, da	gr	1200	1500	sp-oc		my-dc	*flowers*
Crotalaria pallida *Ait.*	*Leguminosae, Papilionoideae*	*h*	*a*	*gro, wee*	*3*	*da, sg*	*gr*	*400*	*800*	*jn-oc*		*my-fb*	

Table 1 (continued)

Croton robustus Kurz	Euphorbiaceae	t	pe	gro	3	eg/bb,egf,da,sg	gr	1000	1500	nv-fb	fb-ap	ja-dc	flowers♂,♀, fruits
Cruddasia insignis Prain	Leguminosae, Papilionoideae	v	pe	gro	3	egf, eg/bb	gr	1100	1400	jl-sp		ja-dc	flowers
Cryptocarya amygdalina Nees	Lauraceae	t	pe	gro	3	egf, eg/bb	gr, ls	1100	1400	my	ap-my	ja-dc	fruits
Cyclea polypetala Dunn	Menispermaceae	wc	pe	gro	3	egf, eg/bb	gr, ls	1000	1400	nv-mr	ap-my	ja-dc	flowers ♂ fruits
Dalbergia cana Grah. *ex* Kurz var. *cana*	Leguminosae, Papilionoideae	t	pd	gro	3	mxf ,egf	gr,ls	900	1350		my-jn	ap-dc	fruits
Dalbergia cultrata Grah. *ex* Bth.	Leguminosae, Papilionoideae	t	pd	gro	3	eg/bb, eg/pine da sg	gr, ls	800	1350	fb-mr	nv-dc	mr-dc	flowers, fruits
Dalbergia lanceolaria L.f. var. *lanceolaria*	Leguminosae, Papilionoideae	t	pd	gro	3	bb/df	gr	500	800	ap	jn	ap-dc	flowers
Dalbergia ovata Grah. *ex* Bth	Leguminosae, Papilionoideae	t	pe	gro	2	egf, eg/bb	gr	950	1350	ja-fb		ja-dc	flowers
Dalbergia rimosa Roxb.	Leguminosae, Papilionoideae	wc	pe	gro	3	egf, eg/bb	gr	1000	1500	my-jl		ja-dc	flowers
Dalbergia stipulacea Roxb.	Leguminosae, Papilionoideae	sc	pd	gro	3	egf,da	gr	1000	1500	ap-my	nv-dc	ja-dc	fruits
Debgreasia longifolia (Burm. f.) Wedd.	Urticaceae	l	pe	gro	3	eg/bb, egf,da,sg	gr,ls	500	1500	sp-nv	nv-ja	ja-dc	flowers♀♂, fruits
Debgreasia wallichiana (Wedd.) Wedd. ssp. *wallichiana*	Utricaceae	l,t	pd	gro	3	rocks in mxf, cliffs	ls	1250	1425	my-jn	ag-sp	my-dc	flowers♀♂, fruits
Dendrocnide sinuata (Bl.) Chew	Urticaceae	t	pe	gro	2	rocks in mxf cliffs, da	gr,ls	550	700	oc-nv	oc-nv	ja-dc	flowers♀, fruits
Dendrophthoe kerrii (Craib) Barl.	Loranthaceae	s	pe	epi, par	2	eg/bb	ls	1200	1425	nv-ja	fb-mr	ja-dc	flowers,fruits
Derris tonkinensis Gagnep.	Leguminosae, Papilionoideae	wc	pd	epl	3	rocks in bb/df cliffs	ls	400	800			my-dc	
Desmodium heterocarpon (L.) DC. ssp. *heterocarpon* var. *heterocarpon*	Leguminosae, Papilionoideae	h	pe	gro	3	bb/df, eg/pine, eg/bb	gr	700	1400	sp-dc	oc-ja	ja-dc	flowers, fruits
Desmodium laxiflorum DC. ssp. *laxiflorum*	Leguminosae, Papilionoideae	h	pd	gro	3	bb/df, eg/bb	gr	1000	1400	oc-nv		my-ja	flowers
Desmodium motorium (Houtt.) Merr.	Leguminosae, Papilionoideae	h	a	gro	3	eg/bb, da	gr	1000	1300	oc-nv	nv-dc	jn-dc	fruits
Desmodium multiflorum DC.	Leguminosae, Papilionoideae	l	pd	gro	3	eg/bb, da, sg	gr	1000	1400		ja-fb	my-fb	fruits

Table 1 (continued)

Desmodium oblatum Baker *ex* Kurz	Leguminosae, Papilionoideae	l	pd	gro	2	eg/bb	gr	1000	1300	oc-dc	dc-ja	jn-ja	fruits
Desmodium repandum (Vahl) DC.	Leguminosae, Papilionoideae	v	pe	gro	3	da, sg	gr	1000	1525	oc-nv	dc-ja	ja-dc	flowers, fruits
Desmodium triflorum (L.) DC.	Leguminosae, Papilionoideae	h	pe	gro, wee	3	eg/pine, eg/bb, da, sg	gr	700	1400	oc-dc	ja-fb	ja-dc	flowers
Desmodium triquetrum (L.) DC. ssp. *triquetrum*	Leguminosae, Papilionoideae	l	pe	gro	3	da, eg/bb	gr, ls	1000	1350	oc-nv	dc-ja	ja-dc	flowers, fruits
Desmodium velutinum (Willd.) DC. ssp. *velutinum* var.*velutinum*	Leguminosae, Papilionoideae	s	pe	gro	3	egf,da,sg	gr	1000	1400	oc-dc	ja-dc	ja-dc	flowers
Desmos (Dasymaschalon yunnanense (Hu) Ban)	Annonaceae	t,l	pe	gro	3	egf	ls	1200	1400	my-jn	oc-nv	ja -dc	flowers, fruits
Dicellostyles zizyphifolia (Griff.) Phup.	Malvaceae	t	pe	gro	3	rocks in mxf	ls	1300	1400		nv-dc	ja-dc	fruits
Dichroa febrifuga Lour.	Saxifragaceae	l	pe	gro	2	streams in eg/bb, egf	gr,ls	1200	1400	my-jn		ja-dc	flowers
Dichrocephala integrifolia (Lmk.) DC.	Compositae	h	a	gro, wee	3	egf, da	gr, ls	1200	1375	ap-jn	my-jn	ap-dc	flowers
Didymocarpus insulsus Craib var. *payapensis* Palee & Maxw.	Gesneriaceae	h	pd	epl	2	rocks in egf, eg/pine	gr,ls	1300	1400	ap-sp	sp-jn	my-dc	flowers, fruits
Didymocarpus longan Lour. ssp. *longan* var. *longan*	Sapindaceae	t	pe	gro	2	egf, eg/bb	gr	800	1200	mr-ap	jl-ag	ja-dc	
Didymocarpus tristis Craib	Gesneriaceae	h	pd	epl	2	streams, rocks in egf, eg/bb	gr	1200	1250	jl-ag	sp-oc	jn-dc	fruits
Dillenia parviflora Griff. var. *kerrii* (Craib) Hoogl.	Dilleniaceae	t	pd	gro	3	egf, eg/bb, da	gr	1000	1500	ja	ap-jn	my-dc	fruits
Dinetus racemosus (Wall.) Sweet	Convolvulaceae	v	a	gro	3	egf,da,sg	ls	1100	1500	oc-nv		my-dc	flowers
Diospyros ferrea (Willd.) Bakh. var. *littorea* (R. Br.) Bakh.	Ebenaceae	t,l	pe	gro	3	rocks, cliffs in mxf	ls	1300	1425	my-jn		ja-dc	flowers♂
Diospyros lotus L.	Ebenaceae	t	pe	cul, int	2	egf	gr	1400	1400	fb-mr		ja-dc	native to Japan
Diospyros martabanica Cl.	Ebenaceae	t	pe	gro	3	egf	ls	1100	1400	fb-mr	my-jn	ja-dc	flowers, fruits
Diospyros winitii Flet.	Ebenaceae	t	pe	gro	3	egf, eg/bb	ls	1200	1375	ap	ap	ja-dc	flowers♂, fruits
Docynia indica (Wall.) Decne.	Rosaceae	t	pe	gro, cul, int	2	egf, da	gr	1100	1350			ja-dc	
Dolichos trilobus L.	Leguminosae, Papilionoideae	v	a	gro	2	mxf, da, sg	gr, ls	1000	1450	ja-fb		jn-ap	fllowers
Drymaria diandra Bl.	Caryophyllaceae	h	a	gro, wee	3	eg/pine, da, sg	gr	1100	1525	ag-fb	sp-fb	my-fb	flowers
Duabanga grandiflora (Roxb. *ex* DC.) Walp.	Sonneratiaceae	t	pe	gro	3	eg/bb, egf	gr, ls	1000	1375	fb-ap		ja-dc	flowers

Table 1 (continued)

Duperrea pavettifolia (Kurz) Pit.	Rubiaceae	l	pe	gro	2	streams in egf	gr,ls	1000	1300	my-jl		ja-dc	flowers
Eclipta prostrata (L.) L.	Compositae	h	a	aqu,gro,wee	3	da	gr,ss	600	1500	my-ag	jn-sp	my-dc	flowers, fruits
Elaeagnus conferta Roxb.	Elaeagnaceae	wc	pe	gro also cul	2	streams in eg/bb	gr	1000	1250	sp-oc	oc-nv	ja-dc	flowers
Elaeocarpus floribundus Bl. var. floribundus	Elaeocarpaceae	t	pe	gro	3	eg/bb, egf	gr,ls	1000	1400	my-jn	sp-oc	ja-dc	flowers, fruits
Elaeocarpus lanceifolius Roxb.	Elaeocarpaceae	t	pe	gro	3	mxf,egf	gr,ls	1000	1400	ap-jn	nv-dc	ja-dc	post
Elaeocarpus stipularis Bl.	Elaeocarpaceae	t	pe	gro	3	egf, eg/bb	gr,ls	900	1400	my-jn	sp-oc	ja-dc	flowers, fruits
Elatostema cyrtandraefolium (Zoll. & Mor.) Miq.	Urticaceae	h	a	gro,epl	3	rocks in mxf, egf	ls	1300	1425		sp-oc	my-dc	fruits
Elatostema lineolatum Wight var. *majus* Wedd.	Urticaceae	h	pe	gro, epl	2	streams, wet areas in egf	gr,ls	1200	1350		nv-ja	ja-dc	fruits
Elatostema monandrum (Ham. *ex* D. Don) Hara	Urticaceae	h	pd	epl	3	rocks in mxf, egf, eg/bb	ls	1300	1425	jn-jl	jl-ag	jn-dc	fruits
Elatostema platyphyllum Wedd. var. *platyphyllum*	Utricaceae	h	pe	gro	3	streams in egf	gr,ls	1000	1275	mr-my	jn-ag	ja-dc	
Elatostema salvinioides W. T. Wang	Urticaceae	h	pd	epl	2	rocks in mxf, eg/bb cliffs	ls	575	1375	ag-sp		my-dc	flowers
Elephantopus scaber L. ssp. *scaber* var. *scaber*	Compositae	h	pe	gro, wee	3	da, sg	gr, ls	800	1500	sp-oc	nv	ja-dc	flowers
Elsholtzia blanda H. Keng	Labiatae	h	pd	gro	2	eg/pine	gr	1200	1325	nv-dc		my-ja	flowers
Embelia sessiflora Kurz	Myrsinaceae	wc	pd	gro	3	eg/bb egf, da, sg	gr	650	1500	ap-my	jl	my-mr	flowers, imm. fruits
Emilla sonchifolia (L.) DC. *ex* Wight	Compositae	h	a	gro,wee	3	da, sg	gr,ss	500	1500	my-jl	jn-ag	my-nv	flowers, fruits
Engelhardia serrata Bl. var. *serrata*	Juglandaceae	t	pd	gro	3	eg/pine, sg, egf, eg/bb	gr	1000	1500	ja-fb	mr-ap	ja-nv	flowers♀
Engelhardia spicata Lechen. *ex* Bl. var. *integra* (Kurz) Mann.	Juglandaceae	t	pd	gro	3	eg/bb, da	ls	1000	1350	fb-mr	mr-ap	ap-fb	
Engelhardia spicata Lesch. *ex* Bl. var. *spicata*	Juglandaceae	t	pd	gro	3	eg/pine sg	gr	700	1400	ja fb	fb-mr	mr-dc	fruits
Entada rheedei Spreng. (ssp.*rheedei*)	Leguminosae, Mimosoideae	wc	pd	gro	3	egf	gr	900	1500	mr-ap	ja-jn	fb -dc	
Epigynum cochinchinensis (Pierre) Midd.	Apocynaceae	wc	pe	gro	3	streams in mxf	ls	550	700	ag-sp		ja-dc	flowers
Epithema carnosum Bth.	Gesneriaceae	h	pd	epl	2	rocks, streams in egf	gr, ls	1100	1350	ag-sp	sp-oc	my-dc	flowers, fruits
Eranthemum tetragonum Wall. *ex* Nees ssp. *tetragonum*	Acanthaceae	h	pe	gro	3	egf, eg/pine, eg/bb	gr	550	1450	dc-fb		ja-dc	flowers

Table 1 (continued)

Eriobotrya salwinensis Hand.-Mazz.	Rosaceae	t	pe	gro	3	rocks in mxf cliffs	ls	1375	1425	nv-dc	fb	ja-dc	flowers, fruits
Eriolaena candollei Wall.	Sterculiaceae	t	pd	gro	3	egf ,eg/pine, da ,sg	gr	1200	1500		dc-fb	jn-fb	fruits
Erythrina stricta Roxb.	Leguminosae, Papilionoideae	t	pd	gro	3	mxf, da	ls , gr	1200	1400	ap		jn-dc	flowers
Erythrina subumbrans (Hassk.) Merr.	Leguminosae, Papilionoideae	t	pe	gro	3	streams in egf, eg/bb	gr, ls	550	1400	ja-fb		ja-dc	flowers
Erythropalum scandens Bl.	Olacaceae	wc	pe	gro	3	streams in mxf	ls	550	800	ag-sp		ja-dc	flowers
Eugenia albiflora Duth. *ex* Kurz	Myrtaceae	t	pe	gro	3	eg/bb, eg/pine	gr	800	1500	fb-ap	jl-ag	ja-dc	
Eugenia formosa Wall.	Myrtaceae	t	pe	gro	3	streams in mxf	gr, ls	500	700	mr-ap	ag-sp	ja-dc	
Eugenia fruticosa (DC.) Roxb.	Myrtaceae	t	pe	gro	3	egf, eg/bb, da, sg	gr	900	1500	ap-my	my-jn	ja-dc	flowers, fruits
Eugenia megacarpa Craib	Myrtaceae	t	pe	gro	3	egf	ls	1100	1400	ja-fb	sp-oc	ja-dc	flowers
Euonymus cochinchinensis Pierre	Celastraceae	l	pe	gro	3	egf	ls	1000	1400	fb-mr	oc-nv	ja-dc	fruits
Euonymus laxiflora Champ. *ex* Bth.	Celastraceae	s	pe	gro	2	rocks in egf cliffs	ls	1300	1375	jl-sp	oc-nv	ja-dc	fruits
Euonymus sootepensis Craib	Celastraceae	cr,v, wc	pe	gro	3	egf	ls	1100	1425	fb-mr	oc-nv	ja-dc	flowers, fruits
Eupatorium adenophorum Spreng.	Compositae	h	pe	gro, int,wee	4	da, sg	gr	600	1525	mr-ap	ap-my	ja-dc	
Eupatorium doichangensis H. Koy	Compositae	h	a	gro	2	bb/df, da	gr	1100	1200	ja-fb	mr	ag-dc	flowers
Eupatorium odoratum L.	Compositae	h	pe	gro, nat,wee	4	da,sg	gr,ls	400	1525	nv-dc	ja-fb	ja-dc	
Euphorbia hirta L.	Euphorbiaceae	h	a	gro,int,nat,wee	3	da, sg	gr	400	1500	ja-dc	ja-dc	ja-dc	
Euphorbia thymifolia L.	Euphorbiaceae	h	a	gro, wee	3	da	gr,ls	425	800	ag-nv	oc-dc	my-dc	fruits
Eurya acuminata DC. var. *wallichiana* Dyer	Theaceae	t	pe	gro	3	da,sg in egf	gr	1000	1500	nv-dc	ja-fb	ja-dc	flowers, fruits
Eurysolen gracilis Prain	Labiatae	s,l	pe	gro	3	mxf, egf, da	gr , ls	1100	1425	nv-fb	ja-mr	ja-dc	flowers, fruits
Evolvulus nummularius (L.) L.	Convolvulaceae	h,cr	pe	gro,wee	3	da	gr,ss	800	1000	my-jl	jn-ag	ja-dc	flowers, fruits
Exacum pteranthum Wall. *ex* Griseb.	Gentianaceae	h	a	gro	3	eg/pine	gr	1250	1325	sp-oc	nv	my-dc	flowers
Fagerlinidia	Rubiaceae	t, l	pe	gro	2	streams in egf	gr, ls	1200	1300	ap	ja-fb	ja-dc	flowers, fruits
Fagopyrum dibotrys (D. Don) Hara	Polygonaceae	h	pd	gro	3	egf, da	gr,hs	1000	1400	(ag) oc-nv		my-ja	flowers
Fagraea ceilianica Thunb.	Loganiaceae	s	pe	epl	2	rocks in mxf cliffs	ls	600	1400		nv-ap	ja-dc	fruits
Falconeria insigne Roy.	Euphorbiaceae	t	pd	gro	2	rocks, cliffs in mxf	ls	1200	1425	ja-fb		jn-dc	flowers♂

Table 1 (continued)

Fernandoa adenophylla (Wall. ex G. Don) Steen.	Bignoniaceae	t	pd	gro	3	da, sg	gr	500	1100	jl-ag		ja-fb my-dc	flowers
Ficus	Moraceae	t,s	pe	epl	2	cliffs in bb/df, egf	ls	400	1300	dc-fb	dc-fb	ja-dc	flowers
Ficus annulata Bl.	Moraceae	t	pd	str, epl	3	mxf, egf	gr, ls	600	1400	ap-sp	ap-sp	ja-dc	flowers, fruits
Ficus anserina (Corn.) C.C. Berg	Moraceae	wc	pe	epl, gro	3	rocks, cliffs in bb/df , egf	gr, ls	400	1350	my-jl	jn-ag	ja (my)-dc	flowers, fruits
Ficus auriculata Lour.	Moraceae	t	pe	gro	3	da, streams in egf, wet areas in eg/bb	gr	900	1500	dc-ag	mr-sp	ja-dc often changin g lvs in dc	flowers
Ficus cyrtophylla Wall. *ex* Miq.	Moraceae	l	pe	gro, epl	2	streams in egf, mxf	ls	550	1350	ap-sp	ap-sp	ja-dc	flowers, fruits
Ficus fistulosa Reinw. *ex* Bl.	Moraceae	t	pe	gro	3	egf, da	gr	1000	1525	ja-dc	ja-dc	ja-dc	flowers
Ficus glaberrima Bl.	Moraceae	t, l	pe	epi, epl	2	eg/bb, rocks , cliffs	gr, ls	1000	1425	nv-dc	nv-dc	ja-dc	flowers
Ficus hirta Vahl var. *hirta*	Moraceae	l	pe	gro	3	da, sg, egf	gr,ls	1000	1400	jn-sp	jl-oc	ja-dc	flowers, fruits
Ficus hirta Vahl var. *roxburghii* (Miq.) King	Moraceae	t	pe	gro	3	egf	gr,ls	1000	1400	ap-my	ap-my	ja-dc	flowers, fruits
Ficus hispida L. f. var. *hispida*	Moraceae	t	pe	gro	3	da, sg	gr	400	1500	ja-dc	ja-dc	ja-dc	
Ficus kurzii King	Moraceae	t	pe	epi	3	rocks in egf	ls	1200	1500	ag-nv	ag-nv	ja-dc	flowers, fruits
Ficus laevis Bl.	Moraceae	wc,cr	pe	gro	2	streams in egf, eb/bb	gr	1100	1300	ja-mr	fb-ap	ja-dc	
Ficus semicordata B.-H. *ex* J.E. Sm. var. *semicordata*	Moraceae	t	pe	gro	3	egf, eg/bb, da, mxf, sg	gr, ls	550	1525	ja-dc	ja-dc	ja-dc	
Ficus subincisa Ham. *ex* J.E. Sm. var. *subincisa*	Moraceae	t,l	pe	gro	3	egf,da, sg	gr, ls	1000	1400	ja-dc	ja-dc	ja-dc	flowers
Ficus subpisocarpa Gagnep. ssp. *pubipoda* C.C. Berg	Moraceae	t	pd	gro	3	egf	gr	1000	1450	jl-ag	sp-oc	mr-ja	flowers
Ficus tinctoria G. Forst. ssp. *gibbosa* (Bl.) Corn. var. *gibbosa*	Moraceae	wc	pe	gro	3	mxf, egf	gr,ss	600	1000	my-jl	jn-ag	ja-dc	flowers, fruits
Ficus variegata Bl. var. *variegata*	Moraceae	t	pd	gro	2	streams in egf, eg/bb	gr	1000	1200			my-fb	
Firmiana colorata (Roxb.) R. Br.	Sterculiaceae	t	pd	gro	3	rocks, cliffs	gr, ls	1000	1425	ja-mr	mr-ap	jn-dc	flowers, leaves
Firmiana kerrii (Craib) Kosterm.	Sterculiaceae	l	pd	gro	2	rocks in mxf cliffs	ls	1350	1425	ja-fb	ap	jn-dc	flowers, leaves
Fissistigma oblongum (Craib) Merr.	Annonaceae	wc	pe	gro	2	egf, eg/pine	gr	900	1100			ja-dc	

Table 1 (continued)

Flacourtia indica (Burm.f.) Merr.	Flacourtiaceae	t	pe	gro	3	egf, da ,sg	gr	900	1500		jl-ag	ja-dc	fruits
Flemingia sootepensis Craib	Leguminosae, Papilionoideae	l	pe	gro	3	mxf, eg/bb, da, sg	gr, ls	550	1400		ja-fb	ja-dc	fruits
Fluggea virosa (Roxb. ex Willd.) Voigt	Euphorbiaceae	s, l	pd	gro	3	rocks in mxf, eg/bb,da	gr,ls	525	1425	jl-sp	sp-oc	my-dc	flowers♂, fruits
Galium punduanum Wall. *ex* Craib	Rubiaceae	h	a	epl	2	rocks in egf cliffs	ls	1300	1400	oc-nv	dc	my-dc	flowers
Garcinia cowa Roxb.	Guttiferae	t	pe	gro	3	mxf, egf, eg/bb	gr,ls	1200	1375	ap	sp	ja-dc	flowers♀
Garcinia propinqua Craib	Guttiferae	t	pe	gro	3	rocks in egf, eg/bb cliffs	ls	1350	1375	my-jn		ja-dc	flowers♂
Garcinia xanthochymus Hk. f. *ex* T. And.	Guttierae	t	pe	gro, epl	3	bb/df, eg/bb	gr,ls, sh	500	900			ja-dc	
Gardenia sootepensis Hutch.	Rubiaceae	t	pd	gro	3	bb/df, eg/bb	gr	900	1100	ap		my-dc	flowers
Garuga pinnata Roxb.	Burseraceae	t	pd	gro	3	eg/bb, da, sg	ls	500	1350			my-dc	
Girardinia hibiscifolia Miq.	Urticaceae	h	a	gro	3	egf,da	ls	1150	1500	oc-nv	nv-dc	my-dc	flowers
Glochidion eriocarpum Champ.	Euphorbiaceae	l	pe	gro	3	egf, eg/pine	gr	1200	1400		ja-fb	ja-dc	fruits
Glochidion oblatum Hk. f.	Euphorbiaceae	t	pe	gro	2	eg/bb	gr	1100	1400		jl-ag	ja-dc	fruits
Glochidion rubrum Bl.	Euphorbiaceae	t	pe	gro	3	da, sg	gr	1000	1500		ja-fb	ja-dc	fruits
*Glochidion sphaerogynum (*M. A.) Kurz	Euphorbiaceae	t	pe	gro	3	eg/bb, da, sg	gr	1000	1400	ja-fb	dc-ja	ja-dc	flowers, fruits
Glycosmis cochinchinensis (Lour.) Pierre *ex* Engl.	Rutaceae	l	pe	gro	3	rocks in mxf	ls	1200	1425	ja-fb	ag	ja-dc	flowers
Glyptopetalum sclerocarpum Kurz	Celastraceae	l	pe	gro	3	egf	ls	1100	1375	ap-my	oc-nv	ja-dc	flowers, fruits
Gmelina arborea Roxb.	Verbenaceae	t	pd	gro	3	da/sg, bb/df, eg/bb	gr	500	1500			my-dc	
Gochnatia decora (Kurz) Cabr.	Compositae	l	pd	gro	2	eg/pine, eg/bb	gr	1200	1375	mr	ap-my	ap-dc	
Gomphogyne heterosperma (Wall.) Kurz	Cucurbitaceae	v	a	gro	3	cliffs, rocks in mxf, eg/bb, bb/df	ls	400	1425	sp-oc		my-dc	flowers♂
Gomphostemma crinitum Wall. *ex* Bth.	Labiatae	h	a	gro	2	streams in mxf	ls	650	700	oc		my-dc	
Gomphostemma lucidum Wall. *ex* Bth.	Labiatae	h	pe	gro	2	rocks in eg/bb	ls	1350	1375	ag		ja-dc	
Gomphostemma strobilinum Wall. *ex* Bth. var. *viridis* (Wall. *ex* Bth.) Hk. f.	Labiatae	h	pe	gro	2	mxf, eg/bb	gr,ls	1300	1425	sp		ja-dc	flowers
Gomphostemma wallichii Pr.	Labiatae	h	pd	gro	2	streams in egf, eg/bb	gr	1000	1300	oc-nv		my-fb	flowers
Goniothalamus cheliensis Hu	Annonaceae	t, l	pe	gro	2	streams, wet areas in egf	gr, ls		1325			ja-dc	

Table 1 continued

Gouania javanica Miq.	Rhamnaceae	wc	pd	gro	3	rocks in mxf cliffs	ls	1400	1425	sp	nv-dc	my-dc	flowers, fruits
Grewia lacei Drum. & Craib	Tiliaceae	s	pd	gro	3	eg/bb, da	ls	1000	1400	sp-oc		my-dc	flowers
Gynostemma pentaphyllum (Thunb.) Mak.	Cucurbitaceae	v	a	gro	3	egf, da	gr, ls	1200	1375	my-jn		my-dc	flowers♂
Gynura longifolia Kerr	Compositae	v	pd	gro	2	streams in egf, eg/bb	gr	1100	1300	fb		jn-mr	
Gynura nepalensis DC.	Compositae	h	a	gro	3	da, weed	gr,ls,ss	600	1525	my-jl	jn-ag	oc-sp	flowers, fruits
Harpullia arborea (Blanco) Radlk.	Sapindaceae	t	pd	gro	3	streams in mxf	ls	500	900	ja-fb		fb-dc	flowers
Harpullia cupanioides Roxb.	Sapindaceae	t	pe	gro	3	egf	ls	1100	1400	my-jn		ja-dc	flowers
Hedyotis coronaria (Kurz) Craib	Rubiaceae	h	pd	gro	2	mxf, eg/bb	gr	800	1300	jn-ag		my-dc	flowers
Hedyotis corymbosa (L.) Lmk.	Rubiaceae	h	a	gro, wee	3	da, sg	gr	400	1200	sp-oc	oc-nv	ja-dc	flowers
Hedyotis elegans Wall. *ex* Kurz	Rubiaceae	h	pe	gro	3	eg/bb	gr	1000	1300		dc-ja	ja-dc	fruits
Hedyotis scandens Roxb.	Rubiaceae	v,h	pe	gro	3	wet areas egf, da	gr,ls	950	1150	oc-nv		ja-dc	flowers
Helicia formosana Hemsl. var. *oblanceolata* Sleum.	Proteaceae	t	pe	gro	2	egf, eg/bb	gr	1000	1400	ap-my	fb-mr	ja-dc	
Helicia nilagirica Bedd.	Proteaceae	t	pe	gro	3	egf	gr	1200	1500	ap		ja-dc	flowers
Heliciopsis terminalis (Kurz) Sleum.	Proteaceae	t	pe	gro	2	egf, eg/bb	gr	1000	1400	ap-my	dc-fb	ja-dc	
Helicteres elongata Wall. *ex* Boj.	Sterculiaceae	s,l	pd	gro	3	eg/bb	gr	1000	1400	my-jn		ap-dc	flowers
Helixanthera parasitica Lour.	Loranthaceae	s	pe	epi, par	3	egf, eg/pine	gr	1000	1500	ap-my		ja-dc	flowers
Heracleum barmanicum Kurz	Umbelliferae	h	pd	gro	3	rocks in mxf, eg/bb cliffs	ls	1375	1425	sp-nv	oc-nv	jl-dc	flowers
Heriteria macrophylla Wall. *ex* Kurz	Sterculiaceae	t	pe	gro	2	eg/bb, egf	ls	1200	1400	mr-ap		ja-dc	seedling, flowers
Heteropanax fragrans (Roxb. *ex* DC.) Seem.	Araliaceae	l	pd	gro	2	da, sg	gr	900	1300			my-dc	
Heterostemma siamica Craib	Asclepiadaceae	v	pe	gro	3	mxf,da	ls	500	800	oc-nv		ja-dc	flowers
Heynea trijuga Roxb. *ex* Sims	Meliaceae	t,l	pe	gro	2	egf, eg/bb	gr	900	1200	fb-mr	nv-dc	ja-dc	fruits
Hibiscus macrophyllus Roxb.*ex* Horn.	Malvaceae	t	pe	gro	3	egf, da, sg	gr, ls	900	1400	mr-ap		ja-dc	
Hiptage bullata Craib	Malpighiaceae	sc	pe	gro	3	rocks in mxf cliffs	ls	1300	1400	ap-my		ja-dc	flowers
Homalium ceylanicum (Gardn.) Bth.	Flacourtiaceae	t	pd	gro	2	egf, eg/bb	gr	1000	1200	jl-ag		my-fb	flowers
Hopea odorata Roxb. var. *odorata*	Dipterocarpaceae	t	pe	gro	2	egf	ss	900	1000	fb-mr		ja-dc	flowers

Table 1 (continued)

Horsfieldia amygdalina (Wall.) Warb. var. macrocarpa Wilde	Myristicaceae	t	pe	gro	2	egf	gr	1000	1000		ap	ja-dc	fruits
Houttuynia cordata Thunb.	Saururaceae	h	pe	gro	3	streams in egf, wet areas in da	gr	800	1500	(dc) ap-my		ja-dc	flowers
Hovenia dulcis Thunb.	Rhamnaceae	t	pd	gro	2	egf, streams in eg/bb	gr	1200	1400			my-dc	
Hoya kerrii Craib	Asclepiadaceae	v	pe	epl	2	rocks in bb/df cliffs	ls	400	600			ja-dc	
Hoya thomsonii Hk. f.	Asclepiadaceae	v	pe	epi, epl	2	rocks in egf	gr	1300	1400		nv-ja	ja-dc	fruits
Hunteria zeylanica (Retz.) Gard. *ex* Thw.	Apocynaceae	t	pe	gro	3	rocks in egf, cliffs	ls	1200	1375	my	ap-my	ap-dc	flowers, fruits
Hydrocotyle javanica Pont. *ex* Thunb.	Umbelliferae	h	pe	gro, cr	3	mostly wet areas in egf, da, eg/bb	gr,ls	1100	1400	jn-sp	jl-nv	ja-dc	flowers, fruits
Hydrocotyle sibthorpioides Lmk.	Umbelliferae	h	a	gro, wee	3	da, sg	gr	900	1500		ap-oc	my-dc	fruits
Hydrolea zeylanica (L.) Vahl	Hydrophyllaceae	h	a	gro	3	wet areas in da		800	1100	ap-my	ap-jn	mr-oc	flowers, fruits
Hymenodictyon orixense (Denn.) Mabb.	Rubiaceae	t	pe	gro	2	rocks in mxf, eg/bb	ls	1000	1425			my-dc	
Hypericum henryi H. Lev. & Van. ssp. *hancockii* H. Rob.	Guttiferae, Hypericeae	s	pe	epl	2	rocks in egf, cliffs	ls	1300	1400	oc	dc-fb	ja-dc	fruits
Hypericum japonicum Thunb. *ex* Murr.	Guttiferae, Hypericeae	h	a	gro	3	wet areas in da, egf	gr	900	1050	ap-my	ap-my	my-dc	flowers, fruits
Ichnocarpus polyanthus (Bl.) P.I. Forst.	Apocynaceae	wc	pe	gro	3	egf	gr	1000	1525	ap-my		ja-dc	flowers
Ilex umbellulata (Wall.) Loesn.	Aquifoliaceae	t	pe	gro	3	egf	gr, ls	1000	1400		jl	ja-dc	fruits
Impatiens claviger Hk. f.	Balsaminaceae	h	pe	gro	3	streams, wet areas in egf	gr,ls	1200	1350	oc-nv	nv-dc	ja-dc	flowers
Impatiens kerriae Craib	Balsaminaceae	h	pd	epl	3	rocks in mxf cliffs	ls	1375	1425	my-nv	nv-dc	my-dc	flowers
Impatiens salangensis T. Shim.	Balsaminaceae	h	a	epl	3	rocks in mxf	ls	1400	1425	jl-dc	sp-ja	my-dc	flowers
Impatiens vioaeflora Hk.f.	Balsaminaceae	h	a	gro	3	egf, eg/bb	gr	1000	1525	ag-dc	sp-dc	my-dc	
Inula cappa (Ham. *ex* D.Don) DC. forma cappa	Compositae	h	pd	gro	3	eg/bb,sg	gr,ls	900	1500	nv-dc	ja-dc	my-dc	flowers
Inula nervosa Wall. *ex* DC.	Compositae	h	a	epl	2	rocks in mxf, egf cliffs	ls	1200	1400	ja-fb	mr	jn-mr	flowers
Inula wissmanniana Hand.-Mazz.	Compositae	h	pd	gro	2	rodks in eg/pine, eg/bb cliffs	gr	1200	1425	dc-fb	mr	my-mr	flowers
Iodes cirrhosa Turcz.	Icacinaceae	wc	pe	gro	2	egf, da, sg	gr	1000	1200		jl	ja-dc	fruits
Isodon coetsa (B. -H. *ex* D. Don) Kudo	Labiatae	s,h	pd	gro	2	eg/bb, da	ls	1200	1400	dc-ja		jl-fb	flowers

Table 1 (continued)

Isodon lophanthoides (B. -H. ex D. Don) Hara var. lophanthoides	Labiatae	h	a	gro	2	eg/bb	gr	1100	1400	sp-oc	nv-dc	my-dc	fruits
Ixora	Rubiaceae	sc	pe	gro	2	streams in mxf	ls	550	600		sp	ja-dc	fruits
Ixora cibdela Craib	Rubiaceae	l	pe	gro	3	egf, eg/bb	gr	900	1100		oc-nv	ja-dc	
Ixora rugosula Wall. *ex* Hk. f.	Rubiaceae	l, wc	pe	gro	2	eg/bb	ls	1275	1350	ap		ja-dc	flowers
Jasminum coarctatum Roxb. var. *vanprukii* (Craib) P. S. Green	Oleaceae	l,s,sc	pe	gro	2	rocks in egf	ls	1100	1350	jn-jl		ja-dc	flowers
Jasminum dispermum Wall. ssp. *forrestianum* (Kob.) P.S. Green	Oleaceae	s	pe	gro	2	rocks in egf	ls	1200	1400		ja dc	ja-dc	friuts
Jasminum funale Decne. *ssp.* funale	Oleaceae	wc	pe	gro	3	rocks in mxf cliffs	ls	1375	1425	ag-sp		ja-dc	flowers
Jasminum nervosum Lour.	Oleaceae	v	pe	gro	3	rocks in mxf, eg/bb	ls	1200	1400	my	my-jn	ja-dc	flowers, fruits
Justicia helferi Cl.	Acanthaceae	h	pe	gro	2	streams in mxf, egf	ls	600	1300	ja-fb		ja-dc	flowers
Justicia procumbens L.	Acanthaceae	h	a	gro	3	eg/pine, eg/bb, da, sg	gr	900	1525	sp-dc		my-dc	flowers
Justicia quadrifaria (Wall. *ex* Nees) T. And.	Acanthaceae	h	pe	gro		streams in egf, eg/bb	gr	1000	1300	sp-fb	nv-mr	ja-dc	flowers
Kibatalia macrophylla (Pierre *ex* Hua) Woods.	Apocynaceae	t	pe	gro	2	mxf	ls	500	700	my-jn		ja-dc	flowers
Knema lenta Warb.	Myristicaceae	t	pe	gro	3	egf, eg/bb	gr	1000	1300			ja-dc	
Knema tenuinervia Wilde ssp. *setosa* Wilde	Myristicaceae	t	pe	gro	2	mxf, eb/bb	gr	500	700			ja-dc	
Kopsia arborea Bl.	Apocynaceae	t	pe	gro	2	rocks in egf	ls	1200	1400	my-jn	my-jn	ja-dc	flowers, fruits
Kydia calycina Roxb.	Malvaceae	t	pd	gro	3	da sg	gr	750	1500	oc-nv		my-dc	flowers
Lactuca parishii Craib *ex* Hoss.	Compositae	h	pd	gro	3	eg/pine, eg/bb, da, sg	gr	1100	1400	ja-fb	fb-mr	jn-ap	flowers
Lagerstroemia tomentosa Presl	Lythraceae	t	pd	gro	3	bb/df, egf	gr	900	1100	ap	oc-nv	ap-dc	flowers
Lagerstroemia villosa Wall. *ex* Kurz	Lythraceae	t	pd	gro	3	da, sg	gr	900	1500		oc-nv	my-fb	fruits
Lagerstromeia venusta Wall. *ex* Cl.	Lythraceae	t	pe	gro	3	eg/bb, sg	gr	800	1000	jn-jl	nv-dc	ja-dc	
Laggera alata (D. Don) Sch. Bip. *ex* Oliv.	Compositae	h	a	gro, wee	3	da, sg	gr	1100	1525			my-dc	
Laggera pterodonta (DC.) Sch. Bip *ex* Oliv.	Compositae	h	a	gro, wee	3	da	gr	600	1250			ag-mr	
Lantana camara L.	Verbenaceae	s, l	pe	gro, int, nat, wee	2	da, sg	gr, ls	1100	1400	ag-oc		ja-dc	

Table 1 (continued)

Laportea interrupta (L.) Chew	Urticaceae	h	a	gro, epl, wee	3	mxf, egf, da	gr,ls	500	1025	ag-oc	sp-nv	my-dc	flowers, fruits
Laportea violacea Gagnep.	Urticaceae	h	a	gro	3	egf,da,sg	ls	1200	1400	oc-nv	nv-dc	my-dc	flowers
Lasianthus kurzii Hk. f.	Rubiaceae	l	pe	gro	2	streams in egf	gr	1000	1300	my-jn		ja-dc	flowers, imm fruits
Leea indica (Burm.f.) Merr.	Leeaceae	s,l	pe	gro	3	egf, eg/bb	gr,ls	500	1500	my-jl	ag-sp	ja-dc	flowers, fruits
Lepidagathis incurva Ham. *ex* D.Don	Acanthaceae	h	pe	gro	3	rocks in mxf, bb/df, eg/pine	gr, ls	400	1500	dc-mr		ja-dc	flowers
Lepisanthes tetraphylla (Vahl) Radlk.	Sapindaceae	l	pe	gro	2	streams in egf, da	gr	900	1100		jn-jl	ja-dc	imm fruits
Lespedeza parviflora Kurz	Leguminosae, Papilionoideae	l	pe	gro	3	eg/bb, da, sg	gr	1000	1500	nv-ja	ja-fb	ja-dc	fruits
Lespedeza sulcata (Schindl.) Craib	Leguminosae, Papilionoideae	l	pd	gro	3	rocks in mxf cliffs	ls	1100	1425	fb		my-ja	
Leucaena leucocephala (Lmk.) De Wit	Leguminosae, Mimosoideae	t, l	pe	gro, int, nat, wee	3	da, sg	gr	400	700			ja-dc	
Leucas decemdentata (Willd.) J.Sm.	Labiatae	h	a	epl	3	egf da	ls	1200	1400	oc-nv		my-dc	flowers
Lindenbergia indica (L.) Vat.	Scrophulariaceae	h	a	epl, gro	3	bb/df, mxf,da	ls	400	700	oc-nv	nv-dc	my-dc	flowers
Lithocarpus auriculatus (Hick. & A. Camus) Barn.	Fagaceae	t	pe	gro	3	egf	gr	1000	1400		sp-oc	ja-dc	fruits
Lithocarpus elegans (B.) Hatus. *ex* Soep.	Fagaceae	t	pe	gro	3	egf	gr	1000	1500		sp-oc	ja-dc	fruits
Lithocarpus polystachyus (Wall. *ex* A. DC.) Rehd.	Fagaceae	t	pe	gro	2	egf, eg/pine	gr	1200	1525	♂oc, ♀dc-ja	jl-ag	ja-dc	flowers♂,♀, fruits
Lithocaupus truncatus (King *ex* Hk. f.) Rehd. & Wils.	Fagaceae	t	pe	gro	2	eg/pine	gr	1250	1325		ag-sp	ja-dc	
Litsea	Lauraceae	t	pe	gro	3	egf, eg/bb	gr	1200	1500			ja-dc	
Litsea cubeba (Lour.) Pers. var. *cubeba*	Lauraceae	t	pe	gro	3	da, sg	gr	1000	1300	ja-fb		ja-dc	flowers
Litsea garrettii Gamb.	Lauraceae	l	pe	gro	3	egf, eg/bb	gr, ls	1100	1300	ap		ja-dc	flowers
Litsea glutinosa (Lour.) C. B. Rob. var. *glutinosa*	Lauraceae	t	pe	gro	3	eg/pine	gr	1100	1350	ap		ja-dc	flowers♂
Litsea semecarpifolia Wall. *ex* Nees	Lauraceae	t	pe	gro	3	eb/bb	gr	1100	1500	ja-fb		ja-dc	
Litsea umbellata (Lour.) Merr.	Lauraceae	t	pe	gro	3	egf	gr	1000	1350	jl-sp		ja-dc	flowers
Litsea zeylanica (Nees) Nees	Lauraceae	t	pe	gro	3	streams in egf	gr, ls	1200	1350	nv-ja		ja-dc	
Lobelia alsinoides Lmk.	Campanulaceae	h	a	gro	3	eg/bb,da,sg, eg/pine	gr	1000	1325	oc	nv	my-dc	flowers

Table 1 (continued)

Lobelia zeylanica L.	Campanulaceae	h, cr	pe	gro	3	da in egf, eg/bb	gr,ls	1000	1500	jn-oc	jl-dc	ja-dc	flowers, fruits
Lysionotus serratus D.Don	Gesneriaceae	h	pd	epi, epl	3	rocks in egf, da, cliffs	ls	1375	1400	jl-sp	sp-oc	my-dc	flowers, fruits
Macaranga denticulata (Bl.) M. A.	Euphorbiaceae	t	pe	gro	3	egf, da, sg	gr	500	1500		my-jn	ja-dc	fruits
Macaranga kurzii (O.K.) Pax & Hoffm.	Euphorbiaceae	l	pe	gro	3	da, sg	gr	1100	1350	jn-ag	jl-sp	ja-dc	flowers♀, fruits
Macaranga siamensis S. J. Davies	Euphorbiaceae	t	pe	gro	3	da, sg	gr,ls	600	900	my-jn		ja-dc	
Machilus bombycina King *ex* Hk. f.	Lauraceae	t	pe	gro	2	egf	gr	1100	1500	ja-fb		ja-dc	flowes
Machilus kurzii King *ex* Hk. f.	Lauraceae	t	pe	gro	2	egf, eg/bb	gr	800	1100	jn-jl		ja-dc	flowers
Maclura fruticosa (Roxb.) Corn.	Moraceae	wc	pe	gro	3	egf, eg/pine	gr, ls	1200	1400	sp-oc	nv-dc	ja-dc	flowers♂, fruits
Macropanax dispermus (Bl.) O.K.	Araliaceae	t	pe	gro	3	egf	gr	1000	1400	ag-oc	dc-ja	ja-dc	flowers, fruits
Maesa montana A. DC.	Myrsinaceae	s,l	pe	gro	3	egf,eg/pine da,sg, eg/bb	gr	1000	1500	ja-fb	nv-fb	ja-dc	flowers, fruits
Maesa permollis Kurz	Myrsinaceae	l	pe	gro	3	egf, streams in mxf	gr,ls	600	1500	ja-fb	ap-my	ja-dc	flowers, fruits
Maesa ramentacea (Roxb.) A. DC.	Myrsinaceae	t	pe	gro	3	da, sg	gr	950	1400	oc-fb		ja-dc	flowers
Magnolia lilifera (L.) Baill. var. *obovata* (Korth.) Gov.	Magnoliaceae	t	pe	gro	3	streams in mxf, egf	gr, ls	550	1300	mr-my		ja-dc	flowers
Mallotus	Euphorbiaceae	t	pe	gro	2	egf	gr,ls	1300	1375		jl-oc	ja-dc	fruits
Mallotus cuneatus Ridl.	Euphorbiaceae	l	pe	gro	2	rocks in egf, mxf,eg/bb cliffs	ls	600	1375	sp	sp-oc	ja-dc	fruits
Mallotus mollissimus (Geisel.) A.S.	Euphorbiaceae	t	pd	gro	2	egf	gr	1000	1100	ap-my	jl	mr-fb	flowers♂, fruits
Mallotus paniculatus (Lmk.) M. A.	Euphorbiaceae	t, l	pe	gro	3	da,sg	gr	900	1525			ja-dc	
Mallotus peltatus (Geisel.) M. - A.	Euphorbiaceae	l	pe	gro	3	mxf	gr,ls	500	800	my-jn		ja-dc	flowers♀
Mallotus philippensis (Lmk.) M. A.	Euphorbiaceae	t	pe	gro	3	da,sg, streams in mxf,eg/bb	gr,ls	600	1500	oc-nv	ja-mr	ja-dc	flowers♂, fruits
Mallotus tetracoccus (Roxb.) Kurz	Euphorbiaceae	t	pe	gro	3	egf, eg/bb	gr	1000	1200	my		ja-dc	flowers♂
Mammea	Guttiferae	t	pe	gro	3	mxf, egf	ls	425	1400		my-jn	ja-dc	fruits
Mangifera caloneura Kurz	Anacardiaceae	t	pe	gro	2	streams in mxf, eg/bb	gr	550	1100	fb		ja-dc	
Maoutia puya (Wall. *ex* Hk.) Wedd.	Urticaceae	h,l	pd	gro	2	bb/df,da,sg	gr	1000	1525	jn-ag	sp-oc	my-dc	flowers♂, fruits

Table 1 (continued)

Markhamia stipulata (Wall.) Seem. ex K. Sch. var. kerrii Sprague	Bignoniaceae	t	pd	gro	3	egf, eg/bb, da, sg	gr, ls	1000	1400	dc-ja	mr-ap	fb-my	
Marsdenia ?glabra Cost.	Asclepiadaceae	v	pe	gro	2	rocks in egf cliffs	ls	1300	1375			ja-dc	
Marsdenia calcicola Kerr	Asclepiadaceae	v	pe	gro	2	rocks in eg/bb, cliffs	ls	1200	1375	ap	sp-oc	ja-dc	flowers
Maytenus (Gymnosporia stylosa Pierre var. *rectispinosa* Craib*)*	Celastraceae	sc	pe	gro	3	rocks in mxf	ls	1300	1375	my		ja-dc	flowers
Melastoma malabathricum L. ssp. *malabathricum*	Melastomataceae	t, l	pe	gro	3	egf, da ,sg	gr	1000	1525	ja-my	jn-ag	ja-dc	flowers
Melia toonsenden Sieb. & Zucc.	Meliaceae	t	pd	gro	3	bb/df, eg/bb	gr, ls	500	1300		oc-fb	my-dc	
Melicope pteleifolia (Champ. *ex* Bth.)T.Hart.	Rutaceae	l,s	pe	gro	3	egf, da, sg	gr, ls	1100	1500	mr-ap	jn-jl	ja-dc	flowers, fruits
Melicope viticina (Wall. *ex* Kurz) T. Hart.	Rutaceae	s	pe	gro	2	eg/bb, eg/pine	gr	1100	1400		my-jn	ja-dc	fruits
Meliosma pinnata (Roxb.) ssp. *barbulata* (Cufod.) Beus. *ex* Welz. var.*barbulata*	Sabiaceae	t	pe	gro	3	egf	gr	1000	1550	ap-my		ja-dc	flowers
Meliosma simplicifolia (Roxb.) Walp. ssp. *fordii* (Hemsl. *ex* Forb. & Hemsl.) Beus.	Sabiaceae	t	pe	gro	2	eg/bb, egf	ls	1200	1375			ja-dc	
Melodinus cochinchinensis (Lour.) Merr.	Apocynaceae	wc	pe	gro	3	egf	ls	1200	1350	ap		ja-dc	flowers
Memecylon umbellatum Burm.f.	Melastomataceae	l	pe	gro	2	rocks in mxf, eg/bb	ls	1200	1425	jl-ag	nv-ja	ja-dc	flowers
Merremia umbellata (L.) Hall. f. ssp.*orientalis* (Hall. f.) Oost.	Convolvulaceae	v	a	gro	3	egf,da,sg	ss	800	1100	fb-mr		jn-ap	flowers
Merremia vitifolia (Burm. f.) Hall. f.	Convolvulaceae	v	a	gro, wee	3	da	gr, ls	500	1525	ja-fb		jn-ap	flowers
Michelia baillonii Pierre	Magnoliaceae	t	pd	gro	3	egf, eg/bb	gr	1000	1300	my-jn	ap-my	my-dc	flowers, fruits
Michelia champaca L. var. *champaca*	Magnoliaceae	t	pe	gro	2	egf	gr	1000	1400	ap-my	my-jn	ja-dc	fruits
Microcos paniculata L.	Tiliaceae	t	pe	gro	3	eg/bb, da, sg	gr, ls	500	900			ja-dc	
Micromelum hirsutum Oliv.	Rutaceae	t	pe	gro	3	egf, eg/bb	gr,ls	1100	1500	ja-fb	mr-jn	ja-dc	flowers, fruits
Micromelum minutum (Forst. f.) Wight & Arn.	Rutaceae	l,s	pe	gro	3	rocks in egf , mxf, cliffs, eg/bb	gr,ls	1000	1500	oc-mr	dc-jl	ja-dc	flowers
Microtropis discolor (Wall.) Wall. *ex* Arn.	Celastraceae	l	pe	gro	2-3	streams in egf	gr,ls	1100	1325	fb-mr	oc-nv	ja-dc	flowers, fruits
Miliusa cuneata Craib	Annonaceae	l	pe	gro	2	streams in egf	ls	1200	1400	my-nv	nv	ja-dc	flowers

Table 1 (continued)

Miliusa thorelii Fin. & Gagnep.	Annonaceae	l	pe	gro	2	streams in bb/df, mxf	gr	500	700	oc		ja-dc	flowers
Millettia pachycarpa Bth.	Leguminosae, Papilionoideae	wc	pd	gro	3	egf, eb/bb	gr	1100	1500			my-fb	
Mimosa diplotricha C. Wrigt *ex* Sauv. var. *diplotricha*	Leguminosae, Mimosoideae	v	a	gro, int, nat, wee	3	da, sg	gr	400	1500	sp-oc		my-dc	
Mimosa pigra L.	Leguminosae, Mimosoideae	h	pe	gro, int, wee	3	da, sg	gr	400	1525	jl-sp		ja-dc	
Mischocarpus pentapetalus (Roxb.) Radlk.	Sapindaceae	t	pe	gro	3	egf	gr	1000	1500	ja-mr	my	ja-dc	flowers, fruits
Mitracarpus villosus (Sw.) DC.	Rubiaceae	h	a	gro, int, nat, wee	3	da, sg	gr	900	1500	sp-oc	nv	my-dc	
Mitragyna rotundifolia (Roxb.) O.K.	Rubiaceae	t	pd	gro	3	da, sg	gr	900	1200	sp-oc		ap-fb	flowers
Mitrephora wangii Hu	Annonaceae	t	pe	gro	3	egf	ls	1200	1425	(dc) fb-mr	jl-sp	ja-dc	flowers, fruits
Mormordica charantia L.	Cucurbitaceae	v	a	gro, wee	3	da	gr, ls	400	700	ag-oc	oc-nv	my-dc	flowers, fruits
Morus macroura Miq.	Moraceae	t	pd	gro	3	egf,eg/pine	gr	1000	1400	fb-mr	ap	fb-dc	flowers, fruits
Mucuna bracteata A. DC.	Leguminosae, Papilionoideae	v	pe	gro	3	eg/bb, da, sg	gr	1000	1500	ja-fb		ja-dc	flowers
Mucuna interrupta Gagnep.	Leguminosae, Papilionoideae	wc	pe	gro	3	mxf, da, sg	ls	1200	1375	ap-sp	sp-oc	ja-dc	flowers, fruits
Mucuna macrocarpa Wall.	Leguminosae, Papilionoideae	wc	pe	gro	3	eg/bb	gr	400	1300	fb-mr	oc-dc	ja-dc	
Mussaenda dehiscens Craib	Rubiaceae	t	pe	gro	2	egf, eg/bb, da	gr	1000	1200	my-jl		ja-dc	flowers
Mussaenda kerrii Craib	Rubiaceae	s, l	pe	gro	2	streams in egf	gr	1000	1375	my-jn		ja-dc	flowers
Mussaenda parva Wall. *ex* G. Don	Rubiaceae	sc	pd	gro	3	rocks in mxf, eg/bb cliffs, da	gr,ls	1200	1425	my-sp	jn-jl	my-dc	flowers, fruits
Mussaenda sanderiana Ridl.	Rubiaceae	wc	pe	gro	3	egf,eg/pine, eg/bb,da,sg	gr	1000	1500	dc-ap		ja-dc	flowers
Mycetia glandulosa Craib	Rubiaceae	h	pe	gro	3	egf	gr, ls	1000	1500	ap-my	ap-my	ja-dc	flowers
Mycetia gracilis Craib	Rubiaceae	l	pe	gro	3	streams in mxf, egf	gr,ls	600	1350	oc-nv	ja-fb	ja-dc	flowers, fruits
Myrsine semiserrata Wall.	Myrsinaceae	l	pe	gro	2	rocks in mxf, cliffs	ls	1200	1425	ja-fb		ja-dc	flowers♀
Nelsonia canescens (Lmk.) Spreng.	Acanthaceae	h	pe	gro	3	egf, eg/bb, da	gr	900	1100	mr-ap	ap-my	ja-dc	flowers, fruits
Nephelium hypolecum Kurz	Sapindaceae	t	pe	gro	3	egf, eg/bb	gr	950	1200	ja-fb		ja-dc	flowers

Table 1 (continued)

Nephelium lappaceum L. var. pallens (Hiern) Leenh.	Sapindaceae	t	pe	gro	2	egf	gr	900	1100		my-jn	ja-dc	fruits
Oenanthe javancia (Bl.) DC.	Umbelliferae	h	a	gro	2	streams in egf, eb/bb	gr	600	1475	dc-ja		jn-mr	flowers
Olea rosea Craib	Oleaceae	t, l	pe	gro	2	da, sg	gr	1000	1100		oc-nv	ja-dc	fruits
Ophiorrhiza aff. *nutans* Cl. *ex* Hk. f.	Rubiaceae	h	pe	gro	2	egf	gr,ls	1100	1375	ap-jl	jn-ag	ja-dc	flowers, fruits
Ophiorrhiza pseudofasciculata Schan.	Rubiaceae	h	a	gro	3	eg/bb	gr	1200	1350	ag-sp	sp-oc	my-dc	flowers, fruits
Ophiorrhiza trichocarpon Bl. var. *trichocarpon*	Rubiaceae	h	pe	gro	3	egf, eg/bb	gr	1000	1400	my-jl(nv)	jn-ag(nv)	ja-dc	flowers
Ophiorrhiziphyllon macrobotryum Kurz	Acanthaceae	h	pe	gro	2	egf	gr	1100	1400	ja-mr		ja-dc	flowers
Oreocnide rubescens (Bl.) Miq.	Urticaceae	t,l	pe	gro	3	streams in eg/pine, egf, mxf	gr,ls	600	1400	fb -ap	sp-dc	ja-dc	fruits
Ormosia sumatrana (Miq.) Prain	Leguminosae, Papilionoideae	t	pe	gro	2	egf,eg/bb	gr	1050	1250		oc-nv	ja-dc	fruits
Ornithoboea wildeana Craib	Gesneriaceae	h	pd	epl	3	rocks in mxf cliffs	ls	425	625	oc-nv		my-dc	flowers
Orophea polycarpa A.DC.	Annonaceae	l	pe	gro	3	streams in mxf	ls	600	800	ja-fb		ja-dc	flowers
Osbeckia stellata Ham. *ex* Ker-Gawl. var. *crinita* (Bth. *ex* Naud.) C. Han.	Melastomataceae	s	pe	gro	3	eg/bb, egf,da,sg	gr, ls	1100	1500	sp-dc	ja	ja-dc	flowers
Ostodes paniculata Bl.	Euphorbiaceae	t	pe	gro	3	streams in mxf, egf, eg/bb	gr,ls,sh	600	1350		jn-sp	ja-dc	fruits
Oxalis corniculata L.	Oxalidaceae	h	a	gro, wee	3	eg/bb,da, sg	gr,ls	900	1400	(fb) my-oc	jn-nv	ap-dc	flowers, fruits
Paederia pallida Craib	Rubiaceae	v	a	gro	3	rocks in mxf,egf,da cliffs	gr,ls	1100	1500	sp-oc	nv-dc	my-dc	flowers, fruits
Palaquium garrettii Flet.	Sapotaceae	t	pe	gro	2	egf	gr	1000	1400	sp-oc		ja-dc	flowers
Parabaena sagittata Miers *ex* Hk. f. & Th.	Menispermaceae	v	pe	gro	3	rocks in mxf, streams in egf, eg/bb	ls	500	1400	my-jn	sp-nv	ja-dc	flowers, fruits
Paraboea glabrisepala Burtt	Gesneriaceae	h	pd	epl	3	rocks in egf, mxf cliffs	ls	1200	1425	ag-oc	oc-nv	jn-dc	flowers, fruits
Paraboea kerrii (Craib) Burtt	Gesneriaceae	s,h	pe	gro	2	egf	ls	1050	1250		nv-dc	ja-dc	fruits
Paramignya scandens (Griff.) Craib var. *scandens*	Rutaceae	wc	pe	gro	2	streams in egf	gr,ls	1000	1325	fb-mr	oc-dc	ja-dc	
Parthenocissus semicordata (Wall.) Pl.	Vitaceae	wc	pe	gro	2	rocks in mxf cliffs	ls	1200	1425	sp	ja-dc	ja-dc	fruits

Table 1 (continued)

Pavetta tomentosa Roxb. ex Sm. var. tomentosa	Rubiaceae	l	pd	gro	3	egf, eg/bb	gr	900	1400	my	nv	my-dc	flowers, fruits
Peperomia pellucida (L.) H. B. K.	Piperaceae	h	a	gro, epl, nat	3	rocks in mxf cliffs, da in egf	gr,ls	500	1200	ag-oc	sp-nv	my-dc	flowers
Peperomia tetraphylla (Forst.f.) Hk. & Arn.	Piperaceae	h	pe	epl, epi	3	rocks in egf, mxf cliffs	gr,ls	1200	1500	ag-sp	sp-nv	ja-dc	flowers, fruits
Pericampylus glaucus (Lmk.) Merr.	Menispermaceae	v	pe	gro	3	egf, da	gr	1100	1400	mr-ap	jl-ag	ja-dc	flowers♀, fruits
Perilla frutescens (L.) Britt.	Labiatae	h	a	cul	2	egf	gr	1050	1500		nv-dc	my-dc	fruits
Petrocosmea	Gesneriaceae	h	pd	epl	2	rocks in egf, cliffs	ls	1300	1400	sp	oc-nv	jn-dc	flowers, fruits
Peucedanum siamicum Craib	Umbelliferae	h	pd	gro	2	da, sg	gr	1500	1525	sp-oc		my-dc	flowers
Phaulopsis dorsiflora (Retz.) Sant.	Acanthaceae	h	pe	gro	3	egf, mxf, eg/bb, da, sg	gr	400	1400	dc-fb		ja-dc	flowers
Phlogacanthus curviflorus (Wall.) Nees var. *curviflorus*	Acanthaceae	s,l	pe	gro	2	streams in egf, eg/bb	gr	1000	1300	nv-fb	dc-mr	ja-dc	flowers, fruits
Phoebe lanceolata (Wall. *ex* Nees) Nees	Lauraceae	t, l	pe	gro	3	egf, eg/bb	gr, ls	1000	1400	ap-my	oc	ja-dc	flowers, fruits
Phoebe pallida (Nees) Nees	Lauraceae	t	pe	gro	3	egf	gr	1000	1200	jl-ag		ja-dc	flowers, imm. fruits
Phoebe paniculata Nees	Lauraceae	t	pd	gro	3	egf	gr	1300	1500	fb-mr		ja-dc	flowers
Phylacium majus Coll. & Hemsl.	Leguminosae, Papilionoideae	v	pe	gro	2	bb/df, eb/bb	gr	950	1200	oc	ja-fb	ja-dc	flowers,fruits
Phyllanthus debilis Klein *ex* Willd.	Euphorbiaceae	h	a, pd	gro	3	eg/pine, eg/bb, da, egf cliffs	gr,ls	1100	1400	sp-fb	oc-fb	jn-fb	flowers, fruits
Phyllanthus emblica L.	Euphorbiaceae	t	pd	gro	3	eg/pine, eg/bb, da, sg	gr	1100	1400		sp-fb	my-dc	
Phyllanthus reticulatus Poir.	Euphorbiaceae	sc	pd	gro	3	streams in bb/df, mxf, da	ls	500	700		sp-oc	my-dc	fruits
Phyllanthus urinaria L.	Euphorbiaceae	h	a	gro, wee	3	da	gr, ls	500	1375	ag-oc	sp-nv	my-dc	flowers, fruits
Picrasma javanica Bl.	Simaroubaceae	t, l	pe	gro	3	streams in mxf, egf	ls	500	1300	ap-nv	ag-sp	ja-dc	flowers
Pilea microphylla (L.) Liebm.	Urticaceae	h	pe	epl, nat	3	egf, eg/bb, da	gr,ls	400	1500	ag-oc	sp-nv	ja-dc	flowers
Pilea stipulosa Miq.	Urticaceae	h	a	epl	3	rocks in mxf, eg/bb	ls	500	1425	jl-ag	sp	my-dc	flowers♂, fruits
Pilea trinervia Wight	Urticaceae	h	pe	gro,epl	3	streams in eg/bb, rocks in mxf, egf	gr, ls	1100	1475	my-sp		ja-dc	flowers♂
Piper boehmeriaefolium (Wall.*ex* Miq) C. DC.	Piperaceae	s	pe	gro	3	rocks in egf	ls	1100	1400	fb-mr		ja-dc	flowers

Table 1 (continued)

Piper brevicaule C. DC.	Piperaceae	v	pe	gro	3	egf	ls	1200	1375		my-jn	ja-dc	fruits
Piper retrofractum Vahl	Piperaceae	v	pe	gro	3	mxf	gr	500	900	my-jn		ja-dc	flowers♀
Piper umbellatum L. var. *glabrius* (Miq.) DC.	Piperaceae	s, l	pe	gro	2	egf	gr	700	950	ag-sp	sp-oc	ja-dc	flowers
Pittosporopsis kerrii Craib	Icacinaceae	l	pe	gro	2	mxf	gr	500	700	fb-ap	my-jn	ja-dc	fruits
Plantago major L.	Plantaginaceae	h	pe	gro, wee	3	egf, da, sg	gr,ls	1200	1500	my-sp	jn-sp	ja-dc	flowers
Platostoma hispidum (L.) Pat.	Labiatae	h	a	gro, wee	3	da, sg	gr	1000	1200	sp-oc	nv	my-dc	flowers
Platostoma intermedium Pat.	Labiatae	h	pd	epl	2	rocks in egf cliffs	ls	1300	1400	oc-dc	dc-ja	my-dc	flowers
Plectranthus bracteatus (Dunn) Sud.	Labiatae	h	a	epl	3	rocks in mxf, eg/bb	ls	1200	1425	sp-oc	nv-dc	my-dc	flowers, fruits
Pogostemon purpurascens Dalz.	Labiatae	l	pe	gro	3	egf eg/pine sg	gr	1100	1400	ja-fb		ja-dc	flowers
Polygala chinensis L.	Polygalaceae	h	a	gro	2	bb/df, eg/pine	gr	800	1375	my-jl	jl-sp	my-dc	flowers
Polygala persicariifolia DC.	Polygalaceae	h	a	gro	3	eg/pine, eg/bb, da	ls	1200	1400	sp-oc	oc-nv	my-dc	flowers
Polygala umbonata Craib	Polygalaceae	h	a	gro, epl	2	rocks, cliffs, mxf, eg/bb	ls	1300	1425	ag-dc	sp-ja	my-ja	flowers
Polygonum chinense L. var. *chinense*	Polygonaceae	h	pe	gro	3	mxf,egf,da,sg	gr,ls	500	1500	my-fb	jn-mr	ja-dc	flowers, fruits
Polygonum chinense L. var. *hispidum* Hk. f.	Polygonaceae	h	pe	gro	3	streams in egf, da	gr	1000	1200	nv-dc	ja-dc	ja-dc	flowers
Polygonum nepalense Meisn.	Polygonaceae	h	a	gro, wee	2	da in egf, eg/pine	gr, ls	1400	1500	ag-oc	sp-nv	my-dc	flowers, fruits
Polygonum odoratum Lour.	Polygonaceae	h	pe	gro	3	streams and wet areas in egf, eg/bb	gr	1100	1300	ja-dc	ja-dc	ja-dc	flowers, fruits
Polygonum persicaria L.	Polygonaceae	h	a	gro, wee	3	da, sg	gr, ls	900	1400	mr-my	mr-my	ap-dc	flowers
Polygonum plebeium R.Br.	Polygonaceae	h	a	gro, wee	3	da, sg	gr	900	1500	mr-nv	jn-dc	ap-dc	flowers
Pometia pinnata J.R. & G.Forst.	Sapindaceae	t	pd	gro	2	streams in mxf, egf	gr, ls	550	1250			mr-dc	
Pottsia laxiflora (Bl.) O.K.	Apocynaceae	v	pe	gro	3	egf, da, sg	gr	900	1100	my-jn		ja-dc	flowers
Pouzoulzia hirta Hassk.	Urticaceae	h	a	gro, wee	3	egf, da	gr	600	1500	my-sp	sp-nv	my-dc	flowers
Prema flavescens Ham. *ex* Cl. *var. flavescens*	Verbenaceae	s	pd	epl	2	eg/pine, eg/bb	gr	1200	1275			my-dc	
Premna fulva Craib	Verbenaceae	wc	pd	gro	3	egf, eg/bb	gr, ls	1100	1350		my-jn	ja-ap jn-dc	
Premna latifolia Roxb.var. *latifolia*	Verbenaceae	wc	pe	gro	3	egf	gr	1000	1500	ap-my		ja-dc	flowers
Premna racemosa Wall. *ex* Schauer	Verbenaceae	l	pd	gro	3	rocks,cliffs in mxf	ls	1300	1425	mr-jn		ap-dc	flowers
Premna subcapitata Rehd.	Verbenaceae	s	pd	epl	3	rocks in mxf, eg/bb cliffs	ls	1375	1425	jl-sp	sp-oc	my-dc	flowers

Table 1 (continued)

Protium serratum (Wall. ex Colebr.) Engl.	Burseraceae	t	pe	gro	3	egf	gr	1000	1400		jl-ag	ja-dc	fruits
Prunus cerasoides Ham. *ex* D.Don	Rosaceae	t	pd	gro, cul	3	da, sg	gr, ls	1000	1375	ja-fb		ap-oc	flowers
Pseuderanthemum latifolium (Vahl) B. Han.	Acanthaceae	s,l	pe	epl,gro	3	rocks, streams in mxf, egf	gr, ls	400	1200	oc-fb	dc-mr	ja-dc	flowers
Pseudodissochaeta septentrionalis (W.W.Sm.) Nayar	Melastomataceae	t, l	pe	gro	3	egf, eg/bb	gr	1000	1350	jl-ag	nv-dc	ja-dc	flowers, fruits
Psidium guajava L.	Myrtaceae	l	pe	gro,cul,int,nat	3	da, sg	gr	1000	1300	my-jn		ja-dc	flowers
Psychotria monticola Kurz var. *monticola*	Rubiaceae	l,s	pe	gro	3	egf	gr, ls	1000	1500	ap-jn	dc-ja	ja-dc	flowers
Psychotria ophioxyloides Wall.	Rubiaceae	l	pe	gro	3	egf	gr, ls	1000	1500	ap-jn	dc-ja	ja-dc	flowers
Psychotria winitii Craib	Rubiaceae	h	pe	gro	3	egf	ls	1000	1400		oc-nv	ja-dc	fruits
Pterospermum grande Craib	Sterculiaceae	t	pe	gro	2	da	gr, ls	1250	1375	my		ja-dc	flowers
Pterospermum grandiflorum Craib	Sterculiaceae	t	pe	gro	3	streams in mxf, egf	ls	550	1000			ja-dc	
Pterospermum semisagittatum B.-H. *ex* Roxb.	Sterculiaceae	t	pe	gro	2	eg/bb	gr	800	1000	my		ja-dc	flowers
Pueraria alopecuroides Craib	Leguminosae, Papilionoideae	v	a	gro	3	da, sg	gr, ls	400	1525	ja-fb		jl-my	flowers
Pueraria montana (Lour.) Merr. var. *chinense* (Ohwi) Maes. & Alm.	Leguminosae, Papilionoideae	v	pe	gro	2	da, sg	gr	900	1225	sp-oc		ja-dc	flowers
Pueraria phaseolioides (Roxb.) Bth. var. *subspicata* (Bth.) Maes.	Leguminosae, Papilionoideae	v	pe	gro,wee	3	da, sg	gr	1000	1500	oc-nv	ja-fb	ja-dc	
Pueraria rigens Craib	Leguminosae, Papilionoideae	wc	pe	gro	3	egf, eg/pine	gr	1100	1450		dc-fb	ja-dc	fruits
Pyrenaria garrettiana Craib	Theaceae	t	pe	gro	3	egf	gr	1100	1400		jn-jl	ja-dc	
Quercus semiserrata Roxb.	Fagaceae	t	pe	gro	3	egf, eg/pine	gr	1100	1400	ja	sp-oc	ja-dc	fruits
Quisqualis indica L. var. *indica*	Combretaceae	wc	pe	gro	3	da, sg	gr	500	1150	ap-my	sp-oc	ja-dc	flowers, imm. fruits
Radermachera hainanensis Merr.	Bignoniaceae	t	pd	gro	3	rocks in mxf cliffs	ls	1375	1425	ap		ap-dc	flowers
Radermachera ignea (Kurz) Steen.	Bignoniaceae	t, l	pe	gro	2	rocks in bb/df cliffs	ls	450	600	sp-oc		my-dc	
Rapanea yunnanensis Mez	Mysinaceae	t	pe	gro	2	eg/bb	gr	1100	1300		sp-oc	ja-dc	fruits
Rauvolfia verticillata (L.) Baill.	Apocynaceae	l	pe	gro	2	egf, da	gr	1200	1400	mr-ap		ja-dc	flowers
Reinwardtia indica Dum.	Linaceae	h	pd	gro	3	egf,eg/bb da	gr, ls	1100	1500	nv-dc (fb)	ja-fb	ja-dc	flowers, fruits
Rhinacanthus calcaratus Nees	Acanthaceae	l	pe	gro	3	streams in mxf	ls	700	800	ja-fb		ja-dc	flowers

Table 1 (continued)

Rhus succedanea L.	Anacardiaceae	l,t	pd	gro	3	rocks in mxf cliffs	ls	1400	1425	jl-sp	oc-nv	jn-dc	flowers, fruits
Rhus chinensis Mill.	Anacardiaceae	l	pd	gro	3	da sg	gr	900	1400	jl-oc	oc-nv	my-dc	fruits
Rhus rhetsoides Craib	Anacardiaceae	t	pd, pe	gro	3	egf	gr	1000	1300	ap	oc-nv	ja-dc	flowers♂, fruits
Rhynchoglossum obliquum Bl.	Gesneriaceae	h	a	epl, gro	3	rocks in mxf cliffs,eg/bb, eg/pine	gr,ls	400	1500	sp-nv	nv-dc	my dc	flowers
Rhynchotechum obovatum (Griff.) Burtt	Gesneriaceae	l	pe	gro	3	streams in eg/bb, egf	gr	1150	1400	my-jn	oc-dc	ja-dc	flowers, fruits
Rinorea ? macrophylla (Decne.) O.K.	Violaceae	l	pe	gro	2	steams in mxf	ls	550	650	ag-sp	sp-oc	ja-dc	flowers, imm fruits
Rorippa indica (L.) Hiern	Cruciferae	h	a	epl	2	rocks in eg/pine	gr	1450	1500	ag	sp-oc	jn-nv	fruits
Rourea minor (Gaertn.) Leenh. ssp. *minor*	Connaraceae	wc	pe	gro	3	egf, eg/bb	gr	1000	1400		ap-my	ja-dc	fruits
Rubus blepharoneurus Card.	Rosaceae	sc	pe	gro	3	egf	gr,ls	1100	1500	ap-my	ap-my	ja-dc	flowers, fruits
Rubus dielsianus Focke	Rosaceae	v	a	gro	2	eg/bb	gr	1100	1250			jn-mr	
Rubus ellipticus J.E. Sm. forma *obcordatus* Franch.	Rosaceae	v	pe	gro	3	eg/bb, da	gr	1200	1525	dc-ja	fb-mr	ja-dc	
Rungia parviflora (Retz.) Nees var. *parviflora*	Acanthaceae	h	a	gro	3	bb/df, eg/bb,da	gr	900	1300	sp-fb	nv-fb	my-fb	flowers
Rungia rivicola Craib	Acanthaceae	h	pe	gro	3	rocks in egf	ls	1100	1400	fb-mr		ja-dc	flowers
Sabia limoniacea Wall. *ex* Hk.f. & Th..	Sabiaceae	wc	pe	gro	2	egf	ls	1200	1400	ja-fb		ja-dc	flowers
Sageretia cordifolia Tard.	Rhamnaceae	wc	pd	gro	3	rocks in mxf cliffs	ls	1375	1425	sp-oc	nv-dc	my-dc	flowers, fruits
Salacia chinensis L.	Celastraceae	l	pe	gro	2	streams in eg/bb	gr	900	1100	nv-dc	dc-ja	ja-dc	flowers
Salix tetrasperma Roxb.	Salicaceae	t	pd	gro	2	streams in egf, eg/bb	gr	1000	1500	sp-oc	dc-nv	oc-sp	flowers♂
Salomonia cantoniensis Lour.	Ploygalaceae	h	a	gro	3	egf, eg/pine, da	gr	1000	1400	sp-nv	oc-dc	my-dc	flowers
Salvia riparia Kunth	Labiatae	h	pe	gro, wee	3	da, sg	gr	900	1300	oc-fb	nv-mr	ja-dc	flowers
Sambucus javanica Reinw. *ex* Bl. ssp. *javanica*	Caprifoliaceae	s,l	pe	gro	3	eg/bb, egf, da, sg	gr,ls	1000	1525	jn-sp	sp-oc	ja-dc	fruits
Sapindus rarak DC.	Sapindaceae	t	pd	gro	2	egf, eg/bb	ls	1000	1375			my-dc	
Sapria himalayana Griff.	Rafflesiaceae	h	pd	gro, par	1	egf, eg/bb	ls	1350	1350	ja-fb		leafless	
Saprosma consimile Kurz	Rubiaceae	l	pe	gro	3	rocks in mxf, egf	ls	1200	1400	my		ja-dc	flowers
Sarcosperma arboreum Bth.	Sapotaceae	t	pe	gro	3	egf	gr	1000	1550	ja-fb	ap-my	ja-dc	flowers, fruits
Saurauia nepaulensis DC.	Saurauiaceae	t	pe	gro	3	egf,da,sg	gr,ls	1100	1400	my-jn		ja-dc	flowers
Saurauia roxburghii Wall.	Saurauiaceae	t	pe	gro	3	egf eg/pine eg/bb	gr	1000	1500	ja-dc	ja-dc	ja-dc	flowers

Table 1 (continued)

Sauropus macranthus Hassk.	Euphorbiaceae	l	pe	gro	2	rocks in egf,eg/bb cliffs	ls	1300	1400	my-jn	sp	ja-dc	flowers♂,♀, fruits
Sauropus poomae Welz. & Chay.	Euphorbiaceae	h	pe	epl	2	rocks in egf cliffs	ls	1250	1400	oc-mr	oc-nv	ja-dc	flowers, fruit
Schefflera bengalensis Gamb.	Araliaceae	s	pe	epi, epl	3	egf	gr,ls	1000	1500	ap-my	my	ja-dc	flowers, fruits
Schefflera ptelotii Merr.	Araliaceae	t ,l, s	pd	epl	3	rocks in mxf	ls	650	1400	ja-fb	fb-ap	my-ap	flowers, fruits
Schefflera pueckleri (C. Koch) Frod.	Araliaceae	s	pe	epi	2	rocks in egf, cliffs	ls	1300	1375	jn-jl		ja-dc	
Schima wallichii (DC.) Korth.	Theaceae	t	pe	gro	4	egf	gr	700	1525	ap-my	dc-mr	ja-dc often changin g lvs dc-ja	flowers, fruits
Scleropyrum pentandrum (Denn.) Mabb.	Santalaceae	t	pe	gro	2	rocks in egf, eb/bb	ls	1200	1400		jl-ag	ja-dc	fruits
Scoparia dulcis L.	Scrophulariaceae	h	a	gro, int, nat, wee	3	da, sg	gr	400	1500	jn-nv	ag-dc	my-dc	
Scurrula ferruginea (Jack) Dans.	Loranthaceae	s	pe	epi, par	3	da, sg	gr	900	1525	jl-sp		ja-dc	flowers
Secamone elliptica R.Br. ssp. *elliptica*	Asclepiadaceae	v,wc	pe	gro	3	rocks in egf/bb mxf cliffs	ls	1300	1425	ap-my	oc-nv	ja-dc	flowers, fruits
Semecarpus cochinchinensis Engl.	Anacardiaceae	t	pe	gro	3	mxf, egf	gr, ls	525	1500	dc-mr	ap	ja-dc	flowers
Senecio scandens B.-H. *ex* D. Don	Compositae	sc	pd	gro	2	rocks in egf cliffs	ls	1400	1425	ja-fb	fb-mr	my-mr	flowers, fruits
Sericocalyx quadrifarius (Wall. *ex* Nees) Brem.	Acanthaceae	h	pe	gro	3	eg/bb	gr	1000	1400	dc-ja		ja-dc	flowers
Shorea roxburghii G. Don	Dipterocarpaceae	t	pd	gro	2	bb/df, eg/bb	gr	750	1100	fb		my-fb	
Shuteria hirsuta Baker	Leguminosae, Papilionoideae	v	pe	gro	3	egf,da,sg	gr	1000	1300	nv-dc		ja-dc	flowers
Shuteria involucrata (Wall.) Wight & Arn. *var. involucrata*	Leguminosae, Papilionoideae	v	pd	gro	3	egf,da,sg, eg/pine	gr	1100	1500	oc-nv	dc-ja	ja-dc	flowers, fruits
Shuteria vestita Wight & Arn.	Leguminosae, Papilionoideae	v	a	gro	2	eg/bb	gr	1100	1300	dc-ja		my-fb	flowers
Sida rhombifolia L. ssp. *rhombifolia*	Malvaceae	h	pe	gro, wee	3	da, sg	gr, ls	400	1500	sp-fb	ja-mr	ja-dc	flowers
Siegesbeckia orientalis L.	Compositae	h	a	gro,wee	3	da,sg	gr	1000	1450	oc-dc	nv-ja	jn-ja	
Solanum aculeatissimum Jacq.	Solanaceae	h	a	gro,nat	3	eg/bb,da,sg	gr	1100	1400	my-jn		ap-dc	flowers
Solanum barbisetum Nees	Solanaceae	h	pd	gro	3	eg/bb, eg/pine, da	gr	1100	1400	my-jn	ag-sp	ap-dc	flowers

Table 1 (continued)

Solanum macrodon Wall. *ex* Nees	Solanaceae	h	a	gro	3	mxf, eg/bb	gr, ls	600	1400	my-sp	sp-nv	ap-dc	flowers
Solanum nigrum L.	Solanaceae	h	a	gro,int,nat,wee	3	da	gr	400	1500	my-dc	jn-ja	my-ja	
Solanum verbascifolium L.	Solanaceae	l	pe	gro	3	da	gr, ls	500	700	ag-oc	sp-nv	ja-dc	
Solena heterophylla Lour. ssp. *heterophylla*	Cucurbitaceae	v	a	gro	2	eg/bb, da, sg, eg/pine	gr	1000	1300			my-dc	
Sonchus wightianus DC. ssp. *wightianus*	Compositae	h	pe	gro, wee	3	weed, eg/pine, da, sg	gr	900	1525	ja-jn	fb-jl	ja-dc	flowers, fruits
Sonerila erecta Jack	Melastomataceae	h	a	gro	3	egf, eg/bb da	gr	1125	1500	oc-nv	nv-dc	my-dc	flowers
Sophora velutina Lindl.	Leguminosae, Papilionoideae	l	pe	gro	2	bb/df, mxf,cliffs	ls	1400	1425		nv-dc	ja-dc	fruits
Spilanthes paniculata Wall. *ex* DC.	Compositae	h	a	gro, wee	3	eg/pine, da, sg	gr,ls	1000	1525	sp-fb	nv-mr	my-mr	flowers
Spondias axillaris Roxb.	Anacardiaceae	t	pd	gro	3	egf	gr, ls	1100	1400	ja-fb	sp-oc	mr-dc	flowers♂
Spondias pinnata (L. f.) Kurz	Anacardiaceae	t	pd	gro	3	bb/df	gr			mr-ap	jn-ag	my-dc	fruits
Stauranthera grandiflora Bth.	Gesneriaceae	h	pe	epl	2	rocks, streams in egf	gr, ls	1200	1325	ag-sp		ja-dc	
Stephania elegans Hk.f. & Th.	Menispermaceae	v	a	gro	3	rocks in egf, mxf cliffs	ls	1300	1425	oc	oc-nv	my-dc	fruits♂
Stephania japonica (Thunb.) Miers var. *discolor* (Bl.) For.	Menispermaceae	v	a	gro	3	egf, eg/bb, da	gr	1000	1300	my-ag		my-dc	flowers♂
Stephania oblata Craib	Menispermaceae	wc	pd	epl	3	rocks in mxf, eg/bb cliffs	ls	1200	1425	ap	jn-jl	my-dc	flowers♂, fruits
Sterculia balanghas L.	Sterculiaceae	t	pd	gro	3	egf, eg/pine	gr	1000	1500			fb-dc	
Sterculia guttata Roxb.	Sterculiaceae	l	pd	gro	2	rocks in mxf	ls	1300	1425	fb-mr		mr-nv	flowers
Sterculia lanceolata Cav. var. *lanceolata*	Sterculiaceae	l	pe	gro	3	egf, mxf	ls	550	1350	sp-nv	my-sp	ja-dc	flowers, fruits
Sterculia lanceolata Cav. var.*principis (*Gagnep.) Pheng.	Sterculiaceae	l	pe	gro	3	egf, eg/bb, bb/df	gr	1000	1400		my-jn	ja-dc	fruits
Sterculia pexa Pierre	Sterculiaceae	t	pd	gro	3	mxf,da,sg	gr, ls	400	1000	dc-ja	fb-mr	my-dc	
Sterculia villosa Roxb.	Sterculiaceae	t	pd	gro	3	rocks in mxf, bb/df cliffs	ls	600	1425	ja-fb		ap-dc	flowers
Stereospermum colais (B.-H.*ex* Dill.) Mabb.	Bignoniaceae	t	pd	gro	3	egf	gr	1100	1500	ap	ja-mr	ap-fb	flowers
Streblus ilicifolius (Vidal) Corn.	Moraceae	l	pe	gro	3	rocks in mxf cliffs	ls	400	700			ja-dc	
Streptocaulon juventas (Lour.) Merr.	Asclepiadaceae	v	pe	gro	3	eg/bb da	gr	1000	1450	my-ja		ja-dc	flowers

Table 1 (continued)

Strobilanthes erectus Cl. *ex* Hoss.	Acanthaceae	l	pe	gro	3	rocks in egf, mxf cliffs	ls	1200	1425	oc-nv		ja-dc	flowers
Strobilanthes rex Cl.	Acanthaceae	l, s	pe	gro	3	egf	gr, ls	1000	1425	ja-fb		ja-dc	flowers
Strobilanthes speciosus Bl.	Acanthaceae	l	pe	gro	4	rocks in egf	ls	1200	1400	oc-nv		ja-dc	flowers
Strobilanthes viscidus Im.	Acanthaceae	h	pe	gro	2	streams in egf, eg/bb	gr	1100	1250			ja-dc	
Styrax benzoides Craib	Styracaceae	t	pe	gro	3	egf, eb/bb,da,sg	gr	1000	1500	my-jn	oc-nv	ja-dc	flowers, fruits
Sumbaviopsis albicans (Bl.) J.J. Sm.	Euphorbiaceae	t	pe	gro	3	rocks, streams in mxf	ls	500	1325			ja-dc	
Symplocos hookeri Cl.	Symplocaceae	t	pe	gro	2	streams, wet areas in egf	gr	1250	1325	oc-nv	ag-sp	ja-dc	
Symplocos macrophylla Wall. *ex* DC. ssp. *sulcata* (Kurz) Noot. var. *sulcata*	Symplocaceae	t	pe	gro	3	egf, eg/bb	gr	1000	1500	oc-nv	mr-ap	ja-dc	flowers
Synedrella nodiflora (L.) Gaertn.	Compositae	h	a	gro, wee	3	da, sg	gr,ls, sh	500	1500	oc-dc	nv-ja	my-fb	
Tabernaemontana bovina Lour.	Apocynaceae	l	pe	gro	3	egf, eg/bb	gr, ls	1100	1425	my	nv-dc	ja-dc	flowers, fruits
Tarenna elliptica Craib var. *elliptica*	Rubiaceae	l,s	pe	gro	3	streams in egf, rocks in mxf	gr,ls	1100	1400	jn	oc-nv	ja-dc	flowers, fruits
Tarenna vanprukii Craib var. *vanprukii*	Rubiaceae	t.l	pe	gro	3	rocks in mxf, cliffs	ls	1300	1425	my	oc-dc	ja-dc	
Tarennoidea wallichii (Hk, f.) Tirv. & Sastre	Rubiaceae	t	pe	gro	2	egf, eg/bb	gr	1200	1400			ja-dc	
Tephrosia kerrii Drum. & Craib	Leguminosae, Papilionoideae	l	pe	gro	3	eg/bb, da, sg	gr	1000	1300		ja-fb	ja-dc	fruits
Ternstroemia gymnanthera (Wight & Arn.) Bedd.	Theaceae	t	pe	gro	3	egf, eg/pine	gr	1200	1400	my-jn	oc	ja-dc	flowers, fruits
Tetradium glabrifolium (Champ.*ex* Bth.) T.Hart.	Rutaceae	t,s	pe	gro	3	egf, da	gr,ls	1000	1375	my-jl	jl-oc	ja-dc	flowers♂♀, fruits
Tetrastigma campylocarpum (Kurz) Planch.	Vitaceae	wc	pe	gro	2	eg/bb	gr	1200	1400	nv-dc	mr-ap	ja-dc	flowers♀
Tetrastigma cruciatum Craib & Gagnep.	Vitaceae	wc	pe	epl,gro	3	streams in bb/df, mxf cliffs	ls	500	1425	fb-ap	nv	ja-dc	flowers♀
Tetrastigma garrettii Gagnep.	Vitaceae	v	pe	gro	3	streams in egf, eg/bb	gr, ls	1000	1300	dc-ja	my-jn	ja-dc	flowers♀, fruits
Tetrastigma laoticum Gagnep.	Vitaceae	wc	pe	gro	2	eg/bb	gr, ls	1200	1350	ap	ag	ja-dc	flowers♀
Tetrastigma quadrangulum Gagnep & Craib	Vitaceae	wc	pe	gro	2	mxf, eg/bb	sh	500	700	oc		ja-dc	flowers♀
Thespesia lampas (Cav.) Dalz. & Gibs. var. *lampas*	Malvaceae	l	pd	gro	2	eg/bb, da, sg	gr	525	1200	oc		my-dc	

Table 1 (continued)

Thladiantha cordifolia (Bl.) Cogn.	Cucurbitaceae	v	a	gro	2	egf eg/pine da sg	gr	1350	1525	ja-dc	oc-nv	my-mr	flowers, fruits
Thladiantha hookeri Cl.	Cucurbitaceae	v	a	gro	2	eg/bb, da, sg	gr	1100	1300	my		my-dc	flowers♂
Thunbergia	Acanthaceae	wc	pe	gro	3	rocks in mxf cliffs, egf, eg/pine	gr,ls	1350	1525	oc-dc	mr	ja-dc	flowers
Thunbergia coccinea Wall.	Acanthaceae	wc	pe	gro	3	streams in egf, eg/bb, da	gr	1100	1500	nv-dc		ja-dc	flowers
Thunbergia grandiflora Roxb.	Acanthaceae	v	pe	gro	3	eg/bb, da	gr	800	1500	ja-fb		ja-dc	flowers
Thunbergia laurifolia Lindl.	Acanthaceae	wc	pe	gro	3	da, sg		500	1500	nv-fb		ja-dc	
Thunbergia similis Craib	Acanthaceae	v	pd	gro	3	bb/df, eg/bb	gr	1000	1300	oc-nv		my-dc	flowers
Tinomiscium petiolare Hk. f. & Th.	Menispermaceae	wc	pe	gro	2	streams in egf, eg/bb, mxf	gr, sh	600	1200	my-jn	sp-oc	ja-dc	
Tinospora sinensis (Lour.) Merr.	Menispermaceae	v	pd	epl	3	rocks in mxf, cliffs	ls	1100	1425	ja-fb	ap-my	my-dc	
Tirpitzia bilocularis Suks. & K. Lar.	Linaceae	h	pd	gro	2	rocks in mxf, da cliffs	ls	1200	1300	ag-sp	ja-fb	jn-fb	flowers
Tithonia diversifolia (Hemsl.) A. Gray	Compositae	h	pe	gro, int, wee	3	da, sg	gr	550	1525	oc-dc		ja-dc	
Toddalia asiatica (L.) Lmk.	Rutaceae	wc	pe	gro	3	egf eg/bb	gr	1000	1400		ap-my	ja-dc	fruits
Torenia pierreana Bon.	Scrophulariaceae	h	a	gro	3	egf, eb/bb	gr	1100	1400	jl-oc	sp-nv	my-dc	flowers
Torenia violacea (Aza. *ex* Blanco) Penn.	Scrophulariaceae	h	a	gro	3	egf, eg/bb, da	gr, ls	1000	1500	sp-oc	nv-dc	ap-dc	flowers
Toxocarpus aff. *wightianus* Hk. & Arn.	Asclepiadaceae	v	pe	gro	3	mxf, egf, da	ls	1250	1400	my-jn		ja-dc	flowers
Trema orientalis (L.) Bl.	Ulmaceae	t	pe	gro	3	da, sg	gr,ls	500	1200	oc	dc	ja-dc	flowers♂
Trevesia palmata (DC.) Vis.	Araliaceae	l	pe	gro	3	mxf, egf	gr, ls	550	1500	fb-mr		ja-dc	
Trichosanthes kerrii Craib	Cucurbitaceae	v	a	gro	2	cliffs in bb/df, mxf	ls	1200	1350	my-oc	my-jn	ap-dc	flowers♂, fruits
Trichosanthes ovigera Bl.	Cucurbitaceae	v	a	gro	3	da,sg	gr	1000	1500	sp-nv		my-dc	flowers♂
Trichosanthes pubera Bl.spp.rubriflos (Thor.ex Cay.) Duy. & Prue. var. rubriflos	Cucurbitaceae	v	a	gro	3	bb/df, egf, eg/bb, da	gr, ls	400	1525	jn-oc	sp-oc	my-dc	flowers, fruits
Tridynamia spectabilis (Kurz) Stap.	Convolvulaceae	v	a	gro	3	mxf,da,sg	ls	450	600	fb-mr	mr-ap	jn-ap	flowers
Trigonostemon thyrsoideus Stapf	Euphorbiaceae	l	pe	gro	2	rocks in eg/bb, cliffs, egf, streams	ls	1250	1300	ap-jn		ja-dc	flowers♂,♀

Table 1 (continued)

Trisepalum prazeri Burtt	Gesneriaceae	s	pd	epl	3	rocks in mxf cliffs	ls	1400	1425	ag-oc	nv-dc	ja-dc	flowers, fruits
Tristaniopsis burmanica (Griff.) Wils. & Wat. var. *rufescens* (Hance) Parn. & Lug.	Myrtaceae	t,l	pe	gro	2	eg/pine	gr	1250	1300	ja-fb	ap-my	ja-dc	flowers
Triumfetta annua L.	Tiliaceae	h	a	gro, wee	3	da	gr, ls	1000	1500	sp-nv	nv-dc	my-dc	flowers
Triumfetta pilosa Roth	Tiliaceae	h	a	gro	3	eg/bb, da	gr	1000	1525	sp-nv	ja-fb	ag-fb	fruits
Triumfetta rhomboidea L.	Tiliaceae	h	a	gro, wee	3	da, sg	gr,ls, sh,ss	500	900		nv-dc	my-dc	
Turpinia pomifera (Roxb.) Wall. *ex* DC.	Staphyleaeaceae	t	pe	gro	3	egf	gr, ls	900	1500	fb-mr	jn-oc	ja-dc	flowers, fruits
Ulmus lancaefolia Roxb. *ex* Wall.	Ulmaceae	t	pe	gro	3	rocks in egf cliffs	ls	1250	1400	sp-oc		ja-dc	flowers
Uncaria macrophylla Wall.	Rubiaceae	wc	pe	gro	3	streams in egf, eg/bb	gr	900	1300	sp-oc	nv-ja	ja-dc	
Uraria poilanei Dy Phon	Leguminosae, Papilionoideae	s	pe	gro	2	egf,da,sg	gr	1050	1250	nv-dc		ja-dc	flowers
Urena lobata L. ssp. *lobata* var. *lobata*	Malvaceae	h	a	gro, wee	3	da, sg	gr,ls, sh,ss	500	1500	oc-dc	nv-fb	my-dc	
Utricularia striatula Sm.	Lentibulariaceae	h	a	epl	2	rocks in eg/pine, egf cliffs	gr, ls	1500	1500	ag-sp	sp-oc	jn-oc	
Vaccinium sprengelii (D. Don) Sleum.	Ericaceae	t, l	pe	gro	3	eg/pine	gr	1200	1450	ja-fb		ja-dc	flowers
Verbena officinalis L.	Verbenaceae	h	a	gro,wee	3	da, sg	gr	1100	1300	jn-fb	jl-mr	my-mr	flowers, fruits
Vernonia attenuata DC.	Compositae	l	pd	gro, epl	3	rocks in eg/bb, mxf cliffs	ls	1250	1425	oc-nv	nv-dc	my-dc	flowers
Vernonia cinerea (L.) Less. var. *cinerea*	Compositae	h	a	gro, wee	3	da, sg	gr,ls, sh,ss	700	1500	my-ja	jn-fb	my-fb	
Vernonia divergens (DC.) Edgew.	Compositae	h	pd	gro	3	egf eg/pine da sg	gr,ls	1200	1500	nv-dc	ja-fb	my-fb	flowers, fruits
Vernonia parishill Hk.f.	Compositae	l	pe	gro	3	egf		1100	1500	mr-ap	ap-my	ja-dc	fruits
Vernonia sutepensis Craib	Compositae	h	pe	gro	3	eg/bb	gr	1000	1500	ja-fb	fb-mr	ja-dc	flowers
Vibunum odoratissimum Ker	Caprifoliaceae	sc	pe	gro	3	rocks in mxf cliffs	ls	1375	1425	dc-ja		ja-dc	flowers
Viburnum garrettii Craib	Caprifoliaceae	s,l	pe	gro	2	streams in egf, eg/bb	gr	1000	1100	jn-jl	oc	ja-dc	flowers, fruits
Vigna radiata (L.) Wilcz. var. sublobata (Roxb.) Verdc.	Leguminosae, Papilionoideae	v	a	gro	3	egf,da	gr	900	1100	oc-nv		my-dc	flowers

Table 1 (continued)

Viscum ovalifolium Wall. *ex* DC.	Viscaceae	s	pe	epi, par	2	egf	gr	1200	1300	fb-mr	my-jn	ja-dc	fruits
Vitex canescens Kurz	Verbenaceae	t	pd	gro	3	bb/df	gr	400	1100			my-dc	
Vitex peduncularis Wall. *ex* Schauer	Verbenaceae	t	pd	gro	3	bb/df,egf, eg/pine	gr	800	1400	ap-my	jl	mr-nv	flowers, fruits
Vitex quinata (Lour.) Will. var. *puberula* (Lam) Mold.	Verbenaceae	t	pe	gro	3	mxf,egf	gr, ls	600	1500	ap	sp	ja-dc	flowers, fruits
Wendlandia ternifolia Cow.	Rubiaceae	l	pe	epl	2	rocks in egf, cliffs	ls	1200	1400	dc-fb	fb	ja-dc	flowers, fruits
Wendlandia tinctoria (Roxb.) DC. ssp. *orientalis* (Craib) Cow.	Rubiaceae	t,l	pe	gro	3	egf,eg/pine,sg	gr	1000	1500	ja-fb		ja-dc	flowers, fruits
Xanthophyllum virens Roxb.	Polygalaceae	t	pe	gro	2	egf, eg/bb	gr	950	1200	mr-ap	ja-ag	ja-dc	
Youngia japonica (L.) DC.	Compositae	h	a	gro, wee	3	eg/bb, da, eg/pine	gr,ls	500	1500	jn-dc	jl-ja	my-dc	flowers
Zanthoxylum oxyphyllum Edgew.	Rutaceae	wc	pe	gro	3	egf	ls	1200	1350	ja		ja-dc	
Zehneria bodinieri (Lev.) Wilde & Duy.	Cucurbitaceae	v	a	gro	3	eg/bb, egf,da	gr, ls	900	1500	oc-dc	nv-ja	my-dc	flowers♂♀, fruits
Zehneria tenuispica Wilde & Duy.	Cucurbitaceae	v	a	gro	3	da, rocks and cliffs mxf, egf	gr, ls	1000	1425	sp-nv	nv-dc	my-dc	flowers♂♀, fruits
Ziziphus incurva Roxb.	Rhamnaceae	t	pe	gro	3	egf	ls	1200	1400	my-sp	oc-nv	ja-dc	
Ziziphus ?attopensis Pierre	Rhamnaceae	wc	pe	gro	3	mxf, eg/bb	gr	500	700			ja-dc	
Ziziphus oenoplia (L.) Mill. var. *oenophia*	Rhamnaceae	wc	pd	gro	3	eg/bb, da, sg	gr	600	1150	mr-ap	oc-nv	my-fb	

Table 2. List of plant species (monocot) under phylum angiospermae surveyed at Doi Tung, Chiang Rai Province

Species	Family	Habit	Aped	Life mode	Abundance	Habitat	Bedrock	Lower	Upper	Flowering	Fruiting	Leafing	Collected
								Elevation (m)		Months			
Aglaonema simplex (Bl.) Bl.	Araceae	h	pe	gro, epl	3	rocks in egf, mxf	gr,ls,sh	550	1350	mr-ap	sp-dc	ja-dc	flowers
Allium chinense G. Don	Liliaceae	h	a	gro, cul, int	2	da	gr	1000	1100	sp-oc		my-dc	flowers
Alocasia	Araceae	h	pe	gro	2	streams in eg/bb	gr	1000	1200			ja-dc	
Alocasia macrorrhizos (L.) G. Don	Araceae	h	pe	gro	3	streams in egf, mxf	gr, ls	550	1350	my		ja-dc	
Alpinia galanga (L.) Willd.	Zingiberaceae	h	pe	gro	2	egf, eg/bb	gr	1000	1300	my-jl	oc-nv	ja-dc	
Alpinia malaccensis (Burm.f.) Rosc.	Zingiberaceae	h	pe	gro	3	eg/bb, streams in egf	gr, ls	1100	1375	fb-jn	mr-sp	ja-dc	flowers, fruits
Amomum	Zingiberaceae	h	pe	gro	3	streams in egf,eg/bb	gr	1100	1300		jl-ag	ja-dc	fruits
Amomum repoense Pierre *ex* Gagnep.	Zingiberaceae	h	pe	gro	3	eg/bb, da	ls	1200	1350			ja-dc	fruits
Amomum uliginosuns Koen.	Zingiberaceae	h	pe	gro	3	eg/bb, da	ls	550	1350			ja-dc	
Amorphophallus	Araceae	h	pd	gro	2	rocks in egf	ls	1300	1375		jl-ag	jn-dc	
Amorphophallus yunnanensis Engl.	Araceae	h	pd	gro	3	rocks in eg/bb	gr, ls	1200	1425	fb-mr, my-jn	my-jl	jl-dc	flowers, fruits
Aphyllorchis montana Rchb. f.	Orchidaceae	h	pe	gro, sap	2	eg/bb, da	gr	1200	1300	ag-sp	sp-oc	leafless	flowers, fruits
Apluda mutica L.	Gramineae	h	pe,pd	gro, wee	3	da, sg	gr,ls, sh,ss	800	1525	oc-dc	nv-ja	my-ja	flowers
Arenga ? *westerhousii* Griff.	Palmae	t	pe	gro, epl	2	rocks in egf	ls	1200	1350			ja-dc	
Arisaema cuspidatum (Roxb.) Engl.	Araceae	h	pd	epl	2	rocks in egf, cliffs	ls	1200	1400	my-jn		my-nv	flowers
Arthraxon lanceolatus (Roxb.) Hochst. var. *lanceolatus*	Gramineae	h	a	epl	3	rocks in bb/df, cliffs	ls	400	600	sp-oc	nv	my-dc	flowers
Arthraxon lancifolius (Trin.) Hochst.	Gramineae	h	a	gro, epl	3	rocks in bb/df, egf, eg/bb, da,sg, cliffs	gr,ls	400	1400	sp-oc	nv-ja	my-dc	flowers, fruits
Arundina graminifolia (D.Don) Hochr.	Orchidaceae	h	pe	gro	2	da	gr	1000	1300	jl-oc		ja-dc	flowers
Arundinella setosa Trin. var. *setosa*	Gramineae	h	pd	gro	3	eg/pine, da, sg	gr	1200	1325	nv-dc	dc-ja	my-dc	flowers

Table 2 (continued)

Asparagus filicinus Ham. *ex* D.Don	Liliaceae	h	pd	gro	3	egf, eg/bb	gr	900	1500	my		my-dc	flowers
Bambusa balcooa Roxb.	Gramineae, Bambusoideae	h	pe	gro	3	streams in eg/bb cliffs	gr, ls	1100	1425	jl-ag	ag-sp	ja-dc	flowers
Bothriochloa bladhii (Retz.) S. T. Blake	Gramineae	h	pd	gro, wee	3	da, sg	gr	1100	1525	sp-ja	oc-fb	my-fb	flowers
Bulbophyllum affine Lindl.	Orchidaceae	h, cr	pe	epi	2	egf, eg/pine	gr	1200	1400	my		ja-dc	flowers
Bulbophyllum pulchellum Ridl.	Orchidaceae	h	pd	epi	2	rocks in mxf, eg/bb cliffs	ls	1375	1425	sp-oc		my-dc	flowers
Calamus nambariensis Becc.	Palmae	s	pe	gro	2	rocks in egf, eg/bb	ls	1200	1375			ja-dc	
Calanthe labrosa (Rchb. f.) Rchb. f.	Orchidaceae	h	pd	epi,epl	2	rocks in mxf, egf	ls	1300	1425	oc-dc		my-nv	flowers
Capillipedium parviflorum (R. Br.) Stapf	Gramineae	h	pe	gro, wee	3	da, sg	gr, ls	1000	1525	my-nv	jl-dc	ja-dc	flowers
Carex baccans Nees	Cyperaceae	h	pe	gro	3	da,sg	ls	1000	1400		ja-fb	ja-dc	fruits
Carex phyllocaula Nel.	Cyperaceae	h	pd	epl	2	rocks in egf, cliffs	ls	1300	1400	ag-sp	sp-oc	my-dc	fruits
Caryota maxima Bl.	Palmae	t	pe	gro	2	egf, eg/bb	gr	1000	1100	ja-dc	ja-dc	ja-dc	
Caryota mitis Lour.	Palmae	l	pe	gro	2	streams in egf	gr	1000	1350			ja-dc	
Chloris pycnothrix Trin.	Gramineae	h	a	gro, int, nat, wee	3	da, sg	gr, ls	900	1375	my-dc	jn-ja	my-dc	flowers
Chrysopogon aciculatus (Retz.) Trin.	Gramineae	h	pe	gro, wee	3	da,sg	gr	700	1525	my-sp	jl-oc	ja-dc	
Cleisostoma racemiferum (Lindl.) Garay	Orchidaceae	h	pe	epi	2	rocks in mxf, eg/bb cliffs	ls	1300	1425	jl-ag		ja-dc	flowers
Coelogyne lactea Rchb. f.	Orchidaceae	h	pe	epl	3	rocks in mxf cliffs	ls	1200	1425	fb-mr		ja-dc	flowers
Collabium	Orchidaceae	h	pe	gro	2	streams in egf	gr,ls	1200	1300	my-jn		ja-dc	flowers
Colocasia fallax Schott	Araceae	h	pd	epl	3	rocks in mxf, egf, eg/bb, cliffs	gr,ls	500	1425	my-jn		my-dc	flowers
Commelina benghalensis L.	Commelinaceae	h	a	gro, wee	3	da, sg	gr, ls	400	800	sp-oc		my-dc	
Commelina diffusa Burm. f.	Commelinaceae	h	pe	gro	3	eg/pine, da	gr	1200	1500	sp-oc		ja-dc	flowers
Commelina paludosa Bl.	Commelinaceae	h	pe	gro	3	mxf, eg/bb, da	gr, ls	550	1400	sp-oc		ja-dc	flowers
Corymborkis veratrifolia (Reinw.) Bl.	Orchidaceae	h	pe	gro	1	mxf	sh	550	550			ja-dc	
Costus globosus Bl.	Zingiberaceae	h	pe	gro	2	streams in egf	gr, ls	1000	1400	jn-ag	nv-dc	ja-dc	
Costus speciosus (Koen.) J E. Sm.	Zingiberaceae	h	pd	gro	3	mxf, eg/bb	gr, ls	1000	1525			my-dc	

Table 2 (continued)

Crepedium acuminatum (D.Don) Szl.	Orchidaceae	h	pd	epl	2	rocks in mxf cliffs	ls	1375	1400	my-jn		ap-dc	flowers
Crinum wattii Baker	Amaryllidaceae	h	pd	gro	2	bb/df, eg/bb	gr	400	1250	my-jn		my-dc	
Curculigo capitulata (Lour.) O.K.	Amaryllidaceae	h	pe	gro	3	streams in egf, eg/bb	gr,ls	1000	1350	my-jn	ag-sp	ja-dc	flowers, fruits
Curcuma	Zingiberaceae	h	pd	gro	2	eg/bb	gr	1100	1350	my		my-dc	flowers
Curcuma zedoaria (Berg.) Rosc.	Zingiberaceae	h	pd	gro	3	bb/df, eg/bb	gr	900	1500	ap-my	jn-jl	my-dc	
Cyanotis cristata (L.) D. Don	Commelinaceae	h	a	gro	3	rocks in mxf, eg/bb cliffs	gr,ls	900	1425	jl-sp	sp-oc	my-dc	flowers
Cymbidium	Orchidaceae	h	pe	epi	2	eg/bb	gr	1100	1300		oc	ja-dc	
Cymbidium lancifolium Hk.	Orchidaceae	h	pe	gro	2	eb/bb	gr	1200	1300	dc-ja	nv-ja	ja-dc	flowers, fruits
Cynodon dactylon (L.) Pers.	Gramineae	h	pe	gro,wee	3	da	gr,sh,ss	900	1200	ja-dc	ja-dc	ja-dc	flowers, fruits
Cyperus cyperoides (L.) O. K.	Cyperaceae	h	pe	gro,wee	3	da, sg	gr,ss	500	1500	ja-dc	ja-dc	ja-dc	
Cyperus exalatus Retz.	Cyperaceae	h	pe	gro	3	streams in egf, ponds, wet areas	gr	900	1100	my-jn	jn-jl	ja-dc	flowers
Cyperus kyllingia Endl.	Cyperaceae	h	pe	gro, wee	3	eg/pine, da, sg	gr,ss	800	1525	my-oc	jn-nv	ja-dc	flowers
Cyperus laxus Lmk. var. *laxus*	Cyperaceae	h	pe	gro, wee	3	mxf, eg/bb, da	gr, ls	500	1350	ag-oc	sp-nv	ja-dc	flowers
Cyperus phyllocaula Nel.	Cyperaceae	h	pd	epl	2	rocks in egf cliffs	ls	1300	1400	ag-sp	sp-oc	my-dc	fruits
Cyrtococcum accrescens (Trin.) Stapf	Gramineae	h	a	gro	3	eg/pine, eg/bb, da	gr, ls	400	1500	jn-oc	jl-nv	my-dc	flowers
Cyrtococcum oxyphyllum (Steud,) Stapf	Gramineae	h	pe	gro		eg/bb, da	gr, ls	1100	1400	ag-sp	sp-oc	ja-dc	flowers
Dendrobium compactum Rol. *ex* Hack.	Orchidaceae	h	pd	epi	2	rocks in mxf cliffs	ls	1400	1425	oc		my-dc	flowers
Dendrocalamus giganteus (Wall.) Munro	Gramineae, Bambusoideae	h	pe	gro	4	rocks in eg/bb	ls	1300	1425			ja-dc	
Dendrocalamus hamiltonii Nees & Arn. *ex* Munro	Gramineae, Bambusoideae	h	pe	gro	3	eg/bb	gr	1100	1300			ja-dc	
Dendrocalamus membranaceus Munro	Gramineae, Bambusoideae	h	pe	gro	4	eg/bb,da	gr	400	1500	nv-dc	ja-dc	ja-dc	flowers
Dendrocalamus nudus Pilg.	Gramineae, Bambusoideae	h	pe	gro	4	eg/bb,da	gr	900	1200	nv-fb	ja-mr	ja-dc	flowers
Dianella ensifolia (L.) DC.	Liliaceae	h	pe	gro	3	egf, eg/bb	gr	1000	1500		jl-sp	ja-dc	

Table 2 (continued)

Dichorisandra thyrsiflora Mikan	Commelinaceae	h	pe	gro,cul	3	egf	gr	1000	1000	ja-dc	ja-dc	ja-dc	flowers
Dienia ophrydis (Koen.) Orm. & Seid.	Orchidaceae	h	pd	gro	2	da, eg/pine	gr	1100	1350	jn-ag	sp-oc	my-dc	flowers
Digitaria radicosa (Presl) Miq.	Gramineae	h	a	gro, wee	3	da, sg	gr	1000	1300	sp-nv	oc-dc	my-dc	flowers
Digitaria setigera Roth *ex* Roem. & Schult. var. *setigera*	Gramineae	h	a	gro, wee	3	da, sg	gr	800	1200	sp-ja	oc-fb	jn-fb	flowers
Dinochloa maclellandii (Munro) Gamb.	Gramineae, Bambusoideae	h	pe	gro	4	egf, eg/bb, da, sg	gr	1100	1450			ja-dc	
Dioscorea alata L.	Dioscoreaceae	v	pd	gro, wee	3	da, sg	gr	800	1525	oc-nv		my-fb	flowers♂
Dioscorea birmanica Pr. & Burk.	Dioscoreaceae	v	pd	gro	3	rocks in mxf, egf, eg/bb	ls	1300	1425	jl-sp		my-dc	flowers♂
Dioscorea bulbifera L.	Dioscoreaceae	v	pd	gro	3	da,sg	gr	1100	1525			jn-dc	
Dioscorea decipiens Hk. f.	Dioscoreaceae	v	pd	gro	2	da, sg	gr	1000	1400	sp-nv	dc-mr	my-mr	
Dioscorea glabra Roxb. var. *glabra*	Dioscoreaceae	v	pe	gro	3	egf,da	gr	1000	1500	oc-nv		ja-dc	flowers♂
Dioscorea hamiltonii Hk. f.	Dioscoreaceae	v	pd	gro	3	da, sg	gr	1100	1500	oc-nv	dc-fb	my-fb	flowers♂
Dioscorea hispida Denn. var. *mollissima (*Bl.) Pr. & Burk.	Dioscoreaceae	v	pd	gro	3	eg/bb, da,sg	gr,ls	900	1400	my-jn		my dc	flowers, imm. fruits
Dioscorea pentaphylla L. var. *communis* Pr. & Burk.	Dioscoreaceae	v	pd	gro, wee	3	da,sg	gr	1000	1525	oc		jn-dc	flowers♂♀
Dioscorea prazeri Pr. & Burk.	Dioscoreaceae	v	pd	gro	3	egf, da	gr	1200	1350	sp-oc		my-dc	flowers♂
Dioscorea rockii Pr. & Burk.	Dioscoreaceae	v	pd	gro	3	rocks in mxf, eg/bb cliffs	ls	1300	1425	jl-ag		my-dc	flowers♂
Disporopsis longifolia Craib	Liliaceae	h	pd	gro	2	eg/bb	gr	1000	1400	my-jn		ap-dc	flowers
Disporum calcaratum Wall. *ex* G. Don	Liliaceae	h	pd	gro	2	eg/pine, da, sg	gr	1000	1500	my-jn	oc-dc	my-dc	flowers,fruits
Dracaena angustifolia Roxb.	Agavaceae	l	pe	gro	2	rocks in egf, mxf	gr,ls, sh	500	1400		oc-nv	ja-dc	
Dracaena loureiri Gagnep.	Agavaceae	pe	pe	epl	2	rocks in egf, mxf cliffs	ls	500	1300			ja-dc	
Echinochloa colona (L.) Link	Gramineae	h	pe	aqu, gro	3	ponds in bb/df	ls	400	600	ag-oc	sp-nv	ja-dc	flowers
Echinochloa stagnina (Retz.) P. Beauv.	Gramineae	h	pe	gro, wee	3	da, sg	gr, ls	1200	1525	sp-dc	oc-ja	ja-dc	flowers
Eleusine indica (L.) Gaertn.	Gramineae	h	pe	gro, wee	3	da	gr,ls	500	1525	jn-nv	jl-dc	ja-dc	
Eria bilobulata Seid.	Orchidaceae	h	pd	epi, epl	3	rocks in mxf, eg/bb cliffs	ls	1300	1425	jl-ag	oc	my-dc	flowers

Table 2 (continued)

Eria globulifera Seid.	Orchidaceae	h	pd	epi	3	rocks in mxf, eg/bb cliffs	ls	1300	1425	jl-ag	oc	my-dc	flowers
Etlingera littoralis (Kon.) Gise.	Zingiberaceae	h	pe	gro	3	streams, wet areas in mxf, egf	gr, ls	550	1300	ap-jn	oc-nv	ja-dc	flowers
Eulophia macrobulbon (Par. & Rchb. f.) Hk. f.	Orchidaceae	h	pd	gro	2	eg/pine, da	gr	1200	1400	jn-jl		ag-dc	flowers
Eulophia spectabilis (Denn.) Sur.	Orchidaceae	h	pd	gro	2	da, sg	gr	1100	1300	my		jn-dc	
Gigantochloa apus (Schult.) Kurz	Gramineae, Bambusoideae	h	pe	gro	3	bb/df, eg/bb	gr, ls	500	1500			ja-dc	
Globba clarkei Baker	Zingiberaceae	h	pd	gro	3	rocks in mxf, egf	gr,ls	600	1400	jl-sp	oc-nv	my-dc	flowers
Globba schomburgkii Hk. f. var. *schomburgkii*	Zingiberaceae	h	pd	gro	3	egf, eg/bb	gr	1000	1300	jl-ag		my-dc	flowers
Habenaria furcifera Lindl.	Orchidaceae		pd	epl	3	rocks in mxf, eg/bb cliffs	ls	1400	1425	jl-ag		my-dc	flowers
Habenaria malintana (Blanco) Merr.	Orchidaceae	h	pd	gro	2	bb/df, eg/bb	gr	850	1400	oc		my-dc	flowers
Hedychium ellipticum Ham. *ex* J.E. Sm.	Zingiberaceae	h	pd	epl	3	rocks in mxf,eg/bb cliffs	ls	1375	1425	jl-ag	sp	my-dc	flowers, fruits
Hedychium gardnerianum Rosc.	Zingiberaceae	h	pd	gro	3	egf, eg/pine, da	gr	1100	1500	sp-oc		my-dc	flowers
Hemipilia calophylla Par. & Rchb. f.	Orchidaceae	h	pd	epl	1	rocks in mxf, eg/bb	ls	1350	1425	jl-ag		my-dc	flowers
Hypoxis aurea Lour.	Amaryllidaceae	h	pd	gro	2	da in eg/pine	gr	1200	1500	my-jl	jn-ag	my-nv	flowers, fruits
Imperata cylindrica (L.) P. Beauv. var. *major* (Nees) C..E. Hubb. *ex* Hubb. & Vaugh.	Gramineae	h	pe	gro, wee	4	da, sg	gr,ls	500	1525	my-oc	jn-dc	ja-dc	
Ischaemum	Gramineae	h	pd	epl	2	rocks in egf cliffs	ls	1300	1400	oc-nv	dc	my-dc	flowers
Liparis olivacea Lindl.	Orchidaceae	h	pd	gro	3	bb/df,eg/bb	gr	1100	1300	jl-ag		my-dc	flowers
Liparis tenuis Rol. *ex* Dow.	Orchidaceae	h	pd	epi	2	rocks in mxf, eg/bb cliffs	ls	1350	1425	jl-ag		my-dc	flowers
Liparis viridiflora (Bl.) Lindl.	Orchidaceae	h	pe	epi, epl	3	rocks in mxf cliffs	ls	1375	1425	ag-sp	oc	ja-dc	flowers
Lophatherum gracile Brongn. var. *gracile*	Graimineae	h	pd	gro	3	eg/bb, da	gr	1100	1300	sp-oc	oc-nv	my-dc	flowers
Melinus repens (Willd.) Zizka	Gramineae	h	a	gro, int, nat, wee	3	da, sg	gr	400	700	sp-oc	sp-oc	my-dc	

Table 2 (continued)

Melocanna baccifera (Roxb.) Kurz	Gramineae, Bambusoideae	h	pe	gro	2	streams in mxf, eg/bb	gr	1000	1300			ja-dc	
Microstegium vagans (Nees *ex* Steud.) A. Camus	Gramineae	h	pe	gro, wee	4	da, sg	gr, ls	450	1500	dc-ja	ja-fb	ja-dc	flowers
Mnesithea striata (Nees *ex* Steud.) Kon. & Sos.	Gramineae	h	pd	gro	3	da	gr	1000	1300	ag-oc	oc-nv	my-ja	flowers
Murdannia japonica (Thunb.) Faden	Commelinaceae	h	pd	gro	3	da in egf	gr	1100	1400	my-jl	jl-sp	my-dc	flowers
Murdannia nudiflora (L.) Bren.	Commelinaceae	h	a	gro, wee	3	egf, da, sg	gr	900	1300	sp-nv	oc-dc	my-dc	flowers
Musa itinerans Chees.	Musaceae	h	pe	gro	3	streams, wet areas in egf, eg/bb	gr, ls	950	1375	ag-oc		ja-dc	
Nervilia aragoana Gaud.	Orchidaceae	h	pd	gro	2	mxf, eg/bb	ls	1200	1350			jn-dc	leaves
Nervilia crociformis (Zoll. & Mor.) Seid.	Orchidaceae	h	pd	gro	2	bb/df, eg/bb	gr	1100	1300			my-dc	leaves
Oberonia	Orchidaceae	h	pe	epi	2	rocks in eg/bb ,mxf, cliffs	ls	1200	1425		fb-mr	ja-dc	
Ophiopogon longifolius Decne.	Liliaceae	h	pe	gro	3	egf, eg/bb	ls	1200	1400	my-sp	dc-ja	ja-dc	flowers, fruits
Ophiopogon reptans Hk.f.	Liliaceae	h	pe	gro	2	streams in eg/bb	gr	1100	1200	my-jn	nv-dc	ja-dc	fruits
Oplismenus burmannii (Retz.) P. Beauv.	Gramineae	h	pe	gro, wee	3	da, sg	gr	800	1500	oc-ja	nv-fb	ja-dc	flowers
Oplismenus compositus (L.) P. Beauv.	Gramineae	h	a	gro	3	da in eg/pine, eg/bb	gr, ls	400	1500	sp-oc	oc-nv	my-dc	flowers
Ornithochilus difformis (Wall. *ex* Lindl.) Schltr.	Orchidaceae	h	pe	epi	2	egf, eg/bb	gr	1100	1400	jl-ag		ja-dc	flowers
Pandanus sect. Rykia (de Vr.) Kurz	Pandanaceae	l	pe	gro	2	rocks in egf, cliffs	ls	1300	1375			ja-dc	
Pandanus sect. Rykia (de Vr.) Kurz	Pandanaceae	l	pe	gro	2	streams in bb/df, mxf	gr	500	600			ja-dc	
Panicum brevifolium L.	Gramineae	h	a	gro, wee	3	da, sg	gr	900	1200	sp-oc	oc-nv	my-dc	flowers
Panicum maximum Jacq.	Gramineae	h	pe	gro, wee	3	da, sg	gr	500	1100	sp-oc	oc-nv	ja-dc	
Panicum notatum Retz.	Gramineae	h	pe	gro	3	egf, eg/bb	gr	1000	1450	my-jl	my-jl	ja-dc	flowers
Panicum repens L.	Gramineae	h	pe	gro	3	streams in eg/bb	gr	1000	1300	oc-dc	nv-ja	ja-dc	flowers
Panisea uniflora (Lindl.) Lindl.	Orchidaceae	h	pe	epi	4	rocks in egf, mxf cliffs	ls	1300	1425	ap	ap-my	ja-dc	flowers, fruits
Paphiopedilum charlesworthii (Rol.) Pfitz.	Orchidaceae	h	pe	epl	0,1	rocks in mxf, eg/bb cliffs	ls	1200	1425			ja-dc	

Table 2 (continued)

Paris polyphylla J. E. Sm.	Liliaceae	h	pd	gro	2	rocks in egf cliffs	gr,ls	1200	1375	my-jn	sp	my-dc	
Paspalum conjugatum Berg.	Gramineae	h	a	gro, wee	3	da	gr, ls	1100	1525	ag-oc	sp-nv	my-dc	
Peliosanthes teta Andr. *ssp. humilis* (Andr.) Jess.	Liliaceae	h	pd	gro	2	rocks, streams in egf	gr,ls	1000	1325			ja-dc	
Pennisetum purpureum Schumach.	Gramineae	h	pd	gro, wee	3	da, sg	gr	800	1500	nv-ja	dc-fb	jn-fb	flowers
Peristylus constrictus (Lindl.) Lindl.	Orchidaceae	h	pd	gro	2	eg/bb	gr	1250	1400	my		my-dc	flowers
Peristylus prainii (Hk. f.) Krzl.	Orchidaceae	h	pd	gro	2	bb/df	gr	1000	1100	my-jn		my-nv	flowers
Pholidota articulata Lindl.	Orchidaceae	h	pd	epi	3	rocks in mxf, cliff	ls	1300	1425			jn-dc	
Pholidota bracteata (D. Don) Seid.	Orchidaceae	h	pd	epi, epl	3	rocks in mxf, egf, eg/bb cliffs	ls	1200	1425		oc-ja	my-dc	fruits
Phragmites vallatoria (Pluk. *ex* L.) Veldk.	Gramineae	h	pe	gro, wee	4	da	gr,ls	500	1525	oc-dc	nv-ja	ja-dc	
Phrynium capitatum Willd.	Marantaceae	h	pe	gro	4	streams in egf	gr,ls	925	1350	my-jn	oc-nv	ja-dc	flowers
Pollia haskarlii R. Rao	Commelinaceae	h	pe	gro	3	streams in egf, mxf, eg/bb	gr,ls	500	1400	my-sp	sp-fb	ja-dc	flowers, fruits
Polygonatum kingianum Coll. & Hemsl.	Liliaceae	h	pd	gro	2	egf,eg/bb cliffs	ls	1375	1425	ap-my	sp-oc	ap-nv	flowers, fruits
Porpax lanii Seid.	Orchidaceae	h	pd	epi	3	mxf,egf,eg/bb	ls	1300	1425	jl-ag		my-dc	flowers
Pothos chinensis (Raf.) Merr.	Araceae	v	pe	epi, epl	3	streams, wet areas in egf, mxf, eg/bb	gr, ls	550	1375	ag-sp		ja-dc	flowers
Pseudodracontium	Araceae	h	pd	gro	2	rocks in mxf, eg/bb cliffs	ls	1375	1425			my-oc	
Pseudoechinolaena polystachya (H.B.K.) Stapf	Gramineae	h	a	gro	3	egf,da,sg	gr,ls	550	1525	oc-nv	nv-dc	my-dc	flowers
Rhaphidophora decursiva Schott	Araceae	v, cr	pe	epi, epl	3	mxf, egf, eg/bb	gr, ls,sh	525	1400	sp-oc		ja-dc	flowers
Rhaphidophora gigantea (Schott) Ridl.	Araceae	v, cr	pe	epl	3	rocks in egf, mxf cliffs	ls	500	1375	ag	fb	ja-dc	
Rhaphidophora hookeri Schott	Araceae	v, cr	pe	epi, epl	3	streams in eg/bb, rocks in mxf, egf	gr,ls	550	1375	sp	my-jn	ja-dc	flowers, fruits
Rhopalephora scaberrimum (Bl.) Faden	Commelinaceae	h	pe	gro	3	eg/pine, eg/bb	gr	1200	1375	ag-oc		ja-dc	flowers
Saccharum arundinaceum Retz.	Gramineae	h	pe	gro, wee	3	da, sg	gr,ls	500	1525	sp-dc	nv-ja	ja-dc	flowers

Table 2 (continued)

Saccharum spontaneum L.	Gramineae	h	pe	gro, wee	3	da, sg	gr, ls	400	1525	sp-dc	nv-ja	ja-dc	flowers
Sacciolepis indica (L.) A. Chase	Gramineae	h	a	gro, wee	3	da, sg	gr	900	1525	sp-dc	nv-ja	my-dc	flowers
Sagittaria trifolia L.	Alismataceae	h	ped	gro	2	ponds, wet areas in egf	gr	900	1000	ap-jl	jl-sp	ja-dc	flowers
Schizachyrium brevifolium (Sw.) Nees	Gramineae	h	a	gro	3	da,sg	gr	1000	1400	nv-dc	nv-dc	jn-dc	flowers, fruits
Scirpus juncoides Roxb.	Cyperaceae	h	pe	gro	3	wet areas in da, sg	gr	800	1100	mr-my	mr-my	ja-dc	flowers
Setaria palmifolia (Koen.) Stapf var. *palmifolia*	Gramineae	h	pe	gro	3	da	gr, ls	1000	1525	ag-fb	sp-fb	ja-dc	flowers
Setaria parviflora (Poir.) Kerg.	Gramineae	h	a	gro, wee	3	eg/bb, da, sg	gr	1000	1525	sp-oc	oc-nv	my-dc	flowers
Smilax corbularia Kunth ssp. *corbularia*	Smilacaceae	v	pe	gro	3	egf,eg/bb,da,sg	gr	1000	1450	jn		ja-dc	flowers
Smilax lanceifolia Roxb.	Smilacaceae	v	pe	gro	3	egf	gr, ls	1000	1500	ja-fb	jl-ag	ja-dc	flowers, fruits
Smilax ovalifolia Roxb.	Smilacaceae	v	pe	gro	3	egf, eg/bb	gr	800	1200			ja-dc	
Smilax perfoliata Lour.	Smilacaceae	v	pe	gro	3	da,sg,eg/bb,egf	gr	1000	1525		ap-jn	ja-dc	fruits
Tacca chantrieri Andre	Taccaceae	h	pe	gro	2	egf	ls	1200	1350			ja-dc	
Thaia saprophytica Seid.	Orchidaceae	h	pd	gro, epl	2	rocks in egf	ls	1300	1375	oc		jn-nv	flowers
Themeda triandra Forssk.	Gramineae	h	pe	gro, wee	3	da, sg	gr, ls	500	1525	sp-oc	oc-nv	ja-dc	flowers
Thysanolaena latifolia (Roxb. *ex* Horn.) Honda	Gramineae	h	pe	gro, wee	3	da,sg	gr, ls	500	1525			ja-dc	
Trichotosia dasyphylla (Par. & Rchb. f.) Krzl.	Orchidaceae	h	pe	epi	3	eg/pine	gr	1200	1375			ja-dc	
Tupistra albiflora K. Lar.	Liliaceae	h	pe	gro	2	egf	ls	1300	1400	oc-nv		ja-dc	flowers
Urochloa ruziziensis (Germ. & Evr.) Morr. & Zul.	Gramineae	h	pe	gro, int, nat, wee	3	da, sg	gr	800	1200	oc-ja	nv-fb	ja-dc	flowers
Wallichia siamensis Becc.	Palmae	l	pe	gro	3	egf	gr,ls	1200	1375	sp-oc		ja-dc	flowers
Xyris lobbii Rend.	Xyridaceae	h	pd	gro	2	eg/pine	gr	1250	1325	sp-oc	nv-dc	my-dc	flowers
Zingiber aff. *integrum* Tong	Zingiberaceae	h	pd	gro	3	mxf, da	ls	1300	1375	ag-sp	oc-nv	my-dc	flowers, imm. fruits
Zingiber bradleyanum Craib	Zingiberaceae	h	pe	gro	3	streams in egf, eg/bb	gr	1100	1300		nv	ja-dc	
Zingiber kerrii Craib	Zingiberaceae	h	pd	gro	2	bb/df, eg/bb	gr	1000	1300	jl-ag	oc-nv	my-dc	
Zingiber smilesianum Craib	Zingiberaceae	h	pd	gro	3	egf, eg/bb	gr,ls	1000	1400	jl-ag	oc-dc	my-dc	fruits
?	Orchidaceae	h	pd	epl	2	rocks in egf	ls	1300	1400		oc-nv	jn-nv	fruits

Table 3. List of other plant species surveyed at Doi Tung, Chiang Rai Province

Species	Family	Habit	Aped	Life mode	Abundance	Habitat	Bedrock	Lower	Upper	Flowering	Fruiting	Leafing	Collected
								Elevation (m)		Months			
	Leskeaceae	h	pe	epi	3	egf	ls	1300	1425			ja-dc	
Adiantum philippense L.	Parkeriaceae	h	pd	gro, epl	3	mxf, egf, eg/bb	gr, ls	500	1250	sp-dc	sp-dc	my-dc	sori
Adiantum zollingeri Mett. *ex* Kuhn	Parkeriaceae	h	pd	epl	3	rocks in bb/df, mxf, eg/bb cliffs	gr, ls	500	1500	ag-oc	ag-oc	my-dc	sori
Aglaomorpha coronans (Wall. ex Mett.) Copel.	Polypodiaceae	h	pe	epi	2	eg/bb	ls	1100	1325			ja-dc	
Angiopteris evecta (Forst.) Hoffm.	Marattiaceae	h	pe	gro	3	streams in egf,eg/bb	gr	1100	1400	ja-dc	ja-dc	ja-dc	sori
Aniscocampium cumingianum Presl	Athyriaceae	h	pd	gro	3	bb/df, eg/bb	gr, ls	550	1100	sp-nv	sp-nv		sori
Araiostegia imbricata Ching	Davalliaceae	h	pd	epi	3	rocks in mxf, eg/bb cliffs	ls	1300	1425	jl-sp	jl-sp	my-dc	sori
Asplenium cheilosorum Kunze *ex* Mett.	Aspleniaceae	h	pe	epl	3	rocks and streams in egf	gr	1100	1325	nv-fb	nv-fb	ja-dc	sori
Asplenium greviellei Wall. *ex* Hk. & Grev.	Aspleniaceae	h	pe	epl	3	rocks in eg/bb, mxf,cliffs	ls	1300	1400	sp-nv	sp-nv	ja-dc	sori
Asplenium interjectum Christ	Aspleniaceae	h	pd	gro	3	rocks in egf,eg/bb cliffs	ls	1300	1425	jl-sp	jl-sp	my-dc	sori
Asplenium obscurum Bl.	Aspleniaceae	h	pe	epl	2	streams in eg/bb	gr	1050	1200	ja-dc	ja-dc	ja-dc	
Athyrium anisopterum Christ	Athyriaceae	h	pd	gro	3	bb/df, eg/bb	gr	1000	1400	jl-sp		my-dc	sori
Blechnum orientale L.	Blechnaceae	h	pe	gro	3	streams in egf, wet areas in eg/bb	gr	500	1500	jn-nv	jn-nv	ja-dc	sori
Blechnum orientale L.	Dryopteridaceae	h	pe	gro	3	streams in egf	gr, ls	1100	1300	dc-fb	dc-fb	ja-dc	sori
Bolbitis sinensis (Bak.) K. Iw. var. *sinensis*	Lomariopsidaceae	h	pe	epl	3	streams, wet areas in egf	gr, ls	900	1350	nv-ja	nv-ja	ja-dc	sori
Bolbitis virens (Wall. *ex* Hk. & Grev.) Schott var. *virens*	Lomariopsidaceae	h	pe	epl	2	rocks, streams in egf	gr,ls	1000	1325			ja-dc	
Brachymenium	Bryaceae	h	pe	epl	3	rocks in eg/pine	gr	1450	1525	sp-oc	sp-oc	ja-dc	capsules

Table 3 (continued)

Brachymenium nepalense Hk.	Bryaceae	h	pe	epi	3	eg/pine	gr	1450	1525	sp-oc	sp-oc	ja-dc	capsules
Brainea insignis (Hk.) J. Sm.	Blechnaceae	h, l	pe	gro	3	egf, eg/pine	gr	1200	1450			ja-dc	sori
Brainea insignis (Hk.) J. Sm.	Dryopteridaceae	h	pe	gro	3	eg/bb,da	gr	1100	1400	nv-dc	nv-dc	ja-dc	sori
Cephalotaxus griffithii Hk. f.	Cephalotaxaceae	t	pe	gro	2	egf	ls	1375	1400		jl-dc	ja-dc	fruits
Cheilanthes fragilis Hk.	Parkeriaceae	h	pd	epl	3	rock in mxf, eg/bb cliffs	ls	1300	1425	jl-ag		my-dc	sori
Cheilanthes pseudoargentea (S.K.Wu) K. Iw.	Parkeriaceae	h	pd	gro	3	rocks in mxf, cliffs	ls	1375	1400	fb-ap	fb-ap	jn-ap	sori
Cibotium baromtez (L.) J. Sm.	Dicksoniaceae	h	pe	gro	3	egf, da	ls	1200	1500	sp-oc	sp-oc	ja-dc	sori
Davallia trichomanoides Bl. var. *lorranii* (Hance) Holtt.	Davalliaceae	h	pd	epi	3	egf	gr	1000	1300	jl-sp		my-dc	sori
*Davallodes membranulosum (*Wall. *ex* Hk.) Copel.	Davalliaceae	h	pd	epi, epl	3	rocks in bb/df, mxf, cliffs	ls	1300	1425	jl-sp	jl-sp	my-dc	sori
Dicranopteris curranii Copel.	Gleicheniaceae	h	pe	gro	3	da	gr	1200	1350	jl-sp		ja-dc	sori
Dicranopteris linearis (Burm. f.) Underw. var. *linearis*	Gleicheniaceae	h	pe	gro	3	da	gr	600	1525	jn-sp		ja-dc	sori
Diplazium esculentum (Retz.) Sw.	Athyriaceae	h	pe	gro	3	streams in bb/df, wet areas in eg/bb	gr	700	1150	ja-fb	ja-fb	ja-dc	sori
Diplazium muricatum (Mett.) v. A. v. Ros.	Athyriaceae	h	pe	gro	3	rocks in egf,eg/bb	ls	1125	1400	oc-nv	oc-nv	ja-dc	sori
Drymoglossum piloselloides (L.) Presl var. *piloselloides*	Polypodiaceae	h, cr	pe	epi, epl	3	rocks in mxf, egf	ls	1100	1400	ag-oc	ag-oc	ja-dc	sori
Drynaria propinqua (Wall. *ex* Mett.) J. Sm. *ex* Bedd.	Polypodiaceae	h	pd	epi	2	egf, eg/bb	gr, ls	1000	1500	jl-sp	jl-sp	my-ja	sori
Drynaria rigidula (Sw.) Bedd.	Polypodiaceae	h	pd	epi	3	eg/bb	gr	1000	1400	my-jl	my-jl	my-dc	sori
Dryopteris cochleata (D. Don) C. Chr.	Dryopteridaceae	h	pe	gro	3	eg/bb,da	gr	1100	1400	nv-dc	nv-dc	ja-dc	sori
Dumortiera hirsuta (Sw.) Nees	Marchantiaceae	h	pe	epl	3	rocks, streams in egf, eg/bb	gr	1100	1200	oc-nv	oc-nv	ja-dc	sporophyte

Table 3 (continued)

Entodon macrocarpus (Hedw.) Mitt.	Entodontaceae	h	pe	epi	3	eg/pine	gr	1300	1450	my-ag	my-ag	ja-dc	capsules
Entodon macropodus (Medw.) Mitt.	Entodontaceae	h	pe	epl	3	rocks in egf, mxf	ls	1300	1425	sp-oc	sp-oc	ja-dc	capsules
Entodon plicatus C. Muell.	Entodontaceae	h	pe	epi	3	rocks in egf, eb/bb	ls	1200	1400	sp-nv	sp-nv	ja-dc	capsules
Equisetum debile Roxb. *ex* Vauch.	Equisetaceae	h	pe	gro	2	wet areas in bb/df	gr, ls	400	800			ja-dc	
Fissidens nobilis Griff.	Fissidentaceae	h	pe	epl	2	rocks, streams wet areas in egf	gr, ls	1200	1325			ja-dc	
Himantocladium plumula (Nees) Fleisch.	Neckeraceae	h	pe	epi	3	egf, cliffs	ls	1300	1425			ja-dc	
Hymenophyllum polyanthos (Sw.) Sw.	Hymenophyllaceae	h	pe	epi	2	egf	ls	1200	1375	sp-nv	sp-nv		sori
Hyophila involuta (Hk.) Jaeg.	Pottiaceae	h	pe	epl	3	rocks in eg/pine	gr	1450	1525	sp-oc	sp-oc	ja-dc	capsules
Hypopterygium flavolimbatum Mull. & Hal.	Hypoterygiaceae	h	pe	epl	3	rocks in egf, cliffs	ls	1200	1400			ja-dc	
Lepisorus nudus (Hk.) Ching	Polypodiaceae	h	pe	epi	3	egf, eg/pine	gr, ls	1200	1525	ag-oc	ag-oc	ja-dc	sori
Leptochilus ellipticus (Thunb.) Noot.	Polypodiaceae	h	pe	gro	2	streams in egf, eg/bb	gr, ls	1100	1350	ag-oc	ag-oc	ja-dc	sori
Leucobryum aduncum Dozy & Molk. var.*scalare* (C. Muell. *ex* Fleisch.) A. Eddy	Leucobryaceae	h	pe	epi	3	eg/bb	gr	1100	1400	jl-nv	jl-nv	ja-dc	capsules
Leucostegia immersa Presl	Davalliaceae	h	pd	epi, epl	3	rocks in mxf, eg/bb cliffs	gr, ls	1300	1425	jl-sp	jl-sp	my-dc	sori
Loxogramme involuta (D. Don) Presl	Polypodiaceae	h	pe	epi,epl	3	rocks in mxf cliffs	ls	1300	1425	sp-nv	sp-nv	ja-dc	sori
Lycopodium cernuum L.	Lycopodiaceae	h	pe	gro	3	egf,da,sg	gr	600	1300	ja-dc	ja-dc	ja-dc	strobili
Lygodium flexuosum (L.) Sw.	Schizaeaceae	v	pd	gro	3	eg/bb, da	gr	500	1500	sp-oc	sp-oc	my-dc	sori
Lygodium polystachyum Wall. *ex* Moore	Schizaeaceae	v	pe	gro	3	bb/df, eg/pine, eg/bb	gr	700	1100	ap-jl	ap-jl	ja-dc	
Meteoriopsis squarrosa (Hk.) Fleish. var. *squarrosa*	Meteoriaceae	h	pe	epi, epl	4	rocks, cliffs	ls	1200	1425			ja-dc	

Table 3 (continued)

Microlepia speluncae (L.) Moore	Dennstaedtiaceae	h	pe	gro	3	eg/bb, da	gr	1200	1500	ja-dc	ja-dc	ja-dc	sori
Microsorum zippelii (Bl.) Ching	Polypodiaceae	h	pd	epi, epl	3	rocks and streams in egf, mxf, eg/bb cliffs	gr,ls	1000	1425	sp-ja	sp-ja	jn-fb	sori
Oleandra undulata (Willd.) Ching	Oleandraceae	h	pd	gro	3	eg/pine, eg/bb	gr	1100	1400	ag-oc	ag-oc	my-dc	sori
Ophioglossum petiolatum Hk.	Ophioglosaceae	h	pd	gro, epi	2	egf, da	gr, ls	950	1375	jn-oc	jn-oc	my-dc	sori
Papillaria semitorta (C. Muell.) Jaeg.	Meteoriaceae	h	pe	epi	4	rocks in mxf, cliffs	ls	1300	1425			ja-dc	
Phaeoceros laevis (L.) Prosk.	Anthocerotaceae	h	pe	gro	2	eg/bb	gr	1100	1500	sp-oc	sp-oc	ja-dc	sporophyte
Phymatosorus lucidus (Roxb.) P.S.	Polypodiaceae	h	pe	epl	3	rocks in mxf cliffs	ls	1200	1425	dc-ap	dc-ap	ja-dc	sori
Pinus kesiya Roy. *ex* Gord.	Pinaceae	t	pe	gro also cul	2	eg/pine	gr	1200	1500	fb-mr		ja-dc	
Pityogramma calomelanos (L.) Link	Parkeriaceae	h	pe	gro	2	egf,da,sg	gr	1100	1200	oc-dc	oc-dc	ja-dc	sori
Plagiomnium succulentum (Mitt.) Kop.	Mniaceae	h	pe	epl	3	rocks in mxf, egf, cliffs	ls	1200	1400			ja-dc	
Platycerium wallichii Hk.	Polypodiaceae	h	pd	epi	2	dof, eg/bb	gr	500	1050	ag-oc	ag-oc	jn-dc	
Pogonatum neesii (C.Muell.) Dozy	Polytrichaceae	h	pe	gro	4	eg/bb	gr	1100	1400	oc-nv	oc-nv	ja-dc	capsules
Polypodium mamneiense H.Christ	Polypodiaceae	h	pd	epi, epl	3	egf	ls	1100	1400	jl-sp	jl-sp	jn-dc	sori
Polystichum lindsaefolium Scort. *Ex* Ridl.	Dryopteridaceae	h	pe	epl	3	mxf, egf	ls	1300	1425	sp-nv	sp-nv	ja-dc	sori
Pteridium aquilinum (L.) Kuhn *ssp. Aquilinum* var. *wightianum* (Ag.) Tyr.	Dennstaedtiaceae	h	pe	gro	4	da, sg	gr, ls	1000	1525			ja-dc	
Pteridrys cnemidaria (Christ) C. Chr. & Ching	Dryopteridaceae	h	pe	gro	2	streams in mxf	sh	500	700	nv-ja	nv-ja	ja-dc	sori
Pteris biaurita L.	Pteridaceae	h	pe	gro	3	mxf, da	gr, ls	500	1500	sp-oc	sp-oc	ja-dc	
Pteris longipes D. Don	Pteridaceae	h	pe	gro	2	streams in egf	gr, ls	1200	1350			ja-dc	
Pteris subquinata Wall. *Ex* Ag.	Pteridaceae	h	pd	epl	3	rocks in egf cliffs	ls	1200	1400	sp-nv	sp-nv		sori
Pteris venusta O. K.	Pteridaceae	h	pe	gro	2	eg/bb, da	ls	1100	1350	ag-oc	ag-oc	ja-dc	

Table 3 (continued)

Pyrrosia lingua (Thunb.) Far. Var. *heteractis* (Mett. *Ex* Kuhn) Hoven.	Polypodiaceae	h	pe	gro, epl	3	rocks in mxf cliffs	ls	500	1425	sp-dc	sp-dc	ja-dc	sori
Pyrrosia porosa (Wall. *Ex* Presl) Hoven. Var. *tonkinensis* (Gies.) Hoven.	Polypodiaceae	h	pe	gro, epi, epl	3	rocks in mxf, egf cliffs	gr, ls	1200	1425	sp-dc	sp-dc	ja-dc	sori
Racopilum orthocarpum Wils. *ex* Mitt.	Racopiliaceae	h	pe	epi	3	egf	gr, ls	1100	1400	my-ag	my-ag	ja-dc	capsules
Rhodobryum giganteum (Schwaegr.) Par.	Bryaceae	h	pe	epl	3	rocks in eg/bb, cliffs	ls	1200	1425	ag-oc	ag-oc	ja-dc	
Rhytidium	Rhitidiaceae	h	pe	epi	3	eg/pine	gr	1450	1525	sp-oc	sp-oc	ja-dc	capsules
Selaginella helferi Warb.	Selaginellaceae	v, h	a	gro	3	eg/bb, da	gr	500	1150	oc-fb	oc-fb	my-ja	sporangia
Selaginella involvens (Sw.) Spr.	Selaginellaceae	h	pd	epi,epl	3	rock in mxf, eg/bb	ls	1300	1425	jl-sp	jl-sp	my-dc	sporangia
Selaginella kurzii Bak.	Selaginellaceae	h	a	epl	3	rocks in bb/df cliffs	ls	400	800	sp-oc	sp-oc	jn-dc	sporangia
Selaginella minutifolia Spr.	Selaginellaceae	h	a	gro	3	eg/bb	ls	1100	1300	oc-nv	oc-nv	my-nv	sporangia
Selaginella roxburghii (Hk. & Grev.) Spr. Var. *roxburghii*	Selaginellaceae	h	a	epl	3	rocks in mxf, egf, eg/bb cliffs	ls	1300	1400	sp-nv	sp-nv	my-dc	sporangia
Selaginella tenuifolia Spr.	Selaginellaceae	h	a	gro	3	egf, da	gr	900	1450	sp-nv	sp-nv	my-dc	sporangia
Sphenomeris chinensis (L.) Maxon var.*chinensis*	Lindsaeaceae	h	pe	gro	3	egf,da	gr	1100	1400	ja-dc	ja-dc	ja-dc	sori
Stereophyllum	Plagiotheciaceae	h	pe	epi	3	egf, eg/pine	gr	900	1200	jl-sp	jl-sp	ja-dc	capsules
Targionia hypophilla L.	Targioniaceae	h	pe	epl	3	rocks in egf, cliffs	ls	1300	1425			ja-dc	
Tectaria decurrens (Presl) Copel.	Dryopteridaceae	h	pe	gro	3	streams in egf	gr, ls	1100	1300	dc-fb	dc-fb	ja-dc	sori
Tectaria herpetocaulos Holtt.	Dryopteridaceae	h	pe	gro	3	egf, eg/bb	gr, ls	550	1375	sp-nv	sp-nv	ja-dc	sori
Thelypteris nudata (Roxb.) Mort. var. *nudata*	Thelypteridaceae	h	pe	gro	3	mostly streams, wet areas in eg/bb, egf	gr, ls	1100	1500	jl-oc	jl-oc	ja-dc	sori
Thelypteris parasitica (L.) Fosb.	Thelypteridaceae	h	pe	gro	3	egf,da,sg	gr	1100	1500	ja-dc	ja-dc	ja-dc	sori

Table 3 (continued)

Thelypteris subelata (Bak.) K. Iw.	Thelypteridaceae	h	pe	gro	3	egf,eg/bb	ls	1125	1400	sp-nv	sp-nv	ja-dc	sori
Thelypteris terminans (Hk.) Tag. & K. Iw.	Thelypteridaceae	h	pe	gro	3	eg/bb	gr,ls	800	1250	ag-dc	ag-dc	ja-dc	sori
Thelypteris truncate (Poir.) K. Iw.	Thelypteridaceae	h	pe	gro	2	streams in egf, eg/bb	gr	1000	1200	ja-dc	ja-dc	ja-dc	sori
Thuidium orientale Mitt. *ex* Dix.	Thuidiaceae	h	pe	epi	3	mxf, egf, cliffs	ls	1200	1400			ja-dc	
Woodwardia japonica (L. f.) Sm.	Blechnaceae	h	pe	gro	2,3	eg/bb, egf	gr, ls	1100	1400	jl-dc	jl-dc	ja-dc	sori

Table 4. List of plant species (dicot) arranged in morphological family order under phylum angiospermae surveyed at Doi Tung, Chiang Rai Province

Species	Family	Habit	Aped	Life mode	Abundance	Habitat	Bedrock	Lower	Upper	Flowering	Fruiting	Leafing	Collected
								Elevation (m)		Months			
Clematis eichleri (Tam.) Tam.	Ranunculaceae	v	pd	gro	2	da,sg	gr	1000	1100	nv-dc		my-dc	flowers
Clematis fulvicoma Rehd. & Wils.	Ranunculaceae	wc, v	pd	epl, gro	3	rocks in mxf cliffs	ls	1375	1425	sp-oc	oc-nv	my-dc	flowers, fruits
Clematis thaimontana Tam.	Ranunculaceae	v	pd	gro	2	streams in mxf da sg	ls	700	800	ja-dc	fb	jn-fb	fruits
Dillenia parviflora Griff. var. *kerrii* (Craib) Hoogl.	Dilleniaceae	t	pd	gro	3	egf, eg/bb, da	gr	1000	1500	ja	ap-jn	my-dc	fruits
Magnolia lilifera (L.) Baill. var. *obovata* (Korth.) Gov.	Magnoliaceae	t	pe	gro	3	streams in mxf, egf	gr, ls	550	1300	mr-my		ja-dc	flowers
Michelia baillonii Pierre	Magnoliaceae	t	pd	gro	3	egf, eg/bb	gr	1000	1300	my-jn	ap-my	my-dc	flowers, fruits
Michelia champaca L. var. *champaca*	Magnoliaceae	t	pe	gro	2	egf	gr	1000	1400	ap-my	my-jn	ja-dc	fruits
Desmos (Dasymaschalon yunnanense (Hu) Ban)	Annonaceae	t,l	pe	gro	3	egf	ls	1200	1400	my-jn	oc-nv	ja -dc	flowers, fruits
Fissistigma oblongum (Craib) Merr.	Annonaceae	wc	pe	gro	2	egf, eg/pine	gr	900	1100			ja-dc	

Table 4 (continued)

Goniothalamus cheliensis Hu	Annonaceae	t, l	pe	gro	2	streams, wet areas in egf	gr, ls		1325			ja-dc	
Miliusa cuneata Craib	Annonaceae	l	pe	gro	2	streams in egf	ls	1200	1400	my-nv	nv	ja-dc	flowers
Miliusa thorelii Fin. & Gagnep.	Annonaceae	l	pe	gro	2	streams in bb/df, mxf	gr	500	700	oc		ja-dc	flowers
Mitrephora wangii Hu	Annonaceae	t	pe	gro	3	egf	ls	1200	1425	(dc) fb-mr	jl-sp	ja-dc	flowers, fruits
Orophea polycarpa A.DC.	Annonaceae	l	pe	gro	3	streams in mxf	ls	600	800	ja-fb		ja-dc	flowers
Aspidocarya uvifera Hk. f. & Th.	Menispermaceae	v	pe	gro	2	streams in eg/bb	gr	1200	1300	my-jn		ja-dc	flowers♂
Cyclea polypetala Dunn	Menispermaceae	wc	pe	gro	3	egf, eg/bb	gr, ls	1000	1400	nv-mr	ap-my	ja-dc	flowers ♂ fruits
Parabaena sagittata Miers *ex* Hk. f. & Th.	Menispermaceae	v	pe	gro	3	rocks in mxf, streams in egf, eg/bb	ls	500	1400	my-jn	sp-nv	ja-dc	flowers, fruits
Pericampylus glaucus (Lmk.) Merr.	Menispermaceae	v	pe	gro	3	egf, da	gr	1100	1400	mr-ap	jl-ag	ja-dc	flowers♀, fruits
Stephania elegans Hk.f. & Th.	Menispermaceae	v	a	gro	3	rocks in egf, mxf cliffs	ls	1300	1425	oc	oc-nv	my-dc	fruits♂
Stephania japonica (Thunb.) Miers var. *discolor* (Bl.) For.	Menispermaceae	v	a	gro	3	egf, eg/bb, da	gr	1000	1300	my-ag		my-dc	flowers♂
Stephania oblata Craib	Menispermaceae	wc	pd	epl	3	rocks in mxf, eg/bb cliffs	ls	1200	1425	ap	jn-jl	my-dc	flowers♂, fruits
Tinomiscium petiolare Hk. f. & Th.	Menispermaceae	wc	pe	gro	2	streams in egf, eg/bb, mxf	gr, sh	600	1200	my-jn	sp-oc	ja-dc	
Tinospora sinensis (Lour.) Merr.	Menispermaceae	v	pd	epl	3	rocks in mxf, cliffs	ls	1100	1425	ja-fb	ap-my	my-dc	
Cardamine hirsuta L.	Cruciferae	h	a	gro, wee	2	da, sg	ls	1300	1375	oc	nv	my-dc	flowers
Rorippa indica (L.) Hiern	Cruciferae	h	a	epl	2	rocks in eg/pine	gr	1450	1500	ag	sp-oc	jn-nv	fruits
Capparis assamica Hk.f. & Th.	Capparaceae	l	pe	gro	2	eg/bb	ls	1200	1300	ap		ja-dc	flowers
Capparis sabifolia Hk.f. & Th.	Capparaceae	l	pe	gro	3	rocks in mxf, cliffs	ls	1350	1400	ap		ja-dc	flowers
Rinorea ? macrophylla (Decne.) O.K.	Violaceae	l	pe	gro	2	steams in mxf	ls	550	650	ag-sp	sp-oc	ja-dc	flowers, imm fruits

Table 4 (continued)

Polygala chinensis L.	Polygalaceae	h	a	gro	2	bb/df, eg/pine	gr	800	1375	my-jl	jl-sp	my-dc	flowers
Polygala persicariifolia DC.	Polygalaceae	h	a	gro	3	eg/pine, eg/bb, da	ls	1200	1400	sp-oc	oc-nv	my-dc	flowers
Polygala umbonata Craib	Polygalaceae	h	a	gro, epl	2	rocks, cliffs, mxf, eg/bb	ls	1300	1425	ag-dc	sp-ja	my-ja	flowers
Salomonia cantoniensis Lour.	Ploygalaceae	h	a	gro	3	egf, eg/pine, da	gr	1000	1400	sp-nv	oc-dc	my-dc	flowers
Xanthophyllum virens Roxb.	Polygalaceae	t	pe	gro	2	egf, eg/bb	gr	950	1200	mr-ap	ja-ag	ja-dc	
Calophyllum polyanthum Wall *ex* Pl. & Tr.	Guttiferae	t	pe	gro	3	egf	gr	1100	1500			ja-dc	
Garcinia cowa Roxb.	Guttiferae	t	pe	gro	3	mxf, egf, eg/bb	gr,ls	1200	1375	ap	sp	ja-dc	flowers♀
Garcinia propinqua Craib	Guttiferae	t	pe	gro	3	rocks in egf, eg/bb cliffs	ls	1350	1375	my-jn		ja-dc	flowers♂
Garcinia xanthochymus Hk. f. *ex* T. And.	Guttierae	t	pe	gro, epl	3	bb/df, eg/bb	gr,ls, sh	500	900			ja-dc	
Mammea	Guttiferae	t	pe	gro	3	mxf, egf	ls	425	1400		my-jn	ja-dc	fruits
Cratoxylum cochinchinense (Lour.) Bl.	Guttiferae, Hypericeae	t	pd	gro	3	egf,da,sg	gr	1000	1300	ap-my	oc-dc	my-dc	flowers, fruits
Cratoxylum formosum (Jack) Dyer ssp. *pruniflorum* (Kurz) Gog.	Guttiferae, Hypericeae	t	pd	gro	3	eg/bb, da, sg	gr	500	1100	ap		my-dc	
Hypericum henryi H. Lev. & Van. ssp. *hancockii* H. Rob.	Guttiferae, Hypericeae	s	pe	epl	2	rocks in egf, cliffs	ls	1300	1400	oc	dc-fb	ja-dc	fruits
Hypericum japonicum Thunb. *ex* Murr.	Guttiferae, Hypericeae	h	a	gro	3	wet areas in da, egf	gr	900	1050	ap-my	ap-my	my-dc	flowers, fruits
Casearia graveolens Dalz.	Flacourtiaceae	t	ped	gro	3	mxf, egf	gr,ls	1200	1400	my-jn	my-jn	ja-dc	flowers, fruits
Casearia grewiifolia Vent. var *gelonioides* (Bl.) Sleum.	Flacourtiaceae	t	pe	gro	3	egf	gr	1000	1550	mr-ap	jn-jl	ja-dc	fruits
Flacourtia indica (Burm.f.) Merr.	Flacourtiaceae	t	pe	gro	3	egf, da ,sg	gr	900	1500		jl-ag	ja-dc	fruits
Homalium ceylanicum (Gardn.) Bth.	Flacourtiaceae	t	pd	gro	2	egf, eg/bb	gr	1000	1200	jl-ag		my-fb	flowers
Anneslea fragrans Wall.	Theaceae	t	pe	gro	3	egf, eg/pine	gr	1200	1450	nv-dc	ap*my	ja-dc	flowers
Camellia sinensis (L.) O.K. var. *assamica* (Mast.) Kita.	Theaceae	l	pe	gro also cul	2	streams in egf	gr	1100	1400	oc		ja-dc	flowers
Eurya acuminata DC. var. *wallichiana* Dyer	Theaceae	t	pe	gro	3	da,sg in egf	gr	1000	1500	nv-dc	ja-fb	ja-dc	flowers, fruits

Table 4 (continued)

Pyrenaria garrettiana Craib	Theaceae	t	pe	gro	3	egf	gr	1100	1400		jn-jl	ja-dc	
Schima wallichii (DC.) Korth.	Theaceae	t	pe	gro	4	egf	gr	700	1525	ap-my	dc-mr	ja-dc often changing lvs dc-ja	flowers, fruits
Ternstroemia gymnanthera (Wight & Arn.) Bedd.	Theaceae	t	pe	gro	3	egf, eg/pine	gr	1200	1400	my-jn	oc	ja-dc	flowers, fruits
Saurauia roxburghii Wall.	Saurauiaceae	t	pe	gro	3	egf eg/pine eg/bb	gr	1000	1500	ja-dc	ja-dc	ja-dc	flowers
Saurauia nepaulensis DC.	Saurauiaceae	t	pe	gro	3	egf,da,sg	gr,ls	1100	1400	my-jn		ja-dc	flowers
Hopea odorata Roxb. var. *odorata*	Dipterocarpaceae	t	pe	gro	2	egf	ss	900	1000	fb-mr		ja-dc	flowers
Shorea roxburghii G. Don	Dipterocarpaceae	t	pd	gro	2	bb/df, eg/bb	gr	750	1100	fb		my-fb	
Abelmoschus moschatus Medic. ssp. *moschatus* var. *moschatus*	Malvaceae	h	a	gro	2	da, sg	gr	1000	1200	oc		my-dc	
Dicellostyles zizyphifolia (Griff.) Phup.	Malvaceae	t	pe	gro	3	rocks in mxf	ls	1300	1400		nv-dc	ja-dc	fruits
Hibiscus macrophyllus Roxb.*ex* Horn.	Malvaceae	t	pe	gro	3	egf, da, sg	gr, ls	900	1400	mr-ap		ja-dc	
Kydia calycina Roxb.	Malvaceae	t	pd	gro	3	da sg	gr	750	1500	oc-nv		my-dc	flowers
Sida rhombifolia L. ssp. *rhombifolia*	Malvaceae	h	pe	gro, wee	3	da, sg	gr, ls	400	1500	sp-fb	ja-mr	ja-dc	flowers
Thespesia lampas (Cav.) Dalz. & Gibs. var. *lampas*	Malvaceae	l	pd	gro	2	eg/bb, da, sg	gr	525	1200	oc		my-dc	
Urena lobata L. ssp. *lobata* var. *lobata*	Malvaceae	h	a	gro, wee	3	da, sg	gr,ls, sh,ss	500	1500	oc-dc	nv-fb	my-dc	
Bombax anceps Pierre var. *anceps*	Bombacaceae	t	pd	gro	3	bb/df, eg/bb	gr	400	1000	ja-fb		my-dc	
Bombax insigne Wall.	Bombaceae	t	pd	gro	2	eg/bb, da, sg	gr	400	900	ja-fb	mr-ap	my-nv	
Byttneria aspera Colebr.	Sterculiaceae	wc	pe	gro	3	streams in mxf, da	gr, ls	500	1500	oc-nv		ja-dc	flowers
Eriolaena candollei Wall.	Sterculiaceae	t	pd	gro	3	egf ,eg/pine, da ,sg	gr	1200	1500		dc-fb	jn-fb	fruits
Firmiana colorata (Roxb.) R. Br.	Sterculiaceae	t	pd	gro	3	rocks, cliffs	gr, ls	1000	1425	ja-mr	mr-ap	jn-dc	flowers, leaves
Firmiana kerrii (Craib) Kosterm.	Sterculiaceae	l	pd	gro	2	rocks in mxf cliffs	ls	1350	1425	ja-fb	ap	jn-dc	flowers, leaves
Helicteres elongata Wall. *ex* Boj.	Sterculiaceae	s,l	pd	gro	3	eg/bb	gr	1000	1400	my-jn		ap-dc	flowers
Heriteria macrophylla Wall. *ex* Kurz	Sterculiaceae	t	pe	gro	2	eg/bb, egf	ls	1200	1400	mr-ap		ja-dc	seedling, flowers
Pterospermum grande Craib	Sterculiaceae	t	pe	gro	2	da	gr, ls	1250	1375	my		ja-dc	flowers

Table 4 (continued)

Pterospermum grandiflorum Craib	Sterculiaceae	t	pe	gro	3	streams in mxf, egf	ls	550	1000			ja-dc	
Pterospermum semisagittatum B.-H. *ex* Roxb.	Sterculiaceae	t	pe	gro	2	eg/bb	gr	800	1000	my		ja-dc	flowers
Sterculia balanghas L.	Sterculiaceae	t	pd	gro	3	egf, eg/pine	gr	1000	1500			fb-dc	
Sterculia guttata Roxb.	Sterculiaceae	l	pd	gro	2	rocks in mxf	ls	1300	1425	fb-mr		mr-nv	flowers
Sterculia lanceolata Cav. var. *lanceolata*	Sterculiaceae	l	pe	gro	3	egf, mxf	ls	550	1350	sp-nv	my-sp	ja-dc	flowers, fruits
Sterculia lanceolata Cav. var.*principis (*Gagnep.) Pheng.	Sterculiaceae	l	pe	gro	3	egf, eg/bb, bb/df	gr	1000	1400		my-jn	ja-dc	fruits
Sterculia pexa Pierre	Sterculiaceae	t	pd	gro	3	mxf,da,sg	gr, ls	400	1000	dc-ja	fb-mr	my-dc	
Sterculia villosa Roxb.	Sterculiaceae	t	pd	gro	3	rocks in mxf, bb/df cliffs	ls	600	1425	ja-fb		ap-dc	flowers
Colona flagrocarpa (Cl.) Craib	Tiliaceae	t	pd	gro	3	eg/bb	gr	900	1400		ja fb	my-fb	fruits
Colona floribunda (Kurz) Craib	Tiliaceae	t	pd	gro	3	egf,da,sg	gr	600	1300	oc	nv-dc	my-dc	fruits
Grewia lacei Drum. & Craib	Tiliaceae	s	pd	gro	3	eg/bb, da	ls	1000	1400	sp-oc		my-dc	flowers
Microcos paniculata L.	Tiliaceae	t	pe	gro	3	eg/bb, da, sg	gr, ls	500	900			ja-dc	
Triumfetta annua L.	Tiliaceae	h	a	gro, wee	3	da	gr, ls	1000	1500	sp-nv	nv-dc	my-dc	flowers
Triumfetta pilosa Roth	Tiliaceae	h	a	gro	3	eg/bb, da	gr	1000	1525	sp-nv	ja-fb	ag-fb	fruits
Triumfetta rhomboidea L.	Tiliaceae	h	a	gro, wee	3	da, sg	gr,ls, sh,ss	500	900		nv-dc	my-dc	
Elaeocarpus floribundus Bl. var. *floribundus*	Elaeocarpaceae	t	pe	gro	3	eg/bb, egf	gr,ls	1000	1400	my-jn	sp-oc	ja-dc	flowers, fruits
Elaeocarpus lanceifolius Roxb.	Elaeocarpaceae	t	pe	gro	3	mxf,egf	gr,ls	1000	1400	ap-jn	nv-dc	ja-dc	post
Elaeocarpus stipularis Bl.	Elaeocarpaceae	t	pe	gro	3	egf, eg/bb	gr,ls	900	1400	my-jn	sp-oc	ja-dc	flowers, fruits
Reinwardtia indica Dum.	Linaceae	h	pd	gro	3	egf,eg/bb da	gr, ls	1100	1500	nv-dc (fb)	ja-fb	ja-dc	flowers, fruits
Tirpitzia bilocularis Suks. & K. Lar.	Linaceae	h	pd	gro	2	rocks in mxf, da cliffs	ls	1200	1300	ag-sp	ja-fb	jn-fb	flowers
Aspidopterys nutans (Roxb. *ex* DC.) Juss.	Malpighiaceae	wc	pe	gro	2	da in mxf	gr	600	700	oc-nv	mr-ap	ja-dc	
Aspidopterys (aff. *thorelii* Dop)	Malpighiaceae	wc	pe	gro	3	rocks in mxf cliffs	ls	1375	1425	sp-oc	oc-nv	ja-dc	flowers
Hiptage bullata Craib	Malpighiaceae	sc	pe	gro	3	rocks in mxf cliffs	ls	1300	1400	ap-my		ja-dc	flowers
Oxalis corniculata L.	Oxalidaceae	h	a	gro, wee	3	eg/bb,da, sg	gr,ls	900	1400	(fb) my-oc	jn-nv	ap-dc	flowers, fruits

Table 4 (continued)

Impatiens claviger Hk. f.	Balsaminaceae	h	pe	gro	3	streams, wet areas in egf	gr,ls	1200	1350	oc-nv	nv-dc	ja-dc	flowers
Impatiens kerriae Craib	Balsaminaceae	h	pd	epl	3	rocks in mxf cliffs	ls	1375	1425	my-nv	nv-dc	my-dc	flowers
Impatiens salangensis T. Shim.	Balsaminaceae	h	a	epl	3	rocks in mxf	ls	1400	1425	jl-dc	sp-ja	my-dc	flowers
Impatiens vioaeflora Hk.f.	Balsaminaceae	h	a	gro	3	egf, eg/bb	gr	1000	1525	ag-dc	sp-dc	my-dc	
Boenninghauseana albiflora (Hk.) Roxb. *ex* Meissn.	Rutaceae	s	pd	epl	2	cliffs, rocks in egf	ls	1300	1400	oc	nv-dc	my-dc	flowers, fruits
Glycosmis cochinchinensis (Lour.) Pierre *ex* Engl.	Rutaceae	l	pe	gro	3	rocks in mxf	ls	1200	1425	ja-fb	ag	ja-dc	flowers
Micromelum hirsutum Oliv.	Rutaceae	t	pe	gro	3	egf, eg/bb	gr,ls	1100	1500	ja-fb	mr-jn	ja-dc	flowers, fruits
Micromelum minutum (Forst. f.) Wight & Arn.	Rutaceae	l,s	pe	gro	3	rocks in egf , mxf, cliffs, eg/bb	gr,ls	1000	1500	oc-mr	dc-jl	ja-dc	flowers
Melicope pteleifolia (Champ. *ex* Bth.)T.Hart.	Rutaceae	l,s	pe	gro	3	egf, da, sg	gr, ls	1100	1500	mr-ap	jn-jl	ja-dc	flowers, fruits
Melicope viticina (Wall. *ex* Kurz) T. Hart.	Rutaceae	s	pe	gro	2	eg/bb, eg/pine	gr	1100	1400		my-jn	ja-dc	fruits
Paramignya scandens (Griff.) Craib var. *scandens*	Rutaceae	wc	pe	gro	2	streams in egf	gr,ls	1000	1325	fb-mr	oc-dc	ja-dc	
Tetradium glabrifolium (Champ.*ex* Bth.) T.Hart.	Rutaceae	t,s	pe	gro	3	egf, da	gr,ls	1000	1375	my-jl	jl-oc	ja-dc	flowers♂♀, fruits
Toddalia asiatica (L.) Lmk.	Rutaceae	wc	pe	gro	3	egf eg/bb	gr	1000	1400		ap-my	ja-dc	fruits
Zanthoxylum oxyphyllum Edgew.	Rutaceae	wc	pe	gro	3	egf	ls	1200	1350	ja		ja-dc	
Brucea javanica (L.) Merr.	Simaroubaceae	l	pd	gro	3	rocks in mxf cliffs	ls	1200	1425	fb-mr	sp-dc	mr-dc	flowers, fruits
Picrasma javanica Bl.	Simaroubaceae	t, l	pe	gro	3	streams in mxf, egf	ls	500	1300	ap-nv	ag-sp	ja-dc	flowers
Garuga pinnata Roxb.	Burseraceae	t	pd	gro	3	eg/bb, da, sg	ls	500	1350			my-dc	
Protium serratum (Wall. *ex* Colebr.) Engl.	Burseraceae	t	pe	gro	3	egf	gr	1000	1400		jl-ag	ja-dc	fruits
Agalia elliptica Bl.	Meliaceae	t	pe	gro	2	egf	ls	1200	1400		ja-fb, my-jn	ja-dc	fruits
Aglaia lawii (Wight) Sald. *ex* Rama.	Meliaceae	t, l	pe	gro	3	mxf, egf, eg/bb	ls	1200	1400	sp	ap-my	ja-dc	flowers, fruits
Aglaia spectabilis (Miq.) Jain & Benn.	Meliaceae	t	pe	gro	3	streams in egf, eg/bb	gr	1100	1300	jl-ag		ja-dc	flowers

Table 4 (continued)

Agalia	Meliaceae	t	pe	gro	2	rocks in egf, cliffs	ls	1350	1375			ja-dc	
Aphanamixis polystachya (Wall.) R.Parker	Meliaceae	t	pe	gro	3	egf, eg/bb	gr	1000	1400		ap-jn	ja-dc	fruits
Chisocheton cumingianus (C.DC.) Harms	Meliaceae	t	pe	gro	2	egf, eg/bb	gr	1000	1100	jl-ag		ja-dc	flowers
Cipadessa baccifera (Roth) Miq.	Meliaceae	t,l	ped	gro,epl	3	rocks and streams in mxf, eg/bb cliffs	ls	450	1425	ap-oc (dc)	fb-oc	ja-dc ap-dc	flowers, fruits
Heynea trijuga Roxb. *ex* Sims	Meliaceae	t,l	pe	gro	2	egf, eg/bb	gr	900	1200	fb-mr	nv-dc	ja-dc	fruits
Melia toonsenden Sieb. & Zucc.	Meliaceae	t	pd	gro	3	bb/df, eg/bb	gr, ls	500	1300		oc-fb	my-dc	
Anacolosa ilicoides Mast.	Olacaceae	t	pe	gro	2	egf	gr, ls	1100	1350	jn-sp	mr-my	ja-dc	
Erythropalum scandens Bl.	Olacaceae	wc	pe	gro	3	streams in mxf	ls	550	800	ag-sp		ja-dc	flowers
Iodes cirrhosa Turcz.	Icacinaceae	wc	pe	gro	2	egf, da, sg	gr	1000	1200		jl	ja-dc	fruits
Pittosporopsis kerrii Craib	Icacinaceae	l	pe	gro	2	mxf	gr	500	700	fb-ap	my-jn	ja-dc	fruits
Ilex umbellulata (Wall.) Loesn.	Aquifoliaceae	t	pe	gro	3	egf	gr, ls	1000	1400		jl	ja-dc	fruits
Celastrus hindisii Bth.	Celastraceae	wc	pe	gro	2	rocks in mxf cliffs	ls	1400	1425	my-jn	oc	ja-dc	flowers, fruits
Euonymus cochinchinensis Pierre	Celastraceae	l	pe	gro	3	egf	ls	1000	1400	fb-mr	oc-nv	ja-dc	fruits
Euonymus laxiflora Champ. *ex* Bth.	Celastraceae	s	pe	gro	2	rocks in egf cliffs	ls	1300	1375	jl-sp	oc-nv	ja-dc	fruits
Euonymus sootepensis Craib	Celastraceae	cr,v, wc	pe	gro	3	egf	ls	1100	1425	fb-mr	oc-nv	ja-dc	flowers, fruits
Glyptopetalum sclerocarpum Kurz	Celastraceae	l	pe	gro	3	egf	ls	1100	1375	ap-my	oc-nv	ja-dc	flowers, fruits
Maytenus (Gymnosporia stylosa Pierre var. *rectispinosa* Craib*)*	Celastraceae	sc	pe	gro	3	rocks in mxf	ls	1300	1375	my		ja-dc	flowers
Microtropis discolor (Wall.) Wall. *ex* Arn.	Celastraceae	l	pe	gro	2-3	streams in egf	gr,ls	1100	1325	fb-mr	oc-nv	ja-dc	flowers, fruits
Salacia chinensis L.	Celastraceae	l	pe	gro	2	streams in eg/bb	gr	900	1100	nv-dc	dc-ja	ja-dc	flowers
Berchemia floribunda (Wall.) Wall. *ex* Brongn.	Rhamnaceae	wc	pe	gro	3	streams in egf, eb/bb	gr	1000	1300		fb-mr	ja-dc	fruits
Gouania javanica Miq.	Rhamnaceae	wc	pd	gro	3	rocks in mxf cliffs	ls	1400	1425	sp	nv-dc	my-dc	flowers, fruits
Hovenia dulcis Thunb.	Rhamnaceae	t	pd	gro	2	egf, streams in eg/bb	gr	1200	1400			my-dc	

Table 4 (continued)

Sageretia cordifolia Tard.	Rhamnaceae	wc	pd	gro	3	rocks in mxf cliffs	ls	1375	1425	sp-oc	nv-dc	my-dc	flowers, fruits
Ziziphus ?attopensis Pierre	Rhamnaceae	wc	pe	gro	3	mxf, eg/bb	gr	500	700			ja-dc	
Ziziphus incurva Roxb.	Rhamnaceae	t	pe	gro	3	egf	ls	1200	1400	my-sp	oc-nv	ja-dc	
Ziziphus oenoplia (L.) Mill. var. *oenophia*	Rhamnaceae	wc	pd	gro	3	eg/bb, da, sg	gr	600	1150	mr-ap	oc-nv	my-fb	
Cayratia japonica (Thunb.) Gagnep.	Vitaceae	v	pd	gro	3	mxf streams, egf	ls	500	1425	jl-nv		my-dc	flowers
Cayratia pedata (Lour.) Juss.	Vitaceae	v	a	gro	2	rocks in mxf, da, sg, eg/bb cliffs	ls	1200	1425	jl ag	sp-oc	my-dc	flowers
Cayratia (*vide Cissus auriculata* (Roxb.) DC.)	Vitaceae	wc	pd	gro	3	da, sg	gr	1100	900		my-jn	my-dc	fruits
Cissus adnata (Wall. *ex* Wight & Arn.) Roxb.	Vitaceae	wc	pe	gro	3	egf, eg/pine, sg	gr	1000	1200	jl ag		ja-dc	flowers
Cissus convolvulacea Pl.	Vitaceae	v	ped	gro	3	streams in egf	ls	600	800		fb-mr	ja-dc	fruits
Cissus discolor Bl. var. *discolor*	Vitaceae	v	pe	gro	3	egf, da, eg/bb, mxf cliffs	gr, ls	550	1500	my-sp	oc-dc	ja-dc	flowers, fruits
Parthenocissus semicordata (Wall.) Pl.	Vitaceae	wc	pe	gro	2	rocks in mxf cliffs	ls	1200	1425	sp	ja-dc	ja-dc	fruits
Tetrastigma campylocarpum (Kurz) Planch.	Vitaceae	wc	pe	gro	2	eg/bb	gr	1200	1400	nv-dc	mr-ap	ja-dc	flowers♀
Tetrastigma cruciatum Craib & Gagnep.	Vitaceae	wc	pe	epl,gro	3	streams in bb/df, mxf cliffs	ls	500	1425	fb-ap	nv	ja-dc	flowers♀
Tetrastigma garrettii Gagnep.	Vitaceae	v	pe	gro	3	streams in egf, eg/bb	gr, ls	1000	1300	dc-ja	my-jn	ja-dc	flowers♀, fruits
Tetrastigma laoticum Gagnep.	Vitaceae	wc	pe	gro	2	eg/bb	gr, ls	1200	1350	ap	ag	ja-dc	flowers♀
Tetrastigma quadrangulum Gagnep & Craib	Vitaceae	wc	pe	gro	2	mxf, eg/bb	sh	500	700	oc		ja-dc	flowers♀
Leea indica (Burm.f.) Merr.	Leeaceae	s,l	pe	gro	3	egf, eg/bb	gr,ls	500	1500	my-jl	ag-sp	ja-dc	flowers, fruits
Allophyllus cobbe (L.) Raeus.	Sapindaceae	t,l	pe	gro	3	rocks in mxf, egf, eg/bb	ls	1200	1400	jl-nv	oc-fb	ja-dc	flowers, fruits
Didymocarpus longan Lour. ssp. *longan* var. *longan*	Sapindaceae	t	pe	gro	2	egf, eg/bb	gr	800	1200	mr-ap	jl-ag	ja-dc	
Harpullia arborea (Blanco) Radlk.	Sapindaceae	t	pd	gro	3	streams in mxf	ls	500	900	ja-fb		fb-dc	flowers

Table 4 (continued)

Harpullia cupanioides Roxb.	Sapindaceae	t	pe	gro	3	egf	ls	1100	1400	my-jn		ja-dc	flowers
Lepisanthes tetraphylla (Vahl) Radlk.	Sapindaceae	l	pe	gro	2	streams in egf, da	gr	900	1100		jn-jl	ja-dc	imm fruits
Mischocarpus pentapetalus (Roxb.) Radlk.	Sapindaceae	t	pe	gro	3	egf	gr	1000	1500	ja-mr	my	ja-dc	flowers, fruits
Nephelium hypolecum Kurz	Sapindaceae	t	pe	gro	3	egf, eg/bb	gr	950	1200	ja-fb		ja-dc	flowers
Nephelium lappaceum L. var. *pallens* (Hiern) Leenh.	Sapindaceae	t	pe	gro	2	egf	gr	900	1100		my-jn	ja-dc	fruits
Pometia pinnata J.R. & G.Forst.	Sapindaceae	t	pd	gro	2	streams in mxf, egf	gr, ls	550	1250			mr-dc	
Sapindus rarak DC.	Sapindaceae	t	pd	gro	2	egf, eg/bb	ls	1000	1375			my-dc	
Acer chiangdaoensis Santi.	Aceraceae	t	pd	gro, epl	3	rocks in mxf, egf cliffs	ls	1300	1425	my-jn	jl-fb	ja-nv	flowers, fruits
Aesculus assamica Griff.	Hippocastanaceae	t	pd	gro, cul	3	eg/pine da	ls	1300	1350	ap		fb-dc	flowers
Turpinia pomifera (Roxb.) Wall. *ex* DC.	Staphyleaeaceae	t	pe	gro	3	egf	gr, ls	900	1500	fb-mr	jn-oc	ja-dc	flowers, fruits
Meliosma pinnata (Roxb.) ssp. *barbulata* (Cufod.) Beus. *ex* Welz. var.*barbulata*	Sabiaceae	t	pe	gro	3	egf	gr	1000	1550	ap-my		ja-dc	flowers
Meliosma simplicifolia (Roxb.) Walp. ssp. *fordii* (Hemsl. *ex* Forb. & Hemsl.) Beus.	Sabiaceae	t	pe	gro	2	eg/bb, egf	ls	1200	1375			ja-dc	
Sabia limoniacea Wall. *ex* Hk.f. & Th..	Sabiaceae	wc	pe	gro	2	egf	ls	1200	1400	ja-fb		ja-dc	flowers
Mangifera caloneura Kurz	Anacardiaceae	t	pe	gro	2	streams in mxf, eg/bb	gr	550	1100	fb		ja-dc	
Rhus chinensis Mill.	Anacardiaceae	l	pd	gro	3	da sg	gr	900	1400	jl-oc	oc-nv	my-dc	fruits
Rhus rhetsoides Craib	Anacardiaceae	t	pd, pe	gro	3	egf	gr	1000	1300	ap	oc-nv	ja-dc	flowers♂, fruits
Rhus succedanea L.	Anacardiaceae	l,t	pd	gro	3	rocks in mxf cliffs	ls	1400	1425	jl-sp	oc-nv	jn-dc	flowers, fruits
Semecarpus cochinchinensis Engl.	Anacardiaceae	t	pe	gro	3	mxf, egf	gr, ls	525	1500	dc-mr	ap	ja-dc	flowers
Spondias axillaris Roxb.	Anacardiaceae	t	pd	gro	3	egf	gr, ls	1100	1400	ja-fb	sp-oc	mr-dc	flowers♂
Spondias pinnata (L. f.) Kurz	Anacardiaceae	t	pd	gro	3	bb/df	gr			mr-ap	jn-ag	my-dc	fruits
Rourea minor (Gaertn.) Leenh. ssp. *minor*	Connaraceae	wc	pe	gro	3	egf, eg/bb	gr	1000	1400		ap-my	ja-dc	fruits
Acacia megaladena Desv. var. *garrettii* Niels.	Leguminosae, Mimosoideae	wc	pd	gro	3	rocks in mxf cliffs	ls	1300	1425	ap-jn	ja-fb	ap-ja	flowers , fruits
Albizia chinensis (Osb.) Merr.	Leguminosae, Mimosoideae	t	pd	gro	3	da, sg, eb/bb	gr	750	1525	ap-jn	dc-fb	mr-ja	flowers , fruits

Table 4 (continued)

Albizia crassiramea Lace	Leguminosae, Mimosoideae	t	pd	gro	3	da, sg	gr	800	1100	ag-sp		fb-dc	flowers
Albizia lucidor (Steud.) I. Niels.	Leguminosae, Mimosoideae	t	pe	gro	2	eg/bb	gr	1000	1250			ja-dc	
Albizia odoratissima (L. f.) Bth.	Leguminosae, Mimosoideae	t	pe	gro	3	egf ,da ,sg	gr	1000	1550	ap-my		ja-dc	flowers
Archidendron clyperia (Jack) Niels. ssp. *clypearia* var. *clypearia*	Leguminosae, Mimosoideae	t	pe	gro	3	da, sg	gr, ls	1000	1400	fb-mr	ap-jn	ja-dc	
Entada rheedei Spreng. (ssp.*rheedei*)	Leguminosae, Mimosoideae	wc	pd	gro	3	egf	gr	900	1500	mr-ap	ja-jn	fb -dc	
Leucaena leucocephala (Lmk.) De Wit	Leguminosae, Mimosoideae	t, l	pe	gro, int, nat, wee	3	da, sg	gr	400	700			ja-dc	
Mimosa diplotricha C. Wrigt *ex* Sauv. var. *diplotricha*	Leguminosae, Mimosoideae	v	a	gro, int, nat, wee	3	da, sg	gr	400	1500	sp-oc		my-dc	
Mimosa pigra L.	Leguminosae, Mimosoideae	h	pe	gro, int, wee	3	da, sg	gr	400	1525	jl-sp		ja-dc	
Acrocarpus fraxinifolius Wight *ex* Arn.	Leguminosae, Caesalpinioideae	t	pd	gro	3	rocks in egf, cliffs	gr,ls	1000	1400	ja-fb	ap	ap-nv	
Afzelia xylocarpa (Kurz) Craib	Leguminosae, Caesalpinioideae	t	pd	gro	2	bb/df	gr,ls	500	700			my-dc	
Bauhinia ornata Kurz var. *kerrii* (Gagnep.) K. & S.S. Lar.	Leguminosae, Caesalpinioideae	wc	pe	gro	3	egf ,da	ss	900	1100	fb-mr		ja-dc	flowers
Bauhinia variegata L.	Leguminosae, Caesalpinioideae	t	pd	gro	3	eg/pine, eg/bb, bb/df	gr	650	1525	ja-fb		jn-fb	
Chamaecrista leschenaultiana (DC.) Deg.	Leguminosae, Caesalpinioideae	h	a	gro	3	eg/pine, da	gr	1200	1500	sp-oc		my-dc	flowers
Aeschynomene americana L.	Leguminosae, Papilionoideae	h	a	gro, int, nat, wee	3	da, sg	gr	400	1000	sp-oc	dc	my-dc	flowers
Afgekia fillipes (Dunn) Gees.	Leguminosae, Papilionoideae	wc	pd	gro	3	egf,eg/bb	gr	1000	1400	mr-ap	sp-oc	ap-ja	
Arachis pintoi Krap. & Greg.	Leguminosae, Papilionoideae	h	pe	gro,cul,int	3	da	gr	400	1100	ja-dc		ja-dc	flowers
Cajanus goensis Dalz.	Leguminosae, Papilionoideae	v	a	gro	3	egf ,eg/pine sg	gr	600	1400	fb-mr		my-ap	flowers
Callerya atropurpurea (Wall.) Schot	Leguminosae, Papilionoideae	t	pe	gro	2	egf, eg/bb	gr	1200	1300		ag-sp	ja-dc	

Table 4 (continued)

Calopogonium mucunoides Desv.	Leguminosae, Papilionoideae	v	a	gro	3	da, sg	gr	900	1200	oc-nv	dc-ja	my-dc	fruits
Cannvalia ensiformis (L.) A. DC.	Leguminosae, Papilionoideae	v	a	gro	3	da, sg	gr	1000	1200	oc-nv		my-ja	flowers
Crotalaria acicularis B.-H. *ex* Bth.	Leguminosae, Papilionoideae	h	a	gro, wee	3	eg/pine, eg/bb	gr	1100	1400	nv-dc	ja-fb	jn-mr	flowers
Crotalaria albida Hey. *ex* Roth	Leguminosae, Papilionoideae	h	a	gro	3	eg/pine, eg/bb	gr	900	1500	nv-dc	fb-mr	jn-mr	flowers
Crotalaria assamica Bth.	Leguminosae, Papilionoideae	h	a	gro	3	bb/df, da, sg	gr	500	800	oc-nv		my-fb	
Crotalaria bracteata Roxb. *ex* DC.	Leguminosae, Papilionoideae	h	a	gro, wee	3	eg/bb, da, sg	gr	900	1500	sp-oc		my-fb	
Crotalaria cytisoides Roxb. *ex* DC.	Leguminosae, Papilionoideae	l	pd	gro	3	eg/pine, eg/bb	gr	1200	1325		nv-ja	my-ja	fruits
Crotalaria dubia Grah. *ex* Bth.	Leguminosae, Papilionoideae	h	a	gro	3	eg/bb, da	gr	1000	1400	nv-dc	mr-ap	jn-mr	flowers
Crotalaria kurzii Baker *ex* Kurz	Leguminosae, Papilionoideae	h	a	gro	3	egf, eg/pine, eb/bb, da	gr	1200	1500	sp-oc		my-dc	flowers
Crotalaria pallida Ait.	Leguminosae, Papilionoideae	h	a	gro, wee	3	da, sg	gr	400	800	jn-oc		my-fb	
Cruddasia insignis Prain	Leguminosae, Papilionoideae	v	pe	gro	3	egf, eg/bb	gr	1100	1400	jl-sp		ja-dc	flowers
Dalbergia cana Grah. *ex* Kurz var. *cana*	Leguminosae, Papilionoideae	t	pd	gro	3	mxf ,egf	gr,ls	900	1350		my-jn	ap-dc	fruits
Dalbergia cultrata Grah. *ex* Bth.	Leguminosae, Papilionoideae	t	pd	gro	3	eg/bb, eg/pine da sg	gr, ls	800	1350	fb-mr	nv-dc	mr-dc	flowers, fruits
Dalbergia lanceolaria L.f. var. *lanceolaria*	Leguminosae, Papilionoideae	t	pd	gro	3	bb/df	gr	500	800	ap	jn	ap-dc	flowers
Dalbergia ovata Grah. *ex* Bth	Leguminosae, Papilionoideae	t	pe	gro	2	egf, eg/bb	gr	950	1350	ja-fb		ja-dc	flowers
Dalbergia rimosa Roxb.	Leguminosae, Papilionoideae	wc	pe	gro	3	egf, eg/bb	gr	1000	1500	my-jl		ja-dc	flowers
Dalbergia stipulacea Roxb.	Leguminosae, Papilionoideae	sc	pd	gro	3	egf,da	gr	1000	1500	ap-my	nv-dc	ja-dc	fruits
Derris tonkinensis Gagnep.	Leguminosae, Papilionoideae	wc	pd	epl	3	rocks in bb/df cliffs	ls	400	800			my-dc	
Desmodium heterocarpon (L.) DC. ssp. *heterocarpon* var. *heterocarpon*	Leguminosae, Papilionoideae	h	pe	gro	3	bb/df, eg/pine, eg/bb	gr	700	1400	sp-dc	oc-ja	ja-dc	flowers, fruits

Table 4 (continued)

Desmodium laxiflorum DC. ssp. *laxiflorum*	Leguminosae, Papilionoideae	h	pd	gro	3	bb/df, eg/bb	gr	1000	1400	oc-nv		my-ja	flowers
Desmodium motorium (Houtt.) Merr.	Leguminosae, Papilionoideae	h	a	gro	3	eg/bb, da	gr	1000	1300	oc-nv	nv-dc	jn-dc	fruits
Desmodium multiflorum DC.	Leguminosae, Papilionoideae	l	pd	gro	3	eg/bb, da, sg	gr	1000	1400		ja-fb	my-fb	fruits
Desmodium oblatum Baker *ex* Kurz	Leguminosae, Papilionoideae	l	pd	gro	2	eg/bb	gr	1000	1300	oc-dc	dc-ja	jn-ja	fruits
Desmodium repandum (Vahl) DC.	Leguminosae, Papilionoideae	v	pe	gro	3	da, sg	gr	1000	1525	oc-nv	dc-ja	ja-dc	flowers, fruits
Desmodium triflorum (L.) DC.	Leguminosae, Papilionoideae	h	pe	gro, wee	3	eg/pine, eg/bb, da, sg	gr	700	1400	oc-dc	ja-fb	ja-dc	flowers
Desmodium triquetrum (L.) DC. ssp. *triquetrum*	Leguminosae, Papilionoideae	l	pe	gro	3	da, eg/bb	gr, ls	1000	1350	oc-nv	dc-ja	ja-dc	flowers, fruits
Desmodium velutinum (Willd.) DC. ssp. *velutinum* var.*velutinum*	Leguminosae, Papilionoideae	s	pe	gro	3	egf,da,sg	gr	1000	1400	oc-dc	ja-dc	ja-dc	flowers
Dolichos trilobus L.	Leguminosae, Papilionoideae	v	a	gro	2	mxf, da, sg	gr, ls	1000	1450	ja-fb		jn-ap	fllowers
Erythrina stricta Roxb.	Leguminosae, Papilionoideae	t	pd	gro	3	mxf, da	ls , gr	1200	1400	ap		jn-dc	flowers
Erythrina subumbrans (Hassk.) Merr.	Leguminosae, Papilionoideae	t	pe	gro	3	streams in egf, eg/bb	gr, ls	550	1400	ja-fb		ja-dc	flowers
Flemingia sootepensis Craib	Leguminosae, Papilionoideae	l	pe	gro	3	mxf, eg/bb, da, sg	gr, ls	550	1400		ja-fb	ja-dc	fruits
Lespedeza parviflora Kurz	Leguminosae, Papilionoideae	l	pe	gro	3	eg/bb, da, sg	gr	1000	1500	nv-ja	ja-fb	ja-dc	fruits
Lespedeza sulcata (Schindl.) Craib	Leguminosae, Papilionoideae	l	pd	gro	3	rocks in mxf cliffs	ls	1100	1425	fb		my-ja	
Millettia pachycarpa Bth.	Leguminosae, Papilionoideae	wc	pd	gro	3	egf, eb/bb	gr	1100	1500			my-fb	
Mucuna bracteata A. DC.	Leguminosae, Papilionoideae	v	pe	gro	3	eg/bb, da, sg	gr	1000	1500	ja-fb		ja-dc	flowers
Mucuna interrupta Gagnep.	Leguminosae, Papilionoideae	wc	pe	gro	3	mxf, da, sg	ls	1200	1375	ap-sp	sp-oc	ja-dc	flowers, fruits
Mucuna macrocarpa Wall.	Leguminosae, Papilionoideae	wc	pe	gro	3	eg/bb	gr	400	1300	fb-mr	oc-dc	ja-dc	
Ormosia sumatrana (Miq.) Prain	Leguminosae, Papilionoideae	t	pe	gro	2	egf,eg/bb	gr	1050	1250		oc-nv	ja-dc	fruits

Table 4 (continued)

Phylacium majus Coll. & Hemsl.	Leguminosae, Papilionoideae	v	pe	gro	2	bb/df, eb/bb	gr	950	1200	oc	ja-fb	ja-dc	flowers,fruits
Pueraria alopecuroides Craib	Leguminosae, Papilionoideae	v	a	gro	3	da, sg	gr, ls	400	1525	ja-fb		jl-my	flowers
Pueraria montana (Lour.) Merr. var. *chinense* (Ohwi) Maes. & Alm.	Leguminosae, Papilionoideae	v	pe	gro	2	da, sg	gr	900	1225	sp-oc		ja-dc	flowers
Pueraria phaseolioides (Roxb.) Bth. var. *subspicata* (Bth.) Maes.	Leguminosae, Papilionoideae	v	pe	gro,wee	3	da, sg	gr	1000	1500	oc-nv	ja-fb	ja-dc	
Pueraria rigens Craib	Leguminosae, Papilionoideae	wc	pe	gro	3	egf, eg/pine	gr	1100	1450		dc-fb	ja-dc	fruits
Shuteria hirsuta Baker	Leguminosae, Papilionoideae	v	pe	gro	3	egf,da,sg	gr	1000	1300	nv-dc		ja-dc	flowers
Shuteria involucrata (Wall.) Wight & Arn. *var. involucrata*	Leguminosae, Papilionoideae	v	pd	gro	3	egf,da,sg, eg/pine	gr	1100	1500	oc-nv	dc-ja	ja-dc	flowers, fruits
Shuteria vestita Wight & Arn.	Leguminosae, Papilionoideae	v	a	gro	2	eg/bb	gr	1100	1300	dc-ja		my-fb	flowers
Sophora velutina Lindl.	Leguminosae, Papilionoideae	l	pe	gro	2	bb/df, mxf,cliffs	ls	1400	1425		nv-dc	ja-dc	fruits
Tephrosia kerrii Drum. & Craib	Leguminosae, Papilionoideae	l	pe	gro	3	eg/bb, da, sg	gr	1000	1300		ja-fb	ja-dc	fruits
Uraria poilanei Dy Phon	Leguminosae, Papilionoideae	s	pe	gro	2	egf,da,sg	gr	1050	1250	nv-dc		ja-dc	flowers
Vigna radiata (L.) Wilcz. var. *sublobata* (Roxb.) Verdc.	Leguminosae, Papilionoideae	v	a	gro	3	egf,da	gr	900	1100	oc-nv		my-dc	flowers
Docynia indica (Wall.) Decne.	Rosaceae	t	pe	gro, cul, int	2	egf, da	gr	1100	1350			ja-dc	
Eriobotrya salwinensis Hand.-Mazz.	Rosaceae	t	pe	gro	3	rocks in mxf cliffs	ls	1375	1425	nv-dc	fb	ja-dc	flowers, fruits
Prunus cerasoides Ham. *ex* D.Don	Rosaceae	t	pd	gro, cul	3	da, sg	gr, ls	1000	1375	ja-fb		ap-oc	flowers
Rubus blepharoneurus Card.	Rosaceae	sc	pe	gro	3	egf	gr,ls	1100	1500	ap-my	ap-my	ja-dc	flowers, fruits
Rubus dielsianus Focke	Rosaceae	v	a	gro	2	eg/bb	gr	1100	1250			jn-mr	
Rubus ellipticus J.E. Sm. forma *obcordatus* Franch.	Rosaceae	v	pe	gro	3	eg/bb, da	gr	1200	1525	dc-ja	fb-mr	ja-dc	
Dichroa febrifuga Lour.	Saxifragaceae	l	pe	gro	2	streams in eg/bb, egf	gr,ls	1200	1400	my-jn		ja-dc	flowers
Carallia brachiata (Lour.) Merr.	Rhizophoraceae	t	pe	gro	3	egf	gr,ls	1000	1500		ap-my	ja-dc	fruits
Anogeissus acuminata (Roxb. *ex* DC.) Guill.& Perr.	Combretaceae	t	pd	gro	3	bb/df, eg/bb	gr, ls	500	1200	ja-mr	ap-my	my-dc	

Table 4 (continued)

Combretum griffithii Heur. & M. A.	Combretaceae	wc	pd	epl	3	rocks in bb/df cliffs	ls	400	800	fb	mr-ap	my-dc	
Combretum latifolium Bl.	Combretaceae	wc	pd	gro	3	mxf, eb/bb, sg	sh	500	800	dc-ja	my-jn	jn-fb	flowers
Quisqualis indica L. var. *indica*	Combretaceae	wc	pe	gro	3	da, sg	gr	500	1150	ap-my	sp-oc	ja-dc	flowers, imm. fruits
Eugenia albiflora Duth. *ex* Kurz	Myrtaceae	t	pe	gro	3	eg/bb, eg/pine	gr	800	1500	fb-ap	jl-ag	ja-dc	
Eugenia formosa Wall.	Myrtaceae	t	pe	gro	3	streams in mxf	gr, ls	500	700	mr-ap	ag-sp	ja-dc	
Eugenia fruticosa (DC.) Roxb.	Myrtaceae	t	pe	gro	3	egf, eg/bb, da, sg	gr	900	1500	ap-my	my-jn	ja-dc	flowers, fruits
Eugenia megacarpa Craib	Myrtaceae	t	pe	gro	3	egf	ls	1100	1400	ja-fb	sp-oc	ja-dc	flowers
Psidium guajava L.	Myrtaceae	l	pe	gro,cul,int,nat	3	da, sg	gr	1000	1300	my-jn		ja-dc	flowers
Tristaniopsis burmanica (Griff.) Wils. & Wat. var. *rufescens* (Hance) Parn. & Lug.	Myrtaceae	t,l	pe	gro	2	eg/pine	gr	1250	1300	ja-fb	ap-my	ja-dc	flowers
Careya arborea Roxb.	Lecythidaceae	t	pd	gro	2	bb/df, eg/bb	gr	400	1500	mr-ap	my-jn	my-dc	
Memecylon umbellatum Burm.f.	Melastomataceae	l	pe	gro	2	rocks in mxf, eg/bb	ls	1200	1425	jl-ag	nv-ja	ja-dc	flowers
Melastoma malabathricum L. ssp. *malabathricum*	Melastomataceae	t, l	pe	gro	3	egf, da ,sg	gr	1000	1525	ja-my	jn-ag	ja-dc	flowers
Osbeckia stellata Ham. *ex* Ker-Gawl. var. *crinita* (Bth. *ex* Naud.) C. Han.	Melastomataceae	s	pe	gro	3	eg/bb, egf,da,sg	gr, ls	1100	1500	sp-dc	ja	ja-dc	flowers
Pseudodissochaeta septentrionalis (W.W.Sm.) Nayar	Melastomataceae	t, l	pe	gro	3	egf, eg/bb	gr	1000	1350	jl-ag	nv-dc	ja-dc	flowers, fruits
Sonerila erecta Jack	Melastomataceae	h	a	gro	3	egf, eg/bb da	gr	1125	1500	oc-nv	nv-dc	my-dc	flowers
Lagerstroemia tomentosa Presl	Lythraceae	t	pd	gro	3	bb/df, egf	gr	900	1100	ap	oc-nv	ap-dc	flowers
Lagerstromeia venusta Wall. *ex* Cl.	Lythraceae	t	pe	gro	3	eg/bb, sg	gr	800	1000	jn-jl	nv-dc	ja-dc	
Lagerstroemia villosa Wall. *ex* Kurz	Lythraceae	t	pd	gro	3	da, sg	gr	900	1500		oc-nv	my-fb	fruits
Duabanga grandiflora (Roxb. *ex* DC.) Walp.	Sonneratiaceae	t	pe	gro	3	eg/bb, egf	gr, ls	1000	1375	fb-ap		ja-dc	flowers
Adenia penangiana (Wall. ex G. Don) Wilde var. *parvifolia* (Pierre *ex* Gagnep.) Wilde	Passifloraceae	v	a	gro	2	da, sg	gr	1000	1150			my-dc	
Gomphogyne heterosperma (Wall.) Kurz	Cucurbitaceae	v	a	gro	3	cliffs, rocks in mxf, eg/bb, bb/df	ls	400	1425	sp-oc		my-dc	flowers♂

Table 4 (continued)

Gynostemma pentaphyllum (Thunb.) Mak.	Cucurbitaceae	v	a	gro	3	egf, da	gr, ls	1200	1375	my-jn		my-dc	flowers♂
Mormordica charantia L.	Cucurbitaceae	v	a	gro, wee	3	da	gr, ls	400	700	ag-oc	oc-nv	my-dc	flowers, fruits
Solena heterophylla Lour. ssp. *heterophylla*	Cucurbitaceae	v	a	gro	2	eg/bb, da, sg, eg/pine	gr	1000	1300			my-dc	
Thladiantha cordifolia (Bl.) Cogn.	Cucurbitaceae	v	a	gro	2	egf eg/pine da sg	gr	1350	1525	ja-dc	oc-nv	my-mr	flowers, fruits
Thladiantha hookeri Cl.	Cucurbitaceae	v	a	gro	2	eg/bb, da, sg	gr	1100	1300	my		my-dc	flowers♂
Trichosanthes kerrii Craib	Cucurbitaceae	v	a	gro	2	cliffs in bb/df, mxf	ls	1200	1350	my-oc	my-jn	ap-dc	flowers♂, fruits
Trichosanthes ovigera Bl.	Cucurbitaceae	v	a	gro	3	da,sg	gr	1000	1500	sp-nv		my-dc	flowers♂
Trichosanthes pubera Bl.spp.*rubriflos* (Thor.*ex* Cay.) Duy. & Prue. var. *rubriflos*	Cucurbitaceae	v	a	gro	3	bb/df, egf, eg/bb, da	gr, ls	400	1525	jn-oc	sp-oc	my-dc	flowers, fruits
Zehneria bodinieri (Lev.) Wilde & Duy.	Cucurbitaceae	v	a	gro	3	eg/bb, egf,da	gr, ls	900	1500	oc-dc	nv-ja	my-dc	flowers♂♀, fruits
Zehneria tenuispica Wilde & Duy.	Cucurbitaceae	v	a	gro	3	da, rocks and cliffs mxf, egf	gr, ls	1000	1425	sp-nv	nv-dc	my-dc	flowers♂♀, fruits
Begonia acetosella Craib	Begoniaceae	h	pe	gro, rhe	3	streams in egf, wet areas	gr, ls	900	1500	mr-ap	mr-my	ja-dc	flowers, fruits
Begonia cathcartii Hk..f. *ex* Hk. f. & Th.	Begoniaceae	h	pe	gro, epl	3	mostly streams in egf,eg/bb, rarely cliffs in egf on ls	gr, ls	1200	1375	sp-dc	nv-ja	ja-dc	flowers, fruits
Begonia putii Craib	Begoniaceae	h	pd	epl	2	rocks in mxf, egf cliffs	ls	600	1425	oc		jn-dc	flowers
Begonia sect.Uniplacentales Cl.	Begoniaceae	h	pd	epl	3	rocks and cliffs in mxf	ls	550	1375	sp-nv	nv-dc	my-dc	flowers
*Centella asiatica (*L.) Urb.	Umbelliferae	h,cr	pe	gro	3	egf, da, sg	gr	900	1500			ja-dc	
Coriandrum sativum L.	Umbelliferae	h	a	cul	3	da	gr	900	1100	oc-nv	nv-dc	my-dc	flowers
Heracleum barmanicum Kurz	Umbelliferae	h	pd	gro	3	rocks in mxf, eg/bb cliffs	ls	1375	1425	sp-nv	oc-nv	jl-dc	flowers
Hydrocotyle javanica Pont. *ex* Thunb.	Umbelliferae	h	pe	gro, cr	3	mostly wet areas in egf, da, eg/bb	gr,ls	1100	1400	jn-sp	jl-nv	ja-dc	flowers, fruits
Hydrocotyle sibthorpioides Lmk.	Umbelliferae	h	a	gro, wee	3	da, sg	gr	900	1500		ap-oc	my-dc	fruits

Table 4 (continued)

Oenanthe javancia (Bl.) DC.	Umbelliferae	h	a	gro	2	streams in egf, eb/bb	gr	600	1475	dc-ja		jn-mr	flowers
Peucedanum siamicum Craib	Umbelliferae	h	pd	gro	2	da, sg	gr	1500	1525	sp-oc		my-dc	flowers
Aralia thomsonii Seem. *ex* Cl.	Araliaceae	l	pe	gro	3	egf, da, sg	gr, ls	1000	1450	my-jn	jl-ag	ja-dc	flowers, fruits
Brassiopsis hainla (B.-H. *ex* D. Don) Seem.	Araliaceae	t, l	pd	gro	3	rocks in mxf cliffs	ls	1375	1425	nv-dc	ap	my-dc	flowers, fruits
Heteropanax fragrans (Roxb. *ex* DC.) Seem.	Araliaceae	l	pd	gro	2	da, sg	gr	900	1300			my-dc	
Macropanax dispermus (Bl.) O.K.	Araliaceae	t	pe	gro	3	egf	gr	1000	1400	ag-oc	dc-ja	ja-dc	flowers, fruits
Schefflera bengalensis Gamb.	Araliaceae	s	pe	epi, epl	3	egf	gr,ls	1000	1500	ap-my	my	ja-dc	flowers, fruits
Schefflera pueckleri (C. Koch) Frod.	Araliaceae	s	pe	epi	2	rocks in egf, cliffs	ls	1300	1375	jn-jl		ja-dc	
Schefflera ptelotii Merr.	Araliaceae	t ,l, s	pd	epl	3	rocks in mxf	ls	650	1400	ja-fb	fb-ap	my-ap	flowers, fruits
Trevesia palmata (DC.) Vis.	Araliaceae	l	pe	gro	3	mxf, egf	gr, ls	550	1500	fb-mr		ja-dc	
Alangium barbatum (R.Br.) Baill. var. *barbatum*	Alangiaceae	l	pe	gro	2	egf	ls	1100	1400	ap	sp-oc	ja-dc	flowers, fruits
Alangium chinense (Lour.) Harms	Alangiaceae	t	pd	gro	3	eg/bb, da, sg	gr, ls	550	700		nv	my-fb	
Alangium kurzii Craib	Alangiaceae	t	pd	gro	3	egf, da	gr,ls	600	1500	ap-my		ap-dc	flowers
Carlemannia tetragona Hk. f.	Caprifoliaceae	h	a	gro	2	streams in eg/bb, wet areas	gr	1200	1200	jl-ag	oc-nv	ap-dc	flowers, fruits
Sambucus javanica Reinw. *ex* Bl. ssp. *javanica*	Caprifoliaceae	s,l	pe	gro	3	eg/bb, egf, da, sg	gr,ls	1000	1525	jn-sp	sp-oc	ja-dc	fruits
Viburnum garrettii Craib	Caprifoliaceae	s,l	pe	gro	2	streams in egf, eg/bb	gr	1000	1100	jn-jl	oc	ja-dc	flowers, fruits
Vibunum odoratissimum Ker	Caprifoliaceae	sc	pe	gro	3	rocks in mxf cliffs	ls	1375	1425	dc-ja		ja-dc	flowers
Drymaria diandra Bl.	Caryophyllaceae	h	a	gro, wee	3	eg/pine, da, sg	gr	1100	1525	ag-fb	sp-fb	my-fb	flowers
Argostemma lobbii Hk. f.	Rubiaceae	h	a	epl	3	rocks in egf, eg/bb	ls	1200	1400	ja ag		my-dc	flowers

Table 4 (continued)

Argostemma verticillatum Wall.	Rubiaceae	h	pd	epl	3	rocks in mxf, eg/bb	ls	1200	1425	jn-jl	jl-ag	my-dc	flowers, fruits
Borreria alata (Aubl.) DC.	Rubiaceae	h	a	gro, wee	3	da, sg	gr	900	1400	jn-sp	ag-oc	my-dc	flowers
Borreria laevis (Lmk.) Griesb.	Rubiaceae	h	a	gro, wee	3	da, sg	gr, ls	1000	1375	my-nv	jn-dc	my-dc	flowers
Borreria repens DC.	Rubiaceae	h	a	gro	3	da,sg	gr	1000	1400	oc-nv	nv-dc	my-dc	flowers, fruits
Canthium parviflorum Roxb.	Rubiaceae	l	pd	gro	3	egf, da, eg/bb,eg/pi ne	gr,ls	1000	1525	(nv)ap-my	jn-dc	fb-dc	flowers, fruits
Catunaregam spathulifolia Tirv.	Rubiaceae	l	pd	gro	3	bb/df, eg/bb	gr	600	1400	my-jn	nv-dc	my-dc	
Clarkella nana (Edgew.) Hk. f. var. *nana*	Rubiaceae	h	a	epl	2	rocks in mxf, egf, eg/bb cliffs	ls	1375	1425	jl-sp	sp-oc	jn-dc	flowers, fruits
Duperrea pavettifolia (Kurz) Pit.	Rubiaceae	l	pe	gro	2	streams in egf	gr,ls	1000	1300	my-jl		ja-dc	flowers
Fagerlinidia	Rubiaceae	t, l	pe	gro	2	streams in egf	gr, ls	1200	1300	ap	ja-fb	ja-dc	flowers, fruits
Galium punduanum Wall. *ex* Craib	Rubiaceae	h	a	epl	2	rocks in egf cliffs	ls	1300	1400	oc-nv	dc	my-dc	flowers
Gardenia sootepensis Hutch.	Rubiaceae	t	pd	gro	3	bb/df, eg/bb	gr	900	1100	ap		my-dc	flowers
Hedyotis coronaria (Kurz) Craib	Rubiaceae	h	pd	gro	2	mxf, eg/bb	gr	800	1300	jn-ag		my-dc	flowers
Hedyotis corymbosa (L.) Lmk.	Rubiaceae	h	a	gro, wee	3	da, sg	gr	400	1200	sp-oc	oc-nv	ja-dc	flowers
Hedyotis elegans Wall. *ex* Kurz	Rubiaceae	h	pe	gro	3	eg/bb	gr	1000	1300		dc-ja	ja-dc	fruits
Hedyotis scandens Roxb.	Rubiaceae	v,h	pe	gro	3	wet areas egf, da	gr,ls	950	1150	oc-nv		ja-dc	flowers
Hymenodictyon orixense (Denn.) Mabb.	Rubiaceae	t	pe	gro	2	rocks in mxf, eg/bb	ls	1000	1425			my-dc	
Ixora cibdela Craib	Rubiaceae	l	pe	gro	3	egf, eg/bb	gr	900	1100		oc-nv	ja-dc	
Ixora rugosula Wall. *ex* Hk. f.	Rubiaceae	l, wc	pe	gro	2	eg/bb	ls	1275	1350	ap		ja-dc	flowers

Table 4 (continued)

Ixora	Rubiaceae	sc	pe	gro	2	streams in mxf	ls	550	600		sp	ja-dc	fruits
Lasianthus kurzii Hk. f.	Rubiaceae	l	pe	gro	2	streams in egf	gr	1000	1300	my-jn		ja-dc	flowers, imm fruits
Mitracarpus villosus (Sw.) DC.	Rubiaceae	h	a	gro, int, nat, wee	3	da, sg	gr	900	1500	sp-oc	nv	my-dc	
Mitragyna rotundifolia (Roxb.) O.K.	Rubiaceae	t	pd	gro	3	da, sg	gr	900	1200	sp-oc		ap-fb	flowers
Mussaenda dehiscens Craib	Rubiaceae	t	pe	gro	2	egf, eg/bb, da	gr	1000	1200	my-jl		ja-dc	flowers
Mussaenda kerrii Craib	Rubiaceae	s, l	pe	gro	2	streams in egf	gr	1000	1375	my-jn		ja-dc	flowers
Mussaenda parva Wall. *ex* G. Don	Rubiaceae	sc	pd	gro	3	rocks in mxf, eg/bb cliffs, da	gr,ls	1200	1425	my-sp	jn-jl	my-dc	flowers, fruits
Mussaenda sanderiana Ridl.	Rubiaceae	wc	pe	gro	3	egf,eg/pine, eg/bb,da,sg	gr	1000	1500	dc-ap		ja-dc	flowers
Mycetia glandulosa Craib	Rubiaceae	h	pe	gro	3	egf	gr, ls	1000	1500	ap-my	ap-my	ja-dc	flowers
Mycetia gracilis Craib	Rubiaceae	l	pe	gro	3	streams in mxf, egf	gr,ls	600	1350	oc-nv	ja-fb	ja-dc	flowers, fruits
Ophiorrhiza aff. *nutans* Cl. *ex* Hk. f.	Rubiaceae	h	pe	gro	2	egf	gr,ls	1100	1375	ap-jl	jn-ag	ja-dc	flowers, fruits
Ophiorrhiza pseudofasciculata Schan.	Rubiaceae	h	a	gro	3	eg/bb	gr	1200	1350	ag-sp	sp-oc	my-dc	flowers, fruits
Ophiorrhiza trichocarpon Bl. var. *trichocarpon*	Rubiaceae	h	pe	gro	3	egf, eg/bb	gr	1000	1400	my-jl(nv)	jn-ag(nv)	ja-dc	flowers
Paederia pallida Craib	Rubiaceae	v	a	gro	3	rocks in mxf,egf,da cliffs	gr,ls	1100	1500	sp-oc	nv-dc	my-dc	flowers, fruits
Pavetta tomentosa Roxb. *ex* Sm. var. *tomentosa*	Rubiaceae	l	pd	gro	3	egf, eg/bb	gr	900	1400	my	nv	my-dc	flowers, fruits
Psychotria monticola Kurz var. *monticola*	Rubiaceae	l,s	pe	gro	3	egf	gr, ls	1000	1500	ap-jn	dc-ja	ja-dc	flowers
Psychotria ophioxyloides Wall.	Rubiaceae	l	pe	gro	3	egf	gr, ls	1000	1500	ap-jn	dc-ja	ja-dc	flowers
Psychotria winitii Craib	Rubiaceae	h	pe	gro	3	egf	ls	1000	1400		oc-nv	ja-dc	fruits
Saprosma consimile Kurz	Rubiaceae	l	pe	gro	3	rocks in mxf, egf	ls	1200	1400	my		ja-dc	flowers

Table 4 (continued)

Tarenna elliptica Craib var. *elliptica*	Rubiaceae	l,s	pe	gro	3	streams in egf, rocks in mxf	gr,ls	1100	1400	jn	oc-nv	ja-dc	flowers, fruits
Tarenna vanprukii Craib var. *vanprukii*	Rubiaceae	t.l	pe	gro	3	rocks in mxf, cliffs	ls	1300	1425	my	oc-dc	ja-dc	
Tarennoidea wallichii (Hk, f.) Tirv. & Sastre	Rubiaceae	t	pe	gro	2	egf, eg/bb	gr	1200	1400			ja-dc	
Uncaria macrophylla Wall.	Rubiaceae	wc	pe	gro	3	streams in egf, eg/bb	gr	900	1300	sp-oc	nv-ja	ja-dc	
Wendlandia ternifolia Cow.	Rubiaceae	l	pe	epl	2	rocks in egf, cliffs	ls	1200	1400	dc-fb	fb	ja-dc	flowers, fruits
Wendlandia tinctoria (Roxb.) DC. ssp. *orientalis* (Craib) Cow.	Rubiaceae	t,l	pe	gro	3	egf,eg/pine, sg	gr	1000	1500	ja-fb		ja-dc	flowers, fruits
Ageratum conyzoides L.	Compositae	h	a	gro, wee	3	da, sg	gr,ls,ss	400	1525	jn-fb	ag-fb	my-fb	
Anaphalis adnata DC.	Compositae	h	a	gro	3	eg/pine, da, eg/bb	gr	1100	1325	oc-dc	nv-ja	my-ja	flowers, fruits
Anaphalis margaritacea (L.) Bth.	Compositae	h	a	gro	3	eg/pine, da	gr	1200	1325	sp-fb	oc-fb	my-fb	flowers
Artemisia indica Willd.	Compositae	h	pd	gro, wee	3	da, sg	gr,ls	1200	1525	sp-dc	nv-ja	my-dc	flowers
Bidens pilosa L.	Compositae	h	a	gro, wee	3	eg/pine, da, sg	gr	700	1525	my-oc	jn-nv	my-dc	
Blumea balsamifera (L.) DC.	Compositae	h	a	gro, wee	3	da, sg	gr	500	1500	ap-my	my-jn	ja-dc	flowers
Blumea lacera (Burm.f.) DC.	Compositae	h	a	gro	3	eg/bb	gr	1000	1500	ja-fb	fb-mr	jl-mr	flowers
Blumea napifolia DC.	Compositae	h	a	gro	3	eg/bb	gr	1000	1500	ja-fb	fb-mr	jn-mr	flowers
Blumeopsis flava (DC.) Gagnep.	Compositae	h	a	gro	3	egf,eg/bb da	gr	1000	1500	dc-ja	fb-mr	jn-mr	flowers
Conyza sumatrensis (Retz.) Walk.	Compositae	h	a	gro,int,nat,wee	3	da, sg	gr,ls,ss	400	1500	ja-dc	ja-dc	ja-dc	
Crassocephalum crepidioides (Bth.) S. Moore	Compositae	h	a	gro, wee	3	da, sg	gr, ls	900	1525	my-fb	jn-mr	my-mr	
Dichrocephala integrifolia (Lmk.) DC.	Compositae	h	a	gro, wee	3	egf, da	gr, ls	1200	1375	ap-jn	my-jn	ap-dc	flowers
Eclipta prostrata (L.) L.	Compositae	h	a	aqu,gro, wee	3	da	gr,ss	600	1500	my-ag	jn-sp	my-dc	flowers, fruits

Table 4 (continued)

Elephantopus scaber L. ssp. *scaber* var. *scaber*	Compositae	h	pe	gro, wee	3	da, sg	gr, ls	800	1500	sp-oc	nv	ja-dc	flowers
Emilla sonchifolia (L.) DC. *ex* Wight	Compositae	h	a	gro,wee	3	da, sg	gr,ss	500	1500	my-jl	jn-ag	my-nv	flowers, fruits
Eupatorium adenophorum Spreng.	Compositae	h	pe	gro, int,wee	4	da, sg	gr	600	1525	mr-ap	ap-my	ja-dc	
Eupatorium doichangensis H. Koy	Compositae	h	a	gro	2	bb/df, da	gr	1100	1200	ja-fb	mr	ag-dc	flowers
Eupatorium odoratum L.	Compositae	h	pe	gro, nat,wee	4	da,sg	gr,ls	400	1525	nv-dc	ja-fb	ja-dc	
Gochnatia decora (Kurz) Cabr.	Compositae	l	pd	gro	2	eg/pine, eg/bb	gr	1200	1375	mr	ap-my	ap-dc	
Gynura longifolia Kerr	Compositae	v	pd	gro	2	streams in egf, eg/bb	gr	1100	1300	fb		jn-mr	
Gynura nepalensis DC.	Compositae	h	a	gro	3	da, weed	gr,ls,ss	600	1525	my-jl	jn-ag	oc-sp	flowers, fruits
Inula cappa (Ham. *ex* D.Don) DC. forma cappa	Compositae	h	pd	gro	3	eg/bb,sg	gr,ls	900	1500	nv-dc	ja-dc	my-dc	flowers
Inula nervosa Wall. *ex* DC.	Compositae	h	a	epl	2	rocks in mxf, egf cliffs	ls	1200	1400	ja-fb	mr	jn-mr	flowers
Inula wissmanniana Hand.-Mazz.	Compositae	h	pd	gro	2	rodks in eg/pine, eg/bb cliffs	gr	1200	1425	dc-fb	mr	my-mr	flowers
Lactuca parishii Craib *ex* Hoss.	Compositae	h	pd	gro	3	eg/pine, eg/bb, da, sg	gr	1100	1400	ja-fb	fb-mr	jn-ap	flowers
Laggera alata (D. Don) Sch. Bip. *ex* Oliv.	Compositae	h	a	gro, wee	3	da, sg	gr	1100	1525			my-dc	
Laggera pterodonta (DC.) Sch. Bip *ex* Oliv.	Compositae	h	a	gro, wee	3	da	gr	600	1250			ag-mr	
Senecio scandens B.-H. *ex* D. Don	Compositae	sc	pd	gro	2	rocks in egf cliffs	ls	1400	1425	ja-fb	fb-mr	my-mr	flowers, fruits
Siegesbeckia orientalis L.	Compositae	h	a	gro,wee	3	da,sg	gr	1000	1450	oc-dc	nv-ja	jn-ja	
Sonchus wightianus DC. ssp. *wightianus*	Compositae	h	pe	gro, wee	3	weed, eg/pine, da, sg	gr	900	1525	ja-jn	fb-jl	ja-dc	flowers, fruits
Spilanthes paniculata Wall. *ex* DC.	Compositae	h	a	gro, wee	3	eg/pine, da, sg	gr,ls	1000	1525	sp-fb	nv-mr	my-mr	flowers
Synedrella nodiflora (L.) Gaertn.	Compositae	h	a	gro, wee	3	da, sg	gr,ls, sh	500	1500	oc-dc	nv-ja	my-fb	

Table 4 (continued)

Tithonia diversifolia (Hemsl.) A. Gray	Compositae	h	pe	gro, int, wee	3	da, sg	gr	550	1525	oc-dc		ja-dc	
Vernonia attenuata DC.	Compositae	l	pd	gro, epl	3	rocks in eg/bb, mxf cliffs	ls	1250	1425	oc-nv	nv-dc	my-dc	flowers
Vernonia cinerea (L.) Less. var. *cinerea*	Compositae	h	a	gro, wee	3	da, sg	gr,ls, sh,ss	700	1500	my-ja	jn-fb	my-fb	
Vernonia divergens (DC.) Edgew.	Compositae	h	pd	gro	3	egf eg/pine da sg	gr,ls	1200	1500	nv-dc	ja-fb	my-fb	flowers, fruits
Vernonia parishill Hk.f.	Compositae	l	pe	gro	3	egf		1100	1500	mr-ap	ap-my	ja-dc	fruits
Vernonia sutepensis Craib	Compositae	h	pe	gro	3	eg/bb	gr	1000	1500	ja-fb	fb-mr	ja-dc	flowers
Youngia japonica (L.) DC.	Compositae	h	a	gro, wee	3	eg/bb, da, eg/pine	gr,ls	500	1500	jn-dc	jl-ja	my-dc	flowers
Codonopsis javanica (Bl.) Hk. f.	Campanulaceae	v	pe	gro	2	eg/pine, eg/bb	gr	1100	1350	sp-oc		ja-dc	flowers
Lobelia alsinoides Lmk.	Campanulaceae	h	a	gro	3	eg/bb,da,sg , eg/pine	gr	1000	1325	oc	nv	my-dc	flowers
Lobelia zeylanica L.	Campanulaceae	h, cr	pe	gro	3	da in egf, eg/bb	gr,ls	1000	1500	jn-oc	jl-dc	ja-dc	flowers, fruits
Agapetes lobbii Cl.	Ericaceae	l	pe	epl , gro	3	rocks in mxf cliffs	ls	1375	1425	ja-fb		ja-dc	flowers
Agapetes megacarpa W.W. Sm.	Ericaceae	l	pe	epl	3	rocks in mxf cliffs	ls	1375	1425	oc-fb	ap	ja-dc	flowers
Craibiodendron stellatum (Pierre) W.W. Sm.	Ericaceae	t	pe	gro	3	eg/pine	gr	1200	1450			ja-dc	
Vaccinium sprengelii (D. Don) Sleum.	Ericaceae	t, l	pe	gro	3	eg/pine	gr	1200	1450	ja-fb		ja-dc	flowers
Plantago major L.	Plantaginaceae	h	pe	gro, wee	3	egf, da, sg	gr,ls	1200	1500	my-sp	jn-sp	ja-dc	flowers
Ardisia attenuata Wall.*ex* A. DC.	Myrsinaceae	l	pe	gro	2	rocks in mxf, egf cliffs	ls	1400	1425	ja-dc		ja-dc	flowers
Ardisia corymbifera Mez var. *corymbifera*	Myrsinaceae	l	pe	gro	3	egf	gr,ls	1000	1375	my-jn	oc-dc	ja-dc	flowers, fruits
Ardisia quinquegona Bl.	Myrsinaceae	l	pe	gro	3	streams in egf	gr,ls	1100	1350	ap	my-jl	ja-dc	fruits

Table 4 (continued)

Embelia sessiflora Kurz	Myrsinaceae	wc	pd	gro	3	eg/bb egf, da, sg	gr	650	1500	ap-my	jl	my-mr	flowers, imm. fruits
Maesa montana A. DC.	Myrsinaceae	s,l	pe	gro	3	egf,eg/pine da,sg, eg/bb	gr	1000	1500	ja-fb	nv-fb	ja-dc	flowers, fruits
Maesa permollis Kurz	Myrsinaceae	l	pe	gro	3	egf, streams in mxf	gr,ls	600	1500	ja-fb	ap-my	ja-dc	flowers, fruits
Maesa ramentacea (Roxb.) A. DC.	Myrsinaceae	t	pe	gro	3	da, sg	gr	950	1400	oc-fb		ja-dc	flowers
Myrsine semiserrata Wall.	Myrsinaceae	l	pe	gro	2	rocks in mxf, cliffs	ls	1200	1425	ja-fb		ja-dc	flowers♀
Rapanea yunnanensis Mez	Mysinaceae	t	pe	gro	2	eg/bb	gr	1100	1300		sp-oc	ja-dc	fruits
Palaquium garrettii Flet.	Sapotaceae	t	pe	gro	2	egf	gr	1000	1400	sp-oc		ja-dc	flowers
Sarcosperma arboreum Bth.	Sapotaceae	t	pe	gro	3	egf	gr	1000	1550	ja-fb	ap-my	ja-dc	flowers, fruits
Diospyros ferrea (Willd.) Bakh. var. *littorea* (R. Br.) Bakh.	Ebenaceae	t,l	pe	gro	3	rocks, cliffs in mxf	ls	1300	1425	my-jn		ja-dc	flowers♂
Diospyros lotus L.	Ebenaceae	t	pe	cul, int	2	egf	gr	1400	1400	fb-mr		ja-dc	native to Japan
Diospyros martabanica Cl.	Ebenaceae	t	pe	gro	3	egf	ls	1100	1400	fb-mr	my-jn	ja-dc	flowers, fruits
Diospyros winitii Flet.	Ebenaceae	t	pe	gro	3	egf, eg/bb	ls	1200	1375	ap	ap	ja-dc	flowers♂, fruits
Symplocos hookeri Cl.	Symplocaceae	t	pe	gro	2	streams, wet areas in egf	gr	1250	1325	oc-nv	ag-sp	ja-dc	
Symplocos macrophylla Wall. *ex* DC. ssp. *sulcata* (Kurz) Noot. var. *sulcata*	Symplocaceae	t	pe	gro	3	egf, eg/bb	gr	1000	1500	oc-nv	mr-ap	ja-dc	flowers
Styrax benzoides Craib	Styracaceae	t	pe	gro	3	egf, eb/bb,da,sg	gr	1000	1500	my-jn	oc-nv	ja-dc	flowers, fruits
Chionanthus ramiflorus Roxb.	Oleaceae	t	pe	gro	3	egf	ss	900	1100	fb-mr		ja-dc	flowers
Jasminum coarctatum Roxb. var. *vanprukii* (Craib) P. S. Green	Oleaceae	l,s,sc	pe	gro	2	rocks in egf	ls	1100	1350	jn-jl		ja-dc	flowers
Jasminum dispermum Wall. ssp. *forrestianum* (Kob.) P.S. Green	Oleaceae	s	pe	gro	2	rocks in egf	ls	1200	1400		ja dc	ja-dc	friuts

Table 4 (continued)

Jasminum funale Decne. *ssp.* funale	Oleaceae	wc	pe	gro	3	rocks in mxf cliffs	ls	1375	1425	ag-sp		ja-dc	flowers
Jasminum nervosum Lour.	Oleaceae	v	pe	gro	3	rocks in mxf, eg/bb	ls	1200	1400	my	my-jn	ja-dc	flowers, fruits
Olea rosea Craib	Oleaceae	t, l	pe	gro	2	da, sg	gr	1000	1100		oc-nv	ja-dc	fruits
Alstonia scholaris (L.) R.Br. var. *scholaris*	Apocynaceae	t	pd	gro	3	egf, da	gr	1000	1400	sp-oc		mr-dc	flowers
Amalocalyx microlobus Pierre *ex* Spire	Apocynaceae	v,wc	pe	gro	3	egf, eg/pine, da	gr	1000	1400	my-jl		ja-dc	flowers
Epigynum cochinchinensis (Pierre) Midd.	Apocynaceae	wc	pe	gro	3	streams in mxf	ls	550	700	ag-sp		ja-dc	flowers
Hunteria zeylanica (Retz.) Gard. *ex* Thw.	Apocynaceae	t	pe	gro	3	rocks in egf, cliffs	ls	1200	1375	my	ap-my	ap-dc	flowers, fruits
Ichnocarpus polyanthus (Bl.) P.I. Forst.	Apocynaceae	wc	pe	gro	3	egf	gr	1000	1525	ap-my		ja-dc	flowers
Kibatalia macrophylla (Pierre *ex* Hua) Woods.	Apocynaceae	t	pe	gro	2	mxf	ls	500	700	my-jn		ja-dc	flowers
Kopsia arborea Bl.	Apocynaceae	t	pe	gro	2	rocks in egf	ls	1200	1400	my-jn	my-jn	ja-dc	flowers, fruits
Melodinus cochinchinensis (Lour.) Merr.	Apocynaceae	wc	pe	gro	3	egf	ls	1200	1350	ap		ja-dc	flowers
Pottsia laxiflora (Bl.) O.K.	Apocynaceae	v	pe	gro	3	egf, da, sg	gr	900	1100	my-jn		ja-dc	flowers
Rauvolfia verticillata (L.) Baill.	Apocynaceae	l	pe	gro	2	egf, da	gr	1200	1400	mr-ap		ja-dc	flowers
Tabernaemontana bovina Lour.	Apocynaceae	l	pe	gro	3	egf, eg/bb	gr, ls	1100	1425	my	nv-dc	ja-dc	flowers, fruits
Heterostemma siamica Craib	Asclepiadaceae	v	pe	gro	3	mxf,da	ls	500	800	oc-nv		ja-dc	flowers
Hoya kerrii Craib	Asclepiadaceae	v	pe	epl	2	rocks in bb/df cliffs	ls	400	600			ja-dc	
Hoya thomsonii Hk. f.	Asclepiadaceae	v	pe	epi, epl	2	rocks in egf	gr	1300	1400		nv-ja	ja-dc	fruits
Marsdenia calcicola Kerr	Asclepiadaceae	v	pe	gro	2	rocks in eg/bb, cliffs	ls	1200	1375	ap	sp-oc	ja-dc	flowers
Marsdenia ?glabra Cost.	Asclepiadaceae	v	pe	gro	2	rocks in egf cliffs	ls	1300	1375			ja-dc	

Table 4 (continued)

Secamone elliptica R.Br. ssp. *elliptica*	Asclepiadaceae	v,wc	pe	gro	3	rocks in egf/bb mxf cliffs	ls	1300	1425	ap-my	oc-nv	ja-dc	flowers, fruits
Streptocaulon juventas (Lour.) Merr.	Asclepiadaceae	v	pe	gro	3	eg/bb da	gr	1000	1450	my-ja		ja-dc	flowers
Toxocarpus aff. *wightianus* Hk. & Arn.	Asclepiadaceae	v	pe	gro	3	mxf, egf, da	ls	1250	1400	my-jn		ja-dc	flowers
Buddleja asiatica Lour.	Loganiaceae	l	pd	gro	3	da, sg	gr	500	1500	sp-fb		my-mr	flowers
Fagraea ceilianica Thunb.	Loganiaceae	s	pe	epl	2	rocks in mxf cliffs	ls	600	1400		nv-ap	ja-dc	fruits
Exacum pteranthum Wall. *ex* Griseb.	Gentianaceae	h	a	gro	3	eg/pine	gr	1250	1325	sp-oc	nv	my-dc	flowers
Hydrolea zeylanica (L.) Vahl	Hydrophyllaceae	h	a	gro	3	wet areas in da		800	1100	ap-my	ap-jn	mr-oc	flowers, fruits
Cordia grandis Roxb.	Boraginaceae	t	pe	gro	2	eg/pine,da, sg	gr	1200	1300		ja-mr	ja-dc	fruits
Cordia	Boraginaceae	t	pe	gro	2	da, sg	gr	1000	1100		oc-nv	ja-dc	fruits
Argyreia aggregata (Roxb.) Choisy	Convolvulaceae	wc	pd	gro	3	eg/bb, egf,da,sg	ls	1100	1500	oc-ja		my-dc	flowers
Argyreia capitiformis (Poir.) Oost.	Convolvulaceae	v	pe	gro	3	eg/bb, da, sg	gr	1000	1500	nv-dc	fb-mr	ja-dc	flowers
Argyreia henryi (Craib) Craib	Convolvulaceae	wc	pe	gro	3	da, sg	gr	1000	1200	oc-nv		ja-dc	flowers
Argyreia wallichii Choisy	Convolvulaceae	v	pd	gro	3	egf,da,sg	gr,ls	1000	1525	sp-oc	nv-dc	my-dc	flowers, fruits
Dinetus racemosus (Wall.) Sweet	Convolvulaceae	v	a	gro	3	egf,da,sg	ls	1100	1500	oc-nv		my-dc	flowers
Evolvulus nummularius (L.) L.	Convolvulaceae	h,cr	pe	gro,wee	3	da	gr,ss	800	1000	my-jl	jn-ag	ja-dc	flowers, fruits
Merremia umbellata (L.) Hall. f. ssp.*orientalis* (Hall. f.) Oost.	Convolvulaceae	v	a	gro	3	egf,da,sg	ss	800	1100	fb-mr		jn-ap	flowers
Merremia vitifolia (Burm. f.) Hall. f.	Convolvulaceae	v	a	gro, wee	3	da	gr, ls	500	1525	ja-fb		jn-ap	flowers
Tridynamia spectabilis (Kurz) Stap.	Convolvulaceae	v	a	gro	3	mxf,da,sg	ls	450	600	fb-mr	mr-ap	jn-ap	flowers
Solanum aculeatissimum Jacq.	Solanaceae	h	a	gro,nat	3	eg/bb,da,sg	gr	1100	1400	my-jn		ap-dc	flowers

Table 4 (continued)

Solanum barbisetum Nees	Solanaceae	h	pd	gro	3	eg/bb, eg/pine, da	gr	1100	1400	my-jn	ag-sp	ap-dc	flowers
Solanum macrodon Wall. *ex* Nees	Solanaceae	h	a	gro	3	mxf, eg/bb	gr, ls	600	1400	my-sp	sp-nv	ap-dc	flowers
Solanum nigrum L.	Solanaceae	h	a	gro,int,nat,wee	3	da	gr	400	1500	my-dc	jn-ja	my-ja	
Solanum verbascifolium L.	Solanaceae	l	pe	gro	3	da	gr, ls	500	700	ag-oc	sp-nv	ja-dc	
Adenosma indiana (Lour.) Merr.	Scrophulariaceae	h	a	gro	3	eg/pine	gr	1250	1325	sp-oc	nv-dc	my-dc	flowers
Alectra avensis (Bth.) Merr.	Scrophulariaceae	h	a	gro	2	eg/pine, da	gr	1250	1500	oc-dc	dc-ja	my-dc	flowers
Lindenbergia indica (L.) Vat.	Scrophulariaceae	h	a	epl, gro	3	bb/df, mxf,da	ls	400	700	oc-nv	nv-dc	my-dc	flowers
Scoparia dulcis L.	Scrophulariaceae	h	a	gro, int, nat, wee	3	da, sg	gr	400	1500	jn-nv	ag-dc	my-dc	
Torenia pierreana Bon.	Scrophulariaceae	h	a	gro	3	egf, eb/bb	gr	1100	1400	jl-oc	sp-nv	my-dc	flowers
Torenia violacea (Aza. *ex* Blanco) Penn.	Scrophulariaceae	h	a	gro	3	egf, eg/bb, da	gr, ls	1000	1500	sp-oc	nv-dc	ap-dc	flowers
Aeginetia indica Roxb.	Orobanchaceae	h	pd	gro, par	3	rocks in mxf cliffs, egf	gr,ls	600	1500	sp	oc-dc	leafless	
Utricularia striatula Sm.	Lentibulariaceae	h	a	epl	2	rocks in eg/pine, egf cliffs	gr, ls	1500	1500	ag-sp	sp-oc	jn-oc	
Aeschynanthus hildebrandii Hemsl.	Gesneriaceae	h	pe	epi	2	egf, eg/bb	ls	1200	1400			ja-dc	
Aeschynanthus macranthus (Merr.) Pell.	Gesneriaceae	v	pe	epi	2	rocks in mxf, eg/bb	gr,ls	1300	1425	jl-sp	dc-mr	ja-dc	flowers, fruits
Boeica glandulosa Burtt	Gesneriaceae	l	pe	gro	2	streams in egf	gr	1200	1350	sp	oc-nv	ja-dc	flowers, fruits
Chirita hamosa Wall. *ex* R. Br.	Gesneriaceae	h	a	epl	4	rocks in bb/df, mxf cliffs	ls	400	700	sp-nv	oc-dc	my-dc	flowers
Didymocarpus insulsus Craib var. *payapensis* Palee & Maxw.	Gesneriaceae	h	pd	epl	2	rocks in egf, eg/pine	gr,ls	1300	1400	ap-sp	sp-jn	my-dc	flowers, fruits
Didymocarpus tristis Craib	Gesneriaceae	h	pd	epl	2	streams, rocks in egf, eg/bb	gr	1200	1250	jl-ag	sp-oc	jn-dc	fruits

Table 4 (continued)

Epithema carnosum Bth.	Gesneriaceae	h	pd	epl	2	rocks, streams in egf	gr, ls	1100	1350	ag-sp	sp-oc	my-dc	flowers, fruits
Lysionotus serratus D.Don	Gesneriaceae	h	pd	epi, epl	3	rocks in egf, da, cliffs	ls	1375	1400	jl-sp	sp-oc	my-dc	flowers, fruits
Ornithoboea wildeana Craib	Gesneriaceae	h	pd	epl	3	rocks in mxf cliffs	ls	425	625	oc-nv		my-dc	flowers
Paraboea glabrisepala Burtt	Gesneriaceae	h	pd	epl	3	rocks in egf, mxf cliffs	ls	1200	1425	ag-oc	oc-nv	jn-dc	flowers, fruits
Paraboea kerrii (Craib) Burtt	Gesneriaceae	s,h	pe	gro	2	egf	ls	1050	1250		nv-dc	ja-dc	fruits
Petrocosmea	Gesneriaceae	h	pd	epl	2	rocks in egf, cliffs	ls	1300	1400	sp	oc-nv	jn-dc	flowers, fruits
Rhynchoglossum obliquum Bl.	Gesneriaceae	h	a	epl, gro	3	rocks in mxf cliffs,eg/bb, eg/pine	gr,ls	400	1500	sp-nv	nv-dc	my dc	flowers
Rhynchotechum obovatum (Griff.) Burtt	Gesneriaceae	l	pe	gro	3	streams in eg/bb, egf	gr	1150	1400	my-jn	oc-dc	ja-dc	flowers, friuts
Stauranthera grandiflora Bth.	Gesneriaceae	h	pe	epl	2	rocks, streams in egf	gr, ls	1200	1325	ag-sp		ja-dc	
Trisepalum prazeri Burtt	Gesneriaceae	s	pd	epl	3	rocks in mxf cliffs	ls	1400	1425	ag-oc	nv-dc	ja-dc	flowers, fruits
Fernandoa adenophylla (Wall. *ex* G. Don) Steen.	Bignoniaceae	t	pd	gro	3	da, sg	gr	500	1100	jl-ag		ja-fb my-dc	flowers
Markhamia stipulata (Wall.) Seem. *ex* K. Sch. var. *kerrii* Sprague	Bignoniaceae	t	pd	gro	3	egf, eg/bb, da, sg	gr, ls	1000	1400	dc-ja	mr-ap	fb-my	
Radermachera hainanensis Merr.	Bignoniaceae	t	pd	gro	3	rocks in mxf cliffs	ls	1375	1425	ap		ap-dc	flowers
Radermachera ignea (Kurz) Steen.	Bignoniaceae	t, l	pe	gro	2	rocks in bb/df cliffs	ls	450	600	sp-oc		my-dc	
Stereospermum colais (B.-H.*ex* Dill.) Mabb.	Bignoniaceae	t	pd	gro	3	egf	gr	1100	1500	ap	ja-mr	ap-fb	flowers
Andrographis laxiflora (Bl.) Lindau	Acanthaceae	h	a	gro, epl	2	rocks, streams, wet areas in eg/bb, cliffs	gr,ls	1200	1375	ag-oc		my-dc	
Asystasiella neesiana (Wall.) Lindau	Acanthaceae	h	pe	gro	3	streams in egf	gr,ls	1200	1350	oc- nv		ja-dc	flowers

Table 4 (continued)

Barleria strigosa Willd.	Acanthaceae	h	pd	gro	3	bb/df, eg/bb	gr,ls	500	900	oc-nv		my-dc	
Choresthes lanceolata (T. And.) B.Han.	Acanthaceae	h	pe	gro	2	rocks in eg/bb	ls	1200	1300		ap	ja-dc	fruits
Eranthemum tetragonum Wall. *ex* Nees ssp*. tetragonum*	Acanthaceae	h	pe	gro	3	egf, eg/pine, eg/bb	gr	550	1450	dc-fb		ja-dc	flowers
Justicia helferi Cl.	Acanthaceae	h	pe	gro	2	streams in mxf, egf	ls	600	1300	ja-fb		ja-dc	flowers
Justicia procumbens L.	Acanthaceae	h	a	gro	3	eg/pine, eg/bb, da, sg	gr	900	1525	sp-dc		my-dc	flowers
Justicia quadrifaria (Wall. *ex* Nees) T. And.	Acanthaceae	h	pe	gro		streams in egf, eg/bb	gr	1000	1300	sp-fb	nv-mr	ja-dc	flowers
Lepidagathis incurva Ham. *ex* D.Don	Acanthaceae	h	pe	gro	3	rocks in mxf, bb/df, eg/pine	gr, ls	400	1500	dc-mr		ja-dc	flowers
Nelsonia canescens (Lmk.) Spreng.	Acanthaceae	h	pe	gro	3	egf, eg/bb, da	gr	900	1100	mr-ap	ap-my	ja-dc	flowers, fruits
Ophiorrhiziphyllon macrobotryum Kurz	Acanthaceae	h	pe	gro	2	egf	gr	1100	1400	ja-mr		ja-dc	flowers
Phaulopsis dorsiflora (Retz.) Sant.	Acanthaceae	h	pe	gro	3	egf, mxf, eg/bb, da, sg	gr	400	1400	dc-fb		ja-dc	flowers
Phlogacanthus curviflorus (Wall.) Nees var. *curviflorus*	Acanthaceae	s,l	pe	gro	2	streams in egf, eg/bb	gr	1000	1300	nv-fb	dc-mr	ja-dc	flowers, fruits
Pseuderanthemum latifolium (Vahl) B. Han.	Acanthaceae	s,l	pe	epl,gro	3	rocks, streams in mxf, egf	gr, ls	400	1200	oc-fb	dc-mr	ja-dc	flowers
Rhinacanthus calcaratus Nees	Acanthaceae	l	pe	gro	3	streams in mxf	ls	700	800	ja-fb		ja-dc	flowers
Rungia parviflora (Retz.) Nees var. *parviflora*	Acanthaceae	h	a	gro	3	bb/df, eg/bb,da	gr	900	1300	sp-fb	nv-fb	my-fb	flowers
Rungia rivicola Craib	Acanthaceae	h	pe	gro	3	rocks in egf	ls	1100	1400	fb-mr		ja-dc	flowers
Sericocalyx quadrifarius (Wall. *ex* Nees) Brem.	Acanthaceae	h	pe	gro	3	eg/bb	gr	1000	1400	dc-ja		ja-dc	flowers
Strobilanthes erectus Cl. *ex* Hoss.	Acanthaceae	l	pe	gro	3	rocks in egf, mxf cliffs	ls	1200	1425	oc-nv		ja-dc	flowers
Strobilanthes rex Cl.	Acanthaceae	l, s	pe	gro	3	egf	gr, ls	1000	1425	ja-fb		ja-dc	flowers

Table 4 (continued)

Strobilanthes speciosus Bl.	Acanthaceae	l	pe	gro	4	rocks in egf	ls	1200	1400	oc-nv		ja-dc	flowers
Strobilanthes viscidus Im.	Acanthaceae	h	pe	gro	2	streams in egf, eg/bb	gr	1100	1250			ja-dc	
Thunbergia coccinea Wall.	Acanthaceae	wc	pe	gro	3	streams in egf, eg/bb, da	gr	1100	1500	nv-dc		ja-dc	flowers
Thunbergia grandiflora Roxb.	Acanthaceae	v	pe	gro	3	eg/bb, da	gr	800	1500	ja-fb		ja-dc	flowers
Thunbergia laurifolia Lindl.	Acanthaceae	wc	pe	gro	3	da, sg		500	1500	nv-fb		ja-dc	
Thunbergia similis Craib	Acanthaceae	v	pd	gro	3	bb/df, eg/bb	gr	1000	1300	oc-nv		my-dc	flowers
Thunbergia	Acanthaceae	wc	pe	gro	3	rocks in mxf cliffs, egf, eg/pine	gr,ls	1350	1525	oc-dc	mr	ja-dc	flowers
Callicarpa arborea Roxb. var. *arborea*	Verbenaceae	t	pe,pd	gro	3	egf, da ,sg	gr	950	1500	mr-jn		ja-dc	flowers
Clerodendrum chinense (Osb.) Mabb. var. *chinense*	Verbenaceae	l	pe	gro	3	mxf, egf, da, sg	gr, ls	1000	1500	my-jn (oc)	oc-nv	ja-dc	flowers
Clerodendrum disparifoilum Bl.	Verbenaceae	l,s	pe	gro	3	rocks in mxf, egf, eg/bb	ls	500	1400	oc-nv		ja-dc	flowers
Clerodendrum glandulosum Colebr, *ex* Lindl.	Verbenaceae	l	pe	gro	3	da, sg	gr	1000	1400	sp-oc		ja-dc	
Clerodendrum paniculatum L.	Verbenaceae	l	pe	gro	2	da in egf	gr,ls	1000	1400	jn-sp	nv-dc	ja-dc	
Clerodendrum serratum (L.) Moon var. *wallichii* Cl.	Verbenaceae	l	pe	gro	3	bb/df, eg/bb, dg, sg	gr,ls	500	1525	sp-oc	jl-ag	ja-dc	flowers
Clerodendrum subscaposum Hemsl.	Verbenaceae	h	a	gro, epl	3	rocks in egf, mxf, eg/bb	ls	1375	1425	sp	oc-nv	my-dc	flowers, fruits
Congea rockii Mold.	Verbenaceae	wc	pe	gro	2	rocks in eg/bb	ls	1100	1300	fb-mr	ap-my	ja-dc	fruits
Congea tomentosa Roxb. var. *tomentosa*	Verbenaceae	wc	pe	gro	3	eg/bb, da	gr	1000	1400	ja-fb		ja-dc	flowers
Gmelina arborea Roxb.	Verbenaceae	t	pd	gro	3	da/sg, bb/df, eg/bb	gr	500	1500			my-dc	
Lantana camara L.	Verbenaceae	s, l	pe	gro, int, nat, wee	2	da, sg	gr, ls	1100	1400	ag-oc		ja-dc	

Table 4 (continued)

Prema flavescens Ham. *ex* Cl. *var. flavescens*	Verbenaceae	s	pd	epl	2	eg/pine, eg/bb	gr	1200	1275			my-dc	
Premna fulva Craib	Verbenaceae	wc	pd	gro	3	egf, eg/bb	gr, ls	1100	1350		my-jn	ja-ap jn-dc	
Premna latifolia Roxb.var. *latifolia*	Verbenaceae	wc	pe	gro	3	egf	gr	1000	1500	ap-my		ja-dc	flowers
Premna racemosa Wall. *ex* Schauer	Verbenaceae	l	pd	gro	3	rocks,cliffs in mxf	ls	1300	1425	mr-jn		ap-dc	flowers
Premna subcapitata Rehd.	Verbenaceae	s	pd	epl	3	rocks in mxf, eg/bb cliffs	ls	1375	1425	jl-sp	sp-oc	my-dc	flowers
Verbena officinalis L.	Verbenaceae	h	a	gro,wee	3	da, sg	gr	1100	1300	jn-fb	jl-mr	my-mr	flowers, fruits
Vitex canescens Kurz	Verbenaceae	t	pd	gro	3	bb/df	gr	400	1100			my-dc	
Vitex peduncularis Wall. *ex* Schauer	Verbenaceae	t	pd	gro	3	bb/df,egf, eg/pine	gr	800	1400	ap-my	jl	mr-nv	flowers, fruits
Vitex quinata (Lour.) Will. var. *puberula* (Lam) Mold.	Verbenaceae	t	pe	gro	3	mxf,egf	gr, ls	600	1500	ap	sp	ja-dc	flowers, fruits
Achyrospermum densiflorum Bl.	Labiatae	h	a	gro	2	eg/bb	gr	1100	1250		nv-dc	my-dc	fruits
Ajuga brateosa Wall. *ex* Bth.	Labiatae	h	a	gro	2	eg/bb, da		1100	1225	ja-fb	mr	ag-mr	flowers
Colebrookia oppositifolia Sm.	Labiatae	s	pe	gro	3	mostly streams in mxf, egf eg/pine	gr,ls	500	1300	ja-fb	fb-mr	ja-dc	flowers, fruits
Colquhounia elegans Wall. var. *tenuiflora* Pr.	Labiatae	sc	pe	gro	2	rocks in mxf, egf cliffs	ls	1200	1400	ja-fb		ja-dc	flowers
Elsholtzia blanda H. Keng	Labiatae	h	pd	gro	2	eg/pine	gr	1200	1325	nv-dc		my-ja	flowers
Eurysolen gracilis Prain	Labiatae	s,l	pe	gro	3	mxf, egf, da	gr , ls	1100	1425	nv-fb	ja-mr	ja-dc	flowers, fruits
Gomphostemma crinitum Wall. *ex* Bth.	Labiatae	h	a	gro	2	streams in mxf	ls	650	700	oc		my-dc	
Gomphostemma lucidum Wall. *ex* Bth.	Labiatae	h	pe	gro	2	rocks in eg/bb	ls	1350	1375	ag		ja-dc	
Gomphostemma strobilinum Wall. *ex* Bth. var. *viridis* (Wall. *ex* Bth.) Hk. f.	Labiatae	h	pe	gro	2	mxf, eg/bb	gr,ls	1300	1425	sp		ja-dc	flowers

Table 4 (continued)

Gomphostemma wallichii Pr.	Labiatae	h	pd	gro	2	streams in egf, eg/bb	gr	1000	1300	oc-nv		my-fb	flowers
Isodon coetsa (B. -H. *ex* D. Don) Kudo	Labiatae	s,h	pd	gro	2	eg/bb, da	ls	1200	1400	dc-ja		jl-fb	flowers
Isodon lophanthoides (B. -H. *ex* D. Don) Hara var. *lophanthoides*	Labiatae	h	a	gro	2	eg/bb	gr	1100	1400	sp-oc	nv-dc	my-dc	fruits
Leucas decemdentata (Willd.) J.Sm.	Labiatae	h	a	epl	3	egf da	ls	1200	1400	oc-nv		my-dc	flowers
Perilla frutescens (L.) Britt.	Labiatae	h	a	cul	2	egf	gr	1050	1500		nv-dc	my-dc	fruits
Platostoma hispidum (L.) Pat.	Labiatae	h	a	gro, wee	3	da, sg	gr	1000	1200	sp-oc	nv	my-dc	flowers
Platostoma intermedium Pat.	Labiatae	h	pd	epl	2	rocks in egf cliffs	ls	1300	1400	oc-dc	dc-ja	my-dc	flowers
Plectranthus bracteatus (Dunn) Sud.	Labiatae	h	a	epl	3	rocks in mxf, eg/bb	ls	1200	1425	sp-oc	nv-dc	my-dc	flowers, fruits
Pogostemon purpurascens Dalz.	Labiatae	l	pe	gro	3	egf eg/pine sg	gr	1100	1400	ja-fb		ja-dc	flowers
Salvia riparia Kunth	Labiatae	h	pe	gro, wee	3	da, sg	gr	900	1300	oc-fb	nv-mr	ja-dc	flowers
Achyranthes aspera L.	Amaranthaceae	h	a	gro, wee	3	eg/bb, da, sg	ls	400	1250	dc-fb	mr-ap	my-dc	flowers
Achyranthes bidentata Bl. var. *bidentata*	Amaranthaceae	h	a	gro, wee	3	egf, eg/bb	ls	1200	1375	sp-oc	nv-dc	my-dc	flowers
Aerva sanguilonenta (L.) Bl.	Amaranthaceae	h	a	gro	3	rocks in egf cliffs	ls	1200	1400	ja-ap		ja-dc	flowers
Alternanthera sessilis (L.) DC. var. *sessilis*	Amaranthaceae	h	pe	aqu, gro	3	ponds, streams in egf, wet areas in eg/bb	gr	750	1100	my-jn	jn-jl	ja-dc	flowers
Amaranthus spinosus L.	Amaranthaceae	h	a	gro, wee	3	da	gr	400	1150	dc-fb	ja-mr	sp-mr	flowers
Amaranthus viridis L.	Amaranthaceae	h	a	gro, wee	3	da	gr	500	1500	ja-dc	ja-dc	ja-dc	
Celosia argentea L.	Amaranthaceae	h	a	gro, wee	3	da, sg	gr	400	1000	ja-dc	ja-dc	ja-dc	
Fagopyrum dibotrys (D. Don) Hara	Polygonaceae	h	pd	gro	3	egf, da	gr,hs	1000	1400	(ag) oc-nv		my-ja	flowers

Table 4 (continued)

Polygonum chinense L. var. *chinense*	Polygonaceae	h	pe	gro	3	mxf,egf,da, sg	gr,ls	500	1500	my-fb	jn-mr	ja-dc	flowers, fruits
Polygonum chinense L. var. *hispidum* Hk. f.	Polygonaceae	h	pe	gro	3	streams in egf, da	gr	1000	1200	nv-dc	ja-dc	ja-dc	flowers
Polygonum nepalense Meisn.	Polygonaceae	h	a	gro, wee	2	da in egf, eg/pine	gr, ls	1400	1500	ag-oc	sp-nv	my-dc	flowers, fruits
Polygonum odoratum Lour.	Polygonaceae	h	pe	gro	3	streams and wet areas in egf, eg/bb	gr	1100	1300	ja-dc	ja-dc	ja-dc	flowers, fruits
Polygonum persicaria L.	Polygonaceae	h	a	gro, wee	3	da, sg	gr, ls	900	1400	mr-my	mr-my	ap-dc	flowers
Polygonum plebeium R.Br.	Polygonaceae	h	a	gro, wee	3	da, sg	gr	900	1500	mr-nv	jn-dc	ap-dc	flowers
Aristolochia tagala Cham.	Aristolochiaceae	v	pd	gro	3	da	ls	525	900			my-dc	
Sapria himalayana Griff.	Rafflesiaceae	h	pd	gro, par	1	egf, eg/bb	ls	1350	1350	ja-fb		leafless	
Houttuynia cordata Thunb.	Saururaceae	h	pe	gro	3	streams in egf, wet areas in da	gr	800	1500	(dc) ap-my		ja-dc	flowers
Peperomia pellucida (L.) H. B. K.	Piperaceae	h	a	gro, epl, nat	3	rocks in mxf cliffs, da in egf	gr,ls	500	1200	ag-oc	sp-nv	my-dc	flowers
Peperomia tetraphylla (Forst.f.) Hk. & Arn.	Piperaceae	h	pe	epl, epi	3	rocks in egf, mxf cliffs	gr,ls	1200	1500	ag-sp	sp-nv	ja-dc	flowers, fruits
Piper boehmeriaefolium (Wall.*ex* Miq) C. DC.	Piperaceae	s	pe	gro	3	rocks in egf	ls	1100	1400	fb-mr		ja-dc	flowers
Piper brevicaule C. DC.	Piperaceae	v	pe	gro	3	egf	ls	1200	1375		my-jn	ja-dc	fruits
Piper retrofractum Vahl	Piperaceae	v	pe	gro	3	mxf	gr	500	900	my-jn		ja-dc	flowers♀
Piper umbellatum L. var. *glabrius* (Miq.) DC.	Piperaceae	s, l	pe	gro	2	egf	gr	700	950	ag-sp	sp-oc	ja-dc	flowers
Chloranthus nervosus Coll. & Hemsl.	Chloranthaceae	h	pd	gro	2	egf, eg/bb	gr, ls	1300	1400	my-jn		my-dc	flowers
Horsfieldia amygdalina (Wall.) Warb. var. *macrocarpa* Wilde	Myristicaceae	t	pe	gro	2	egf	gr	1000	1000		ap	ja-dc	fruits
Knema lenta Warb.	Myristicaceae	t	pe	gro	3	egf, eg/bb	gr	1000	1300			ja-dc	

Table 4 (continued)

Knema tenuinervia Wilde ssp. *setosa* Wilde	Myristicaceae	t	pe	gro	2	mxf, eb/bb	gr	500	700			ja-dc	
Actinodaphne henryi Gamb.	Lauraceae	t	pe	gro	3	egf, eg/bb	gr, ls	925	1400	ja	my	ja-dc	
Alseodaphne	Lauraceae	t	pe	gro	2	streams in egf, eg/bb	gr	1100	1300	nv-dc	jl-ag	ja-dc	flowers, fruits
Beilschmiedia aff. *intermedia* Allen	Lauraceae	t	pe	gro	2	egf, eg/bb	gr	1050	1200	my-jn		ja-dc	
Cinnamomum caudatum Nees	Lauraceae	t	pe	gro	2	egf	gr, ls	1000	1300	my-jl		ja-dc	flowers
Cinnamomum iners Reinw. *ex* Bl.	Lauraceae	t	pe	gro	3	mxf, egf	gr,ss	500	1100	ja-fb		ja-dc	flowers
Cinnamomum	Lauraceae	t	pe	gro	2	streams in eg/bb	gr	1200	1250			ja-dc	
Cryptocarya amygdalina Nees	Lauraceae	t	pe	gro	3	egf, eg/bb	gr, ls	1100	1400	my	ap-my	ja-dc	fruits
Litsea cubeba (Lour.) Pers. var. *cubeba*	Lauraceae	t	pe	gro	3	da, sg	gr	1000	1300	ja-fb		ja-dc	flowers
Litsea garrettii Gamb.	Lauraceae	l	pe	gro	3	egf, eg/bb	gr, ls	1100	1300	ap		ja-dc	flowers
Litsea glutinosa (Lour.) C. B. Rob. var. *glutinosa*	Lauraceae	t	pe	gro	3	eg/pine	gr	1100	1350	ap		ja-dc	flowers♂
Litsea semecarpifolia Wall. *ex* Nees	Lauraceae	t	pe	gro	3	eb/bb	gr	1100	1500	ja-fb		ja-dc	
Litsea umbellata (Lour.) Merr.	Lauraceae	t	pe	gro	3	egf	gr	1000	1350	jl-sp		ja-dc	flowers
Litsea zeylanica (Nees) Nees	Lauraceae	t	pe	gro	3	streams in egf	gr, ls	1200	1350	nv-ja		ja-dc	
Litsea	Lauraceae	t	pe	gro	3	egf, eg/bb	gr	1200	1500			ja-dc	
Machilus bombycina King *ex* Hk. f.	Lauraceae	t	pe	gro	2	egf	gr	1100	1500	ja-fb		ja-dc	flowes
Machilus kurzii King *ex* Hk. f.	Lauraceae	t	pe	gro	2	egf, eg/bb	gr	800	1100	jn-jl		ja-dc	flowers
Phoebe lanceolata (Wall. *ex* Nees) Nees	Lauraceae	t, l	pe	gro	3	egf, eg/bb	gr, ls	1000	1400	ap-my	oc	ja-dc	flowers, fruits
Phoebe pallida (Nees) Nees	Lauraceae	t	pe	gro	3	egf	gr	1000	1200	jl-ag		ja-dc	flowers, imm. fruits

Table 4 (continued)

Phoebe paniculata Nees	Lauraceae	t	pd	gro	3	egf	gr	1300	1500	fb-mr		ja-dc	flowers
Helicia formosana Hemsl. var. *oblanceolata* Sleum.	Proteaceae	t	pe	gro	2	egf, eg/bb	gr	1000	1400	ap-my	fb-mr	ja-dc	
Helicia nilagirica Bedd.	Proteaceae	t	pe	gro	3	egf	gr	1200	1500	ap		ja-dc	flowers
Heliciopsis terminalis (Kurz) Sleum.	Proteaceae	t	pe	gro	2	egf, eg/bb	gr	1000	1400	ap-my	dc-fb	ja-dc	
Aquilaria crassna Pierre *ex* Lec.	Thymeleaceae	t	pd	gro	1	eg/bb	ls	1200	1250			fb-dc	
Elaeagnus conferta Roxb.	Elaeagnaceae	wc	pe	gro also cul	2	streams in eg/bb	gr	1000	1250	sp-oc	oc-nv	ja-dc	flowers
Dendrophthoe kerrii (Craib) Barl.	Loranthaceae	s	pe	epi, par	2	eg/bb	ls	1200	1425	nv-ja	fb-mr	ja-dc	flowers,fruits
Helixanthera parasitica Lour.	Loranthaceae	s	pe	epi, par	3	egf, eg/pine	gr	1000	1500	ap-my		ja-dc	flowers
Scurrula ferruginea (Jack) Dans.	Loranthaceae	s	pe	epi, par	3	da, sg	gr	900	1525	jl-sp		ja-dc	flowers
Viscum ovalifolium Wall. *ex* DC.	Viscaceae	s	pe	epi, par	2	egf	gr	1200	1300	fb-mr	my-jn	ja-dc	fruits
Scleropyrum pentandrum (Denn.) Mabb.	Santalaceae	t	pe	gro	2	rocks in egf, eb/bb	ls	1200	1400		jl-ag	ja-dc	fruits
Balanophora abbreviata Bl.	Balanophoraceae	h	pd	gro, par	2	streams in egf, eg/bb, da	gr,ls	1125	1350	oc-nv	nv-dc	leafless	flowers♀♂
Balanophora fungosa J.R. & G. Forst. ssp. *indica* (Arn.) B. Han. var. *indica*	Balanophoraceae	h	pe	gro	2	egf	ls	1000	1400	dc-fb		leafless	
Balanophora latisepala (Tiegh.) Lec.	Balanophoraceae	h	pd	gro,par	2	streams in eg/bb	gr	1150	1250	nv-dc		leafless	flowers♀
Acalypha kerrii Craib	Euphorbiaceae	s	pe	gro	3	rocks in mxf, eg/bb	ls	1200	1400	my-jn		ap-dc	flowers
Actephila excelsa (Dalz.) M. A. var. *excelsa*	Euphorbiaceae	t	pe	epl	2	rocks in egf	ls	1300	1375	ag-sp	oc-nv	ja-dc	fruits
Alchornea rugosa (Lour.) M. A. var. *rugosa*	Euphorbiaceae	t	pe	gro	3	rocks in mxf, egf cliffs	ls	1200	1400	ja-fb		ja-dc	flowers♂,♀
Antidesma acidum Retz.	Euphorbiaceae	l	pd	gro	3	eg/bb, da	gr	1000	1400	my-jn		my-dc	flowers♀
*Antidesma bunius (*L.) Spreng. var. *bunius*	Euphorbiaceae	t	pe	gro	3	egf, eg/bb	gr, ls	1200	1500		ag-sp	ja-dc	fruits

Table 4 (continued)

Antidesma montanum Bl. var. montanum	Euphorbiaceae	t	pe	gro	3	egf, eg/bb	ls	1200	1350	ap		ja-dc	flowers♂
Antidesma sootepense Craib	Euphorbiaceae	t,l	pe	gro	3	egf,eg/bb	gr,ls	800	1300	my-ag	jl-dc	ja-dc	flowers♂,♀, fruits
Aporosa octandra (B.-H. *ex* D.Don) Vick. var. *octandra*	Euphorbiaceae	t	pd	gro	3	eg/bb, da	gr, ls	1200	1375	ja-fb	my-jn	my-dc	fruits
Aporosa octandra (B.-H. *ex* D.Don) Vick. var. *yunnanensis* (Pax & Hoffm.) Schot	Euphorbiaceae	t	pd	gro	3	egf	gr	1100	1450	ja-fb	my-jn	ap-dc	fruits
Aporosa villosa (Lindl.) Baill.	Euphorbiaceae	t	pd	gro	3	eg/bb, da, sg	gr	1000	1200	ja-fb	my-jn	ap-ja	flowers♂
Aporosa yunnanensis (Pax & Hoff.) Metc.	Euphorbiaceae	t	pe	gro	3	egf, da, sg	gr	1100	1300	ja-fb	my-jn	ja-dc	flowers♂
Baccaurea ramiflora Lour.	Euphorbiaceae	t	pe	gro	3	mxf	ls	600	1300	fb-mr	my-jn	ja-dc	flowers, fruits
Balakata baccata (Roxb.) Ess.	Euphorbiaceae	t	pe	gro	3	mxf, streams in egf	ss, gr,ls	500	1100	fb-mr	jl	ja-dc	flowers, fruits
Baliospermum calycinum M. A.	Euphorbiaceae	l	pe	gro	2	egf, rocks in eg/bb	gr,ls	1200	1375	ag-sp	sp-oc	ja-dc	flowers♂,♀, fruits
Bischofia javanica Bl.	Euphorbiaceae	t	pd	gro	2	streams in egf, eg/bb	gr	1000	1300	fb-mr	sp-nv	mr-fb	fruits
Breynia retusa (Denn.) Alst.	Euphorbiaceae	l	pe	gro	3	egf, eg/bb	gr	1000	1500	ap-jl	jl-sp	ja-dc	flowers♂
Bridelia glauca Bl.	Euphorbiaceae	t	pe	gro	3	egf	gr	1000	1550	ap-my		ja-dc	flowers
Bridelia tomentosa Bl.	Euphorbiaceae	t,l	pe	gro	3	egf,da,sg	gr	1000	1200	oc-nv	nv-dc	ja-dc	fruits♂
Bridelia stipularis (L.) Bl.	Euphorbiaceae	sc, wc	pd	gro	3	da, sg	gr	900	1200	sp-oc	ja-mr	my-mr	flowers♂, fruits
Cleidion javanicum Bl.	Euphorbiaceae	t	pe	gro	2	mxf, egf	gr	500	900	fb-mr	jn	ja-dc	
Croton robustus Kurz	Euphorbiaceae	t	pe	gro	3	eg/bb,egf,da,sg	gr	1000	1500	nv-fb	fb-ap	ja-dc	flowers♂,♀, fruits
Euphorbia hirta L.	Euphorbiaceae	h	a	gro,int,nat,wee	3	da, sg	gr	400	1500	ja-dc	ja-dc	ja-dc	
Euphorbia thymifolia L.	Euphorbiaceae	h	a	gro, wee	3	da	gr,ls	425	800	ag-nv	oc-dc	my-dc	fruits
Falconeria insigne Roy.	Euphorbiaceae	t	pd	gro	2	rocks, cliffs in mxf	ls	1200	1425	ja-fb		jn-dc	flowers♂

Table 4 (continued)

Fluggea virosa (Roxb. ex Willd.) Voigt	Euphorbiaceae	s, l	pd	gro	3	rocks in mxf, eg/bb,da	gr,ls	525	1425	jl-sp	sp-oc	my-dc	flowers♂, fruits
Glochidion eriocarpum Champ.	Euphorbiaceae	l	pe	gro	3	egf, eg/pine	gr	1200	1400		ja-fb	ja-dc	fruits
Glochidion oblatum Hk. f.	Euphorbiaceae	t	pe	gro	2	eg/bb	gr	1100	1400		jl-ag	ja-dc	fruits
Glochidion rubrum Bl.	Euphorbiaceae	t	pe	gro	3	da, sg	gr	1000	1500		ja-fb	ja-dc	fruits
*Glochidion sphaerogynum (*M. A.) Kurz	Euphorbiaceae	t	pe	gro	3	eg/bb, da, sg	gr	1000	1400	ja-fb	dc-ja	ja-dc	flowers, fruits
Macaranga denticulata (Bl.) M. A.	Euphorbiaceae	t	pe	gro	3	egf, da, sg	gr	500	1500		my-jn	ja-dc	fruits
Macaranga kurzii (O.K.) Pax & Hoffm.	Euphorbiaceae	l	pe	gro	3	da, sg	gr	1100	1350	jn-ag	jl-sp	ja-dc	flowers♀, fruits
Macaranga siamensis S. J. Davies	Euphorbiaceae	t	pe	gro	3	da, sg	gr,ls	600	900	my-jn		ja-dc	
Mallotus cuneatus Ridl.	Euphorbiaceae	l	pe	gro	2	rocks in egf, mxf,eg/bb cliffs	ls	600	1375	sp	sp-oc	ja-dc	fruits
Mallotus mollissimus (Geisel.) A.S.	Euphorbiaceae	t	pd	gro	2	egf	gr	1000	1100	ap-my	jl	mr-fb	flowers♂, fruits
Mallotus paniculatus (Lmk.) M. A.	Euphorbiaceae	t, l	pe	gro	3	da,sg	gr	900	1525			ja-dc	
Mallotus peltatus (Geisel.) M. - A.	Euphorbiaceae	l	pe	gro	3	mxf	gr,ls	500	800	my-jn		ja-dc	flowers♀
Mallotus philippensis (Lmk.) M. A.	Euphorbiaceae	t	pe	gro	3	da,sg, streams in mxf,eg/bb	gr,ls	600	1500	oc-nv	ja-mr	ja-dc	flowers♂, fruits
Mallotus tetracoccus (Roxb.) Kurz	Euphorbiaceae	t	pe	gro	3	egf, eg/bb	gr	1000	1200	my		ja-dc	flowers♂
Mallotus	Euphorbiaceae	t	pe	gro	2	egf	gr,ls	1300	1375		jl-oc	ja-dc	fruits
Ostodes paniculata Bl.	Euphorbiaceae	t	pe	gro	3	streams in mxf, egf, eg/bb	gr,ls,s h	600	1350		jn-sp	ja-dc	fruits
Phyllanthus debilis Klein *ex* Willd.	Euphorbiaceae	h	a, pd	gro	3	eg/pine, eg/bb, da, egf cliffs	gr,ls	1100	1400	sp-fb	oc-fb	jn-fb	flowers, fruits
Phyllanthus emblica L.	Euphorbiaceae	t	pd	gro	3	eg/pine, eg/bb, da, sg	gr	1100	1400		sp-fb	my-dc	

Table 4 (continued)

Phyllanthus reticulatus Poir.	Euphorbiaceae	sc	pd	gro	3	streams in bb/df, mxf, da	ls	500	700		sp-oc	my-dc	fruits
Phyllanthus urinaria L.	Euphorbiaceae	h	a	gro, wee	3	da	gr, ls	500	1375	ag-oc	sp-nv	my-dc	flowers, fruits
Sauropus macranthus Hassk.	Euphorbiaceae	l	pe	gro	2	rocks in egf,eg/bb cliffs	ls	1300	1400	my-jn	sp	ja-dc	flowers♂,♀, fruits
Sauropus poomae Welz. & Chay.	Euphorbiaceae	h	pe	epl	2	rocks in egf cliffs	ls	1250	1400	oc-mr	oc-nv	ja-dc	flowers, fruits
Sumbaviopsis albicans (Bl.) J.J. Sm.	Euphorbiaceae	t	pe	gro	3	rocks, streams in mxf	ls	500	1325			ja-dc	
Trigonostemon thyrsoideus Stapf	Euphorbiaceae	l	pe	gro	2	rocks in eg/bb, cliffs, egf, streams	ls	1250	1300	ap-jn		ja-dc	flowers♂,♀
Buxus	Buxaceae	t	pe	gro	3	rocks in mxf cliffs	ls	1400	1425		nv-dc	ja-dc	fruits
Trema orientalis (L.) Bl.	Ulmaceae	t	pe	gro	3	da, sg	gr,ls	500	1200	oc	dc	ja-dc	flowers♂
Ulmus lancaefolia Roxb. *ex* Wall.	Ulmaceae	t	pe	gro	3	rocks in egf cliffs	ls	1250	1400	sp-oc		ja-dc	flowers
Artocarpus thailandicus C.C. Berg	Moraceae	t	pe	gro	3	egf, da	gr	950	1500	my-jn	my-jn	ja-dc	flowers, fruits
Broussonetia papyrifera Vent.	Moraceae	t,l	pe	gro	3	da, sg	gr	1000	1400	my	my-jn	ja-dc	flowers, fruits
Ficus annulata Bl.	Moraceae	t	pd	str, epl	3	mxf, egf	gr, ls	600	1400	ap-sp	ap-sp	ja-dc	flowers, fruits
Ficus anserina (Corn.) C.C. Berg	Moraceae	wc	pe	epl, gro	3	rocks, cliffs in bb/df , egf	gr, ls	400	1350	my-jl	jn-ag	ja (my)-dc	flowers, fruits
Ficus auriculata Lour.	Moraceae	t	pe	gro	3	da, streams in egf, wet areas in eg/bb	gr	900	1500	dc-ag	mr-sp	ja-dc often changing lvs in dc	flowers
Ficus cyrtophylla Wall. *ex* Miq.	Moraceae	l	pe	gro, epl	2	streams in egf, mxf	ls	550	1350	ap-sp	ap-sp	ja-dc	flowers, fruits
Ficus fistulosa Reinw. *ex* Bl.	Moraceae	t	pe	gro	3	egf, da	gr	1000	1525	ja-dc	ja-dc	ja-dc	flowers
Ficus glaberrima Bl.	Moraceae	t, l	pe	epi, epl	2	eg/bb, rocks , cliffs	gr, ls	1000	1425	nv-dc	nv-dc	ja-dc	flowers

Table 4 (continued)

Ficus hirta Vahl var. *hirta*	Moraceae	l	pe	gro	3	da, sg, egf	gr,ls	1000	1400	jn-sp	jl-oc	ja-dc	flowers, fruits
Ficus hirta Vahl var. *roxburghii* (Miq.) King	Moraceae	t	pe	gro	3	egf	gr,ls	1000	1400	ap-my	ap-my	ja-dc	flowers, fruits
Ficus hispida L. f. var. *hispida*	Moraceae	t	pe	gro	3	da, sg	gr	400	1500	ja-dc	ja-dc	ja-dc	
Ficus kurzii King	Moraceae	t	pe	epi	3	rocks in egf	ls	1200	1500	ag-nv	ag-nv	ja-dc	flowers, fruits
Ficus laevis Bl.	Moraceae	wc,cr	pe	gro	2	streams in egf, eb/bb	gr	1100	1300	ja-mr	fb-ap	ja-dc	
Ficus semicordata B.-H. *ex* J.E. Sm. var. *semicordata*	Moraceae	t	pe	gro	3	egf, eg/bb, da, mxf, sg	gr, ls	550	1525	ja-dc	ja-dc	ja-dc	
Ficus subincisa Ham. *ex* J.E. Sm. var. *subincisa*	Moraceae	t,l	pe	gro	3	egf,da, sg	gr, ls	1000	1400	ja-dc	ja-dc	ja-dc	flowers
Ficus subpisocarpa Gagnep. ssp. *pubipoda* C.C. Berg	Moraceae	t	pd	gro	3	egf	gr	1000	1450	jl-ag	sp-oc	mr-ja	flowers
Ficus tinctoria G. Forst. ssp. *gibbosa* (Bl.) Corn. var. *gibbosa*	Moraceae	wc	pe	gro	3	mxf, egf	gr,ss	600	1000	my-jl	jn-ag	ja-dc	flowers, fruits
Ficus variegata Bl. var. *variegata*	Moraceae	t	pd	gro	2	streams in egf, eg/bb	gr	1000	1200			my-fb	
Ficus	Moraceae	t,s	pe	epl	2	cliffs in bb/df, egf	ls	400	1300	dc-fb	dc-fb	ja-dc	flowers
Maclura fruticosa (Roxb.) Corn.	Moraceae	wc	pe	gro	3	egf, eg/pine	gr, ls	1200	1400	sp-oc	nv-dc	ja-dc	flowers♂, fruits
Morus macroura Miq.	Moraceae	t	pd	gro	3	egf,eg/pine	gr	1000	1400	fb-mr	ap	fb-dc	flowers, fruits
Streblus ilicifolius (Vidal) Corn.	Moraceae	l	pe	gro	3	rocks in mxf cliffs	ls	400	700			ja-dc	
Boehmeria clidemioides Miq. var. *clidemioides*	Urticaceae	s	pe	gro	3	mxf, da	ls	1300	1400	ag-sp		ja-dc	flowers♀♂
Boehmeria hamiltoniana Wall. *ex* Wedd.	Urticaceae	wc,s	pe	epl	3	streams in egf	gr	1100	1300	ja-dc		ja-dc	flowers
Boehmeria diffusa Wedd.	Urticaceae	s, l	pe	gro	3	egf, eg/pine, da, sg	gr	1000	1525	jn-oc		ja-dc	flowers♂
Boehmeria malabarica Wall. *ex* Wedd.	Urticaceae	s	pe	gro,epl	3	rocks in egf, mxf	ls	550	1400	sp	fb-mr	ja-dc	flowers♂, fruits
Boehmeria nivea (L.) Gaud. var. *tenacissima* (Roxb.) Miq.	Urticaceae	t	pe	gro	3	streams in mxf,da	ls	550	700		fb-mr	ja-dc	fruits

Table 4 (continued)

Boehmeria penduliflora Wedd. *ex* Long	Urticaceae	l	pe	gro	3	egf,da,sg	gr	600	900		oc-nv	ja-dc	fruits
Boehmeria pilosiuscula (Bl.) Hassk.	Urticaceae	h	pe	gro	3	egf,da,sg	gr,ls	1200	1425		sp-nv	ja-dc	fruits
Boehmeria platyphylla D.Don	Urticaceae	s,h	pe	gro	3	egf,eg/bb da	ls	600	1200	ag-oc	ja-dc	ja-dc	fruits
Boehmeria aff.*thailandica* Yaha.	Urticaceae	l,s	pe	gro	3	egf,da,sg	ls	1000	1100	oc-dc	ja-dc	ja-dc	fruits
Boehmeria zollingeriana Wedd. var. *zollingeriana*	Urticaceae	s	pd	epl	3	eg/bb,da	ls	400	600	oc-nv		my-dc	flowers
Debgreasia longifolia (Burm. f.) Wedd.	Urticaceae	l	pe	gro	3	eg/bb, egf,da,sg	gr,ls	500	1500	sp-nv	nv-ja	ja-dc	flowers♀♂, fruits
Debgreasia wallichiana (Wedd.) Wedd. ssp. *wallichiana*	Utricaceae	l,t	pd	gro	3	rocks in mxf, cliffs	ls	1250	1425	my-jn	ag-sp	my-dc	flowers♀♂, fruits
Dendrocnide sinuata (Bl.) Chew	Urticaceae	t	pe	gro	2	rocks in mxf cliffs, da	gr,ls	550	700	oc-nv	oc-nv	ja-dc	flowers♀, fruits
Elatostema cyrtandraefolium (Zoll. & Mor.) Miq.	Urticaceae	h	a	gro,epl	3	rocks in mxf, egf	ls	1300	1425		sp-oc	my-dc	fruits
Elatostema lineolatum Wight var. *majus* Wedd.	Urticaceae	h	pe	gro, epl	2	streams, wet areas in egf	gr,ls	1200	1350		nv-ja	ja-dc	fruits
Elatostema monandrum (Ham. *ex* D. Don) Hara	Urticaceae	h	pd	epl	3	rocks in mxf, egf, eg/bb	ls	1300	1425	jn-jl	jl-ag	jn-dc	fruits
Elatostema platyphyllum Wedd. var. *platyphyllum*	Utricaceae	h	pe	gro	3	streams in egf	gr,ls	1000	1275	mr-my	jn-ag	ja-dc	
Elatostema salvinioides W. T. Wang	Urticaceae	h	pd	epl	2	rocks in mxf, eg/bb cliffs	ls	575	1375	ag-sp		my-dc	flowers
Girardinia hibiscifolia Miq.	Urticaceae	h	a	gro	3	egf,da	ls	1150	1500	oc-nv	nv-dc	my-dc	flowers
Laportea interrupta (L.) Chew	Urticaceae	h	a	gro, epl, wee	3	mxf, egf, da	gr,ls	500	1025	ag-oc	sp-nv	my-dc	flowers, fruits
Laportea violacea Gagnep.	Urticaceae	h	a	gro	3	egf,da,sg	ls	1200	1400	oc-nv	nv-dc	my-dc	flowers
Maoutia puya (Wall. *ex* Hk.) Wedd.	Urticaceae	h,l	pd	gro	2	bb/df,da,sg	gr	1000	1525	jn-ag	sp-oc	my-dc	flowers♂, fruits
Oreocnide rubescens (Bl.) Miq.	Urticaceae	t,l	pe	gro	3	streams in eg/pine, egf, mxf	gr,ls	600	1400	fb -ap	sp-dc	ja-dc	fruits
Pouzoulzia hirta Hassk.	Urticaceae	h	a	gro, wee	3	egf, da	gr	600	1500	my-sp	sp-nv	my-dc	flowers

Table 4 (continued)

Pilea microphylla (L.) Liebm.	Urticaceae	h	pe	epl, nat	3	egf, eg/bb, da	gr,ls	400	1500	ag-oc	sp-nv	ja-dc	flowers
Pilea stipulosa Miq.	Urticaceae	h	a	epl	3	rocks in mxf, eg/bb	ls	500	1425	jl-ag	sp	my-dc	flowers♂, fruits
Pilea trinervia Wight	Urticaceae	h	pe	gro,epl	3	streams in eg/bb, rocks in mxf, egf	gr, ls	1100	1475	my-sp		ja-dc	flowers♂
Engelhardia serrata Bl. var. *serrata*	Juglandaceae	t	pd	gro	3	eg/pine, sg, egf, eg/bb	gr	1000	1500	ja-fb	mr-ap	ja-nv	flowers♀
Engelhardia spicata Lechen. *ex* Bl. var. *integra* (Kurz) Mann.	Juglandaceae	t	pd	gro	3	eg/bb, da	ls	1000	1350	fb-mr	mr-ap	ap-fb	
Engelhardia spicata Lesch. *ex* Bl. var. *spicata*	Juglandaceae	t	pd	gro	3	eg/pine sg	gr	700	1400	ja fb	fb-mr	mr-dc	fruits
Betula alnoides Ham. *ex* D.Don	Betulaceae	t	pd	gro	2	egf, eg/bb	gr	1100	1400	ja-fb	fb-mr	fb-dc	flowers♂
Castanopsis acuminatissima (Bl.) A. DC.	Fagaceae	t	pe	gro	3	egf, eg/bb,eg/pine	gr	1200	1525	ja-fb	oc-nv	ja-dc	flowers♂,♀, fruits
Castanopsis argyrophylla King *ex* Hk. f.	Fagaceae	t	pe	gro	3	egf	gr	900	1200	fb-ap		ja-dc	flowers
Castanopsis armata (Roxb.) Spach	Fagaceae	t	pe	gro	3	egf eg/bb	gr	1000	1500	nv-dc	sp-oc	ja-dc	flowers♂,♀
Castanopsis calathiformis (Skan) Rehd. & Wils.	Fagaceae	t	pe	gro	2	eg/bb	gr	1100	1300		oc-nv	ja-dc	fruits
Castanposis diversifolia (Kurz) King *ex* Hk. f.	Fagaceae	t	pe	gro	3	egf, eg/pine	gr	1100	1300	ja-fb		ja-dc	flowers♂
Castanopsis tribuloides (Sm.) A. DC.	Fagaceae	t	pe	gro	3	egf	gr, ls	1000	1525	ap-my	oc	ja-dc	flowers♂,♀, fruits
Lithocarpus auriculatus (Hick. & A. Camus) Barn.	Fagaceae	t	pe	gro	3	egf	gr	1000	1400		sp-oc	ja-dc	fruits
Lithocarpus elegans (B.) Hatus. *ex* Soep.	Fagaceae	t	pe	gro	3	egf	gr	1000	1500		sp-oc	ja-dc	fruits
Lithocarpus polystachyus (Wall. *ex* A. DC.) Rehd.	Fagaceae	t	pe	gro	2	egf, eg/pine	gr	1200	1525	♂oc, ♀dc-ja	jl-ag	ja-dc	flowers♂,♀, fruits
Lithocaupus truncatus (King *ex* Hk. f.) Rehd. & Wils.	Fagaceae	t	pe	gro	2	eg/pine	gr	1250	1325		ag-sp	ja-dc	
Quercus semiserrata Roxb.	Fagaceae	t	pe	gro	3	egf, eg/pine	gr	1100	1400	ja	sp-oc	ja-dc	fruits
Salix tetrasperma Roxb.	Salicaceae	t	pd	gro	2	streams in egf, eg/bb	gr	1000	1500	sp-oc	dc-nv	oc-sp	flowers♂

Table 5. List of plant species (monocot) arranged in morphological family order under phylum angiospermae surveyed at Doi Tung, Chiang Rai Province

Species	Family	Habit	Aped	Life mode	Abundance	Habitat	Bedrock	Lower	Upper	Flowering	Fruiting	Leafing	Collected
								Elevation (m)		Months			
Sagittaria trifolia L.	Alismataceae	h	ped	gro	2	ponds, wet areas in egf	gr	900	1000	ap-jl	jl-sp	ja-dc	flowers
Cyanotis cristata (L.) D. Don	Commelinaceae	h	a	gro	3	rocks in mxf, eg/bb cliffs	gr,ls	900	1425	jl-sp	sp-oc	my-dc	flowers
Commelina benghalensis L.	Commelinaceae	h	a	gro, wee	3	da, sg	gr, ls	400	800	sp-oc		my-dc	
Commelina diffusa Burm. f.	Commelinaceae	h	pe	gro	3	eg/pine, da	gr	1200	1500	sp-oc		ja-dc	flowers
Commelina paludosa Bl.	Commelinaceae	h	pe	gro	3	mxf, eg/bb, da	gr, ls	550	1400	sp-oc		ja-dc	flowers
Dichorisandra thyrsiflora Mikan	Commelinaceae	h	pe	gro, cul	3	egf	gr	1000	1000	ja-dc	ja-dc	ja-dc	flowers
Murdannia japonica (Thunb.) Faden	Commelinaceae	h	pd	gro	3	da in egf	gr	1100	1400	my-jl	jl-sp	my-dc	flowers
Murdannia nudiflora (L.) Bren.	Commelinaceae	h	a	gro, wee	3	egf, da, sg	gr	900	1300	sp-nv	oc-dc	my-dc	flowers
Pollia haskarlii R. Rao	Commelinaceae	h	pe	gro	3	streams in egf, mxf, eg/bb	gr,ls	500	1400	my-sp	sp-fb	ja-dc	flowers, fruits
Rhopalephora scaberrimum (Bl.) Faden	Commelinaceae	h	pe	gro	3	eg/pine, eg/bb	gr	1200	1375	ag-oc		ja-dc	flowers
Xyris lobbii Rend.	Xyridaceae	h	pd	gro	2	eg/pine	gr	1250	1325	sp-oc	nv-dc	my-dc	flowers
Musa itinerans Chees.	Musaceae	h	pe	gro	3	streams, wet areas in egf, eg/bb	gr, ls	950	1375	ag-oc		ja-dc	
Alpinia galanga (L.) Willd.	Zingiberaceae	h	pe	gro	2	egf, eg/bb	gr	1000	1300	my-jl	oc-nv	ja-dc	
Alpinia malaccensis (Burm.f.) Rosc.	Zingiberaceae	h	pe	gro	3	eg/bb, streams in egf	gr, ls	1100	1375	fb-jn	mr-sp	ja-dc	flowers, fruits
Amomum repoense Pierre *ex* Gagnep.	Zingiberaceae	h	pe	gro	3	eg/bb, da	ls	1200	1350			ja-dc	fruits
Amomum uliginosuns Koen.	Zingiberaceae	h	pe	gro	3	eg/bb, da	ls	550	1350			ja-dc	

Table 5 (continued)

Amomum	Zingiberaceae	h	pe	gro	3	streams in egf,eg/bb	gr	1100	1300		jl-ag	ja-dc	fruits
Costus globosus Bl.	Zingiberaceae	h	pe	gro	2	streams in egf	gr, ls	1000	1400	jn-ag	nv-dc	ja-dc	
Costus speciosus (Koen.) J E. Sm.	Zingiberaceae	h	pd	gro	3	mxf, eg/bb	gr, ls	1000	1525			my-dc	
Curcuma zedoaria (Berg.) Rosc.	Zingiberaceae	h	pd	gro	3	bb/df, eg/bb	gr	900	1500	ap-my	jn-jl	my-dc	
Curcuma	Zingiberaceae	h	pd	gro	2	eg/bb	gr	1100	1350	my		my-dc	flowers
Etlingera littoralis (Kon.) Gise.	Zingiberaceae	h	pe	gro	3	streams, wet areas in mxf, egf	gr, ls	550	1300	ap-jn	oc-nv	ja-dc	flowers
Globba clarkei Baker	Zingiberaceae	h	pd	gro	3	rocks in mxf, egf	gr,ls	600	1400	jl-sp	oc-nv	my-dc	flowers
Globba schomburgkii Hk. f. var. *schomburgkii*	Zingiberaceae	h	pd	gro	3	egf, eg/bb	gr	1000	1300	jl-ag		my-dc	flowers
Hedychium ellipticum Ham. *ex* J.E. Sm.	Zingiberaceae	h	pd	epl	3	rocks in mxf,eg/bb cliffs	ls	1375	1425	jl-ag	sp	my-dc	flowers, fruits
Hedychium gardnerianum Rosc.	Zingiberaceae	h	pd	gro	3	egf, eg/pine, da	gr	1100	1500	sp-oc		my-dc	flowers
Zingiber bradleyanum Craib	Zingiberaceae	h	pe	gro	3	streams in egf, eg/bb	gr	1100	1300		nv	ja-dc	
Zingiber aff. *integrum* Tong	Zingiberaceae	h	pd	gro	3	mxf, da	ls	1300	1375	ag-sp	oc-nv	my-dc	flowers, imm. fruits
Zingiber kerrii Craib	Zingiberaceae	h	pd	gro	2	bb/df, eg/bb	gr	1000	1300	jl-ag	oc-nv	my-dc	
Zingiber smilesianum Craib	Zingiberaceae	h	pd	gro	3	egf, eg/bb	gr,ls	1000	1400	jl-ag	oc-dc	my-dc	fruits
Phrynium capitatum Willd.	Marantaceae	h	pe	gro	4	streams in egf	gr,ls	925	1350	my-jn	oc-nv	ja-dc	flowers
Allium chinense G. Don	Liliaceae	h	a	gro, cul, int	2	da	gr	1000	1100	sp-oc		my-dc	flowers
Asparagus filicinus Ham. *ex* D.Don	Liliaceae	h	pd	gro	3	egf, eg/bb	gr	900	1500	my		my-dc	flowers
Dianella ensifolia (L.) DC.	Liliaceae	h	pe	gro	3	egf, eg/bb	gr	1000	1500		jl-sp	ja-dc	

Table 5 (continued)

Disporopsis longifolia Craib	Liliaceae	h	pd	gro	2	eg/bb	gr	1000	1400	my-jn		ap-dc	flowers
Disporum calcaratum Wall. ex G. Don	Liliaceae	h	pd	gro	2	eg/pine, da, sg	gr	1000	1500	my-jn	oc-dc	my-dc	flowers,fruits
Ophiopogon longifolius Decne.	Liliaceae	h	pe	gro	3	egf, eg/bb	ls	1200	1400	my-sp	dc-ja	ja-dc	flowers, fruits
Ophiopogon reptans Hk.f.	Liliaceae	h	pe	gro	2	streams in eg/bb	gr	1100	1200	my-jn	nv-dc	ja-dc	fruits
Paris polyphylla J. E. Sm.	Liliaceae	h	pd	gro	2	rocks in egf cliffs	gr,ls	1200	1375	my-jn	sp	my-dc	
Peliosanthes teta Andr. *ssp. humilis* (Andr.) Jess.	Liliaceae	h	pd	gro	2	rocks, streams in egf	gr,ls	1000	1325			ja-dc	
Polygonatum kingianum Coll. & Hemsl.	Liliaceae	h	pd	gro	2	egf,eg/bb cliffs	ls	1375	1425	ap-my	sp-oc	ap-nv	flowers, fruits
Tupistra albiflora K. Lar.	Liliaceae	h	pe	gro	2	egf	ls	1300	1400	oc-nv		ja-dc	flowers
Dracaena angustifolia Roxb.	Agavaceae	l	pe	gro	2	rocks in egf, mxf	gr,ls, sh	500	1400		oc-nv	ja-dc	
Dracaena loureiri Gagnep.	Agavaceae	pe	pe	epl	2	rocks in egf, mxf cliffs	ls	500	1300			ja-dc	
Crinum wattii Baker	Amaryllidaceae	h	pd	gro	2	bb/df, eg/bb	gr	400	1250	my-jn		my-dc	
Curculigo capitulata (Lour.) O.K.	Amaryllidaceae	h	pe	gro	3	streams in egf, eg/bb	gr,ls	1000	1350	my-jn	ag-sp	ja-dc	flowers, fruits
Hypoxis aurea Lour.	Amaryllidaceae	h	pd	gro	2	da in eg/pine	gr	1200	1500	my-jl	jn-ag	my-nv	flowers, fruits
Smilax corbularia Kunth ssp. *Corbularia*	Smilacaceae	v	pe	gro	3	egf,eg/bb,da,sg	gr	1000	1450	jn		ja-dc	flowers
Smilax lanceifolia Roxb.	Smilacaceae	v	pe	gro	3	egf	gr, ls	1000	1500	ja-fb	jl-ag	ja-dc	flowers, fruits
Smilax ovalifolia Roxb.	Smilacaceae	v	pe	gro	3	egf, eg/bb	gr	800	1200			ja-dc	
Smilax perfoliata Lour.	Smilacaceae	v	pe	gro	3	da,sg,eg/bb,egf	gr	1000	1525		ap-jn	ja-dc	fruits
Aglaonema simplex (Bl.) Bl.	Araceae	h	pe	gro, epl	3	rocks in egf, mxf	gr,ls,s h	550	1350	mr-ap	sp-dc	ja-dc	flowers
Alocasia macrorhizos (L.) G. Don	Araceae	h	pe	gro	3	streams in egf, mxf	gr, ls	550	1350	my		ja-dc	

Table 5 (continued)

Alocasia	Araceae	h	pe	gro	2	streams in eg/bb	gr	1000	1200			ja-dc	
Amorphophallus yunnanensis Engl.	Araceae	h	pd	gro	3	rocks in eg/bb	gr, ls	1200	1425	fb-mr, my-jn	my-jl	jl-dc	flowers, fruits
Amorphophallus	Araceae	h	pd	gro	2	rocks in egf	ls	1300	1375		jl-ag	jn-dc	
Arisaema cuspidatum (Roxb.) Engl.	Araceae	h	pd	epl	2	rocks in egf, cliffs	ls	1200	1400	my-jn		my-nv	flowers
Colocasia fallax Schott	Araceae	h	pd	epl	3	rocks in mxf, egf, eg/bb, cliffs	gr,ls	500	1425	my-jn		my-dc	flowers
Pothos chinensis (Raf.) Merr.	Araceae	v	pe	epi, epl	3	streams, wet areas in egf, mxf, eg/bb	gr, ls	550	1375	ag-sp		ja-dc	flowers
Pseudodracontium	Araceae	h	pd	gro	2	rocks in mxf, eg/bb cliffs	ls	1375	1425			my-oc	
Rhaphidophora decursiva Schott	Araceae	v, cr	pe	epi, epl	3	mxf, egf, eg/bb	gr, ls,sh	525	1400	sp-oc		ja-dc	flowers
Rhaphidophora hookeri Schott	Araceae	v, cr	pe	epi, epl	3	streams in eg/bb, rocks in mxf, egf	gr,ls	550	1375	sp	my-jn	ja-dc	flowers, fruits
Rhaphidophora gigantea (Schott) Ridl.	Araceae	v, cr	pe	epl	3	rocks in egf, mxf cliffs	ls	500	1375	ag	fb	ja-dc	
Dioscorea alata L.	Dioscoreaceae	v	pd	gro, wee	3	da, sg	gr	800	1525	oc-nv		my-fb	flowers♂
Dioscorea birmanica Pr. & Burk.	Dioscoreaceae	v	pd	gro	3	rocks in mxf, egf, eg/bb	ls	1300	1425	jl-sp		my-dc	flowers♂
Dioscorea bulbifera L.	Dioscoreaceae	v	pd	gro	3	da,sg	gr	1100	1525			jn-dc	
Dioscorea decipiens Hk. f.	Dioscoreaceae	v	pd	gro	2	da, sg	gr	1000	1400	sp-nv	dc-mr	my-mr	
Dioscorea glabra Roxb. var. *glabra*	Dioscoreaceae	v	pe	gro	3	egf,da	gr	1000	1500	oc-nv		ja-dc	flowers♂
Dioscorea hamiltonii Hk. f.	Dioscoreaceae	v	pd	gro	3	da, sg	gr	1100	1500	oc-nv	dc-fb	my-fb	flowers♂
Dioscorea hispida Denn. var. *mollissima (*Bl.) Pr. & Burk.	Dioscoreaceae	v	pd	gro	3	eg/bb, da,sg	gr,ls	900	1400	my-jn		my dc	flowers, imm. fruits
Dioscorea pentaphylla L. var. *communis* Pr. & Burk.	Dioscoreaceae	v	pd	gro, wee	3	da,sg	gr	1000	1525	oc		jn-dc	flowers♂♀
Dioscorea prazeri Pr. & Burk.	Dioscoreaceae	v	pd	gro	3	egf, da	gr	1200	1350	sp-oc		my-dc	flowers♂

Table 5 (continued)

Dioscorea rockii Pr. & Burk.	Dioscoreaceae	v	pd	gro	3	rocks in mxf, eg/bb cliffs	ls	1300	1425	jl-ag		my-dc	flowers♂
Arenga ? westerhousii Griff.	Palmae	t	pe	gro, epl	2	rocks in egf	ls	1200	1350			ja-dc	
Calamus nambariensis Becc.	Palmae	s	pe	gro	2	rocks in egf, eg/bb	ls	1200	1375			ja-dc	
Caryota mitis Lour.	Palmae	l	pe	gro	2	streams in egf	gr	1000	1350			ja-dc	
Caryota maxima Bl.	Palmae	t	pe	gro	2	egf, eg/bb	gr	1000	1100	ja-dc	ja-dc	ja-dc	
Wallichia siamensis Becc.	Palmae	l	pe	gro	3	egf	gr,ls	1200	1375	sp-oc		ja-dc	flowers
Pandanus sect. Rykia (de Vr.) Kurz	Pandanaceae	l	pe	gro	2	rocks in egf, cliffs	ls	1300	1375			ja-dc	
Pandanus sect. Rykia (de Vr.) Kurz	Pandanaceae	l	pe	gro	2	streams in bb/df, mxf	gr	500	600			ja-dc	
Tacca chantrieri Andre	Taccaceae	h	pe	gro	2	egf	ls	1200	1350			ja-dc	
Aphyllorchis montana Rchb. f.	Orchidaceae	h	pe	gro, sap	2	eg/bb, da	gr	1200	1300	ag-sp	sp-oc	leafless	flowers, fruits
Arundina graminifolia (D.Don) Hochr.	Orchidaceae	h	pe	gro	2	da	gr	1000	1300	jl-oc		ja-dc	flowers
Bulbophyllum affine Lindl.	Orchidaceae	h, cr	pe	epi	2	egf, eg/pine	gr	1200	1400	my		ja-dc	flowers
Bulbophyllum pulchellum Ridl.	Orchidaceae	h	pd	epi	2	rocks in mxf, eg/bb cliffs	ls	1375	1425	sp-oc		my-dc	flowers
Calanthe labrosa (Rchb. f.) Rchb. f.	Orchidaceae	h	pd	epi,epl	2	rocks in mxf, egf	ls	1300	1425	oc-dc		my-nv	flowers
Cleisostoma racemiferum (Lindl.) Garay	Orchidaceae	h	pe	epi	2	rocks in mxf, eg/bb cliffs	ls	1300	1425	jl-ag		ja-dc	flowers
Coelogyne lactea Rchb. f.	Orchidaceae	h	pe	epl	3	rocks in mxf cliffs	ls	1200	1425	fb-mr		ja-dc	flowers
Collabium	Orchidaceae	h	pe	gro	2	streams in egf	gr,ls	1200	1300	my-jn		ja-dc	flowers
Corymborkis veratrifolia (Reinw.) Bl.	Orchidaceae	h	pe	gro	1	mxf	sh	550	550			ja-dc	
Crepedium acuminatum (D.Don) Szl.	Orchidaceae	h	pd	epl	2	rocks in mxf cliffs	ls	1375	1400	my-jn		ap-dc	flowers

Table 5 (continued)

Cymbidium lancifolium Hk.	Orchidaceae	h	pe	gro	2	eb/bb	gr	1200	1300	dc-ja	nv-ja	ja-dc	flowers, fruits
Cymbidium	Orchidaceae	h	pe	epi	2	eg/bb	gr	1100	1300		oc	ja-dc	
Dendrobium compactum Rol. ex Hack.	Orchidaceae	h	pd	epi	2	rocks in mxf cliffs	ls	1400	1425	oc		my-dc	flowers
Dienia ophrydis (Koen.) Orm. & Seid.	Orchidaceae	h	pd	gro	2	da, eg/pine	gr	1100	1350	jn-ag	sp-oc	my-dc	flowers
Eria bilobulata Seid.	Orchidaceae	h	pd	epi, epl	3	rocks in mxf, eg/bb cliffs	ls	1300	1425	jl-ag	oc	my-dc	flowers
Eria globulifera Seid.	Orchidaceae	h	pd	epi	3	rocks in mxf, eg/bb cliffs	ls	1300	1425	jl-ag	oc	my-dc	flowers
Eulophia macrobulbon (Par. & Rchb. f.) Hk. f.	Orchidaceae	h	pd	gro	2	eg/pine, da	gr	1200	1400	jn-jl		ag-dc	flowers
Eulophia spectabilis (Denn.) Sur.	Orchidaceae	h	pd	gro	2	da, sg	gr	1100	1300	my		jn-dc	
Habenaria furcifera Lindl.	Orchidaceae		pd	epl	3	rocks in mxf, eg/bb cliffs	ls	1400	1425	jl-ag		my-dc	flowers
Habenaria malintana (Blanco) Merr.	Orchidaceae	h	pd	gro	2	bb/df, eg/bb	gr	850	1400	oc		my-dc	flowers
Hemipilia calophylla Par. & Rchb. f.	Orchidaceae	h	pd	epl	1	rocks in mxf, eg/bb	ls	1350	1425	jl-ag		my-dc	flowers
Liparis olivacea Lindl.	Orchidaceae	h	pd	gro	3	bb/df,eg/bb	gr	1100	1300	jl-ag		my-dc	flowers
Liparis viridiflora (Bl.) Lindl.	Orchidaceae	h	pe	epi, epl	3	rocks in mxf cliffs	ls	1375	1425	ag-sp	oc	ja-dc	flowers
Liparis tenuis Rol. *ex* Dow.	Orchidaceae	h	pd	epi	2	rocks in mxf, eg/bb cliffs	ls	1350	1425	jl-ag		my-dc	flowers
Nervilia aragoana Gaud.	Orchidaceae	h	pd	gro	2	mxf, eg/bb	ls	1200	1350			jn-dc	leaves
Nervilia crociformis (Zoll. & Mor.) Seid.	Orchidaceae	h	pd	gro	2	bb/df, eg/bb	gr	1100	1300			my-dc	leaves
Oberonia	Orchidaceae	h	pe	epi	2	rocks in eg/bb ,mxf, cliffs	ls	1200	1425		fb-mr	ja-dc	
Ornithochilus difformis (Wall. *ex* Lindl.) Schltr.	Orchidaceae	h	pe	epi	2	egf, eg/bb	gr	1100	1400	jl-ag		ja-dc	flowers
Panisea uniflora (Lindl.) Lindl.	Orchidaceae	h	pe	epi	4	rocks in egf, mxf cliffs	ls	1300	1425	ap	ap-my	ja-dc	flowers, fruits

Table 5 (continued)

Paphiopedilum charlesworthii (Rol.) Pfitz.	Orchidaceae	h	pe	epl	0,1	rocks in mxf, eg/bb cliffs	ls	1200	1425			ja-dc	
Peristylus constrictus (Lindl.) Lindl.	Orchidaceae	h	pd	gro	2	eg/bb	gr	1250	1400	my		my-dc	flowers
Peristylus prainii (Hk. f.) Krzl.	Orchidaceae	h	pd	gro	2	bb/df	gr	1000	1100	my-jn		my-nv	flowers
Pholidota articulata Lindl.	Orchidaceae	h	pd	epi	3	rocks in mxf, cliff	ls	1300	1425			jn-dc	
Pholidota bracteata (D. Don) Seid.	Orchidaceae	h	pd	epi, epl	3	rocks in mxf, egf, eg/bb cliffs	ls	1200	1425		oc-ja	my-dc	fruits
Porpax lanii Seid.	Orchidaceae	h	pd	epi	3	mxf,egf,eg/bb	ls	1300	1425	jl-ag		my-dc	flowers
Thaia saprophytica Seid.	Orchidaceae	h	pd	gro, epl	2	rocks in egf	ls	1300	1375	oc		jn-nv	flowers
Trichotosia dasyphylla (Par. & Rchb. f.) Krzl.	Orchidaceae	h	pe	epi	3	eg/pine	gr	1200	1375			ja-dc	
?	Orchidaceae	h	pd	epl	2	rocks in egf cliffs	ls	1300	1400		oc-nv	jn-nv	fruits
Carex baccans Nees	Cyperaceae	h	pe	gro	3	da,sg	ls	1000	1400		ja-fb	ja-dc	fruits
Carex phyllocaula Nel.	Cyperaceae	h	pd	epl	2	rocks in egf, cliffs	ls	1300	1400	ag-sp	sp-oc	my-dc	fruits
Cyperus cyperoides (L.) O. K.	Cyperaceae	h	pe	gro,wee	3	da, sg	gr,ss	500	1500	ja-dc	ja-dc	ja-dc	
Cyperus exalatus Retz.	Cyperaceae	h	pe	gro	3	streams in egf, ponds, wet areas	gr	900	1100	my-jn	jn-jl	ja-dc	flowers
Cyperus kyllingia Endl.	Cyperaceae	h	pe	gro, wee	3	eg/pine, da, sg	gr,ss	800	1525	my-oc	jn-nv	ja-dc	flowers
Cyperus laxus Lmk. var. *laxus*	Cyperaceae	h	pe	gro, wee	3	mxf, eg/bb, da	gr, ls	500	1350	ag-oc	sp-nv	ja-dc	flowers
Cyperus phyllocaula Nel.	Cyperaceae	h	pd	epl	2	rocks in egf cliffs	ls	1300	1400	ag-sp	sp-oc	my-dc	fruits
Scirpus juncoides Roxb.	Cyperaceae	h	pe	gro	3	wet areas in da, sg	gr	800	1100	mr-my	mr-my	ja-dc	flowers
Apluda mutica L.	Gramineae	h	pe,pd	gro, wee	3	da, sg	gr,ls, sh,ss	800	1525	oc-dc	nv-ja	my-ja	flowers
Arthraxon lanceolatus (Roxb.) Hochst. var. *lanceolatus*	Gramineae	h	a	epl	3	rocks in bb/df, cliffs	ls	400	600	sp-oc	nv	my-dc	flowers

Table 5 (continued)

Arthraxon lancifolius (Trin.) Hochst.	Gramineae	h	a	gro, epl	3	rocks in bb/df, egf, eg/bb, da,sg, cliffs	gr,ls	400	1400	sp-oc	nv-ja	my-dc	flowers, fruits
Arundinella setosa Trin. var. setosa	Gramineae	h	pd	gro	3	eg/pine, da, sg	gr	1200	1325	nv-dc	dc-ja	my-dc	flowers
Bothriochloa bladhii (Retz.) S. T. Blake	Gramineae	h	pd	gro, wee	3	da, sg	gr	1100	1525	sp-ja	oc-fb	my-fb	flowers
Capillipedium parviflorum (R. Br.) Stapf	Gramineae	h	pe	gro, wee	3	da, sg	gr, ls	1000	1525	my-nv	jl-dc	ja-dc	flowers
Chloris pycnothrix Trin.	Gramineae	h	a	gro, int, nat, wee	3	da, sg	gr, ls	900	1375	my-dc	jn-ja	my-dc	flowers
Chrysopogon aciculatus (Retz.) Trin.	Gramineae	h	pe	gro, wee	3	da,sg	gr	700	1525	my-sp	jl-oc	ja-dc	
Cynodon dactylon (L.) Pers.	Gramineae	h	pe	gro,wee	3	da	gr,sh, ss	900	1200	ja-dc	ja-dc	ja-dc	flowers, fruits
Cyrtococcum accrescens (Trin.) Stapf	Gramineae	h	a	gro	3	eg/pine, eg/bb, da	gr, ls	400	1500	jn-oc	jl-nv	my-dc	flowers
Cyrtococcum oxyphyllum (Steud,) Stapf	Gramineae	h	pe	gro		eg/bb, da	gr, ls	1100	1400	ag-sp	sp-oc	ja-dc	flowers
Digitaria radicosa (Presl) Miq.	Gramineae	h	a	gro, wee	3	da, sg	gr	1000	1300	sp-nv	oc-dc	my-dc	flowers
Digitaria setigera Roth *ex* Roem. & Schult. var. *setigera*	Gramineae	h	a	gro, wee	3	da, sg	gr	800	1200	sp-ja	oc-fb	jn-fb	flowers
Echinochloa colona (L.) Link	Gramineae	h	pe	aqu, gro	3	ponds in bb/df	ls	400	600	ag-oc	sp-nv	ja-dc	flowers
Echinochloa stagnina (Retz.) P. Beauv.	Gramineae	h	pe	gro, wee	3	da, sg	gr, ls	1200	1525	sp-dc	oc-ja	ja-dc	flowers
Eleusine indica (L.) Gaertn.	Gramineae	h	pe	gro, wee	3	da	gr,ls	500	1525	jn-nv	jl-dc	ja-dc	
Imperata cylindrica (L.) P. Beauv. var. *major* (Nees) C..E. Hubb. *ex* Hubb. & Vaugh.	Gramineae	h	pe	gro, wee	4	da, sg	gr,ls	500	1525	my-oc	jn-dc	ja-dc	
Ischaemum	Gramineae	h	pd	epl	2	rocks in egf cliffs	ls	1300	1400	oc-nv	dc	my-dc	flowers
Lophatherum gracile Brongn. var. *gracile*	Graimineae	h	pd	gro	3	eg/bb, da	gr	1100	1300	sp-oc	oc-nv	my-dc	flowers
Melinus repens (Willd.) Zizka	Gramineae	h	a	gro, int, nat, wee	3	da, sg	gr	400	700	sp-oc	sp-oc	my-dc	
Microstegium vagans (Nees *ex* Steud.) A. Camus	Gramineae	h	pe	gro, wee	4	da, sg	gr, ls	450	1500	dc-ja	ja-fb	ja-dc	flowers

Table 5 (continued)

Mnesithea striata (Nees ex Steud.) Kon. & Sos.	Gramineae	h	pd	gro	3	da	gr	1000	1300	ag-oc	oc-nv	my-ja	flowers
Oplismenus burmannii (Retz.) P. Beauv.	Gramineae	h	pe	gro, wee	3	da, sg	gr	800	1500	oc-ja	nv-fb	ja-dc	flowers
Oplismenus compositus (L.) P. Beauv.	Gramineae	h	a	gro	3	da in eg/pine, eg/bb	gr, ls	400	1500	sp-oc	oc-nv	my-dc	flowers
Panicum brevifolium L.	Gramineae	h	a	gro, wee	3	da, sg	gr	900	1200	sp-oc	oc-nv	my-dc	flowers
Panicum maximum Jacq.	Gramineae	h	pe	gro, wee	3	da, sg	gr	500	1100	sp-oc	oc-nv	ja-dc	
Panicum notatum Retz.	Gramineae	h	pe	gro	3	egf, eg/bb	gr	1000	1450	my-jl	my-jl	ja-dc	flowers
Panicum repens L.	Gramineae	h	pe	gro	3	streams in eg/bb	gr	1000	1300	oc-dc	nv-ja	ja-dc	flowers
Paspalum conjugatum Berg.	Gramineae	h	a	gro, wee	3	da	gr, ls	1100	1525	ag-oc	sp-nv	my-dc	
Pennisetum purpureum Schumach.	Gramineae	h	pd	gro, wee	3	da, sg	gr	800	1500	nv-ja	dc-fb	jn-fb	flowers
Phragmites vallatoria (Pluk. *ex* L.) Veldk.	Gramineae	h	pe	gro, wee	4	da	gr,ls	500	1525	oc-dc	nv-ja	ja-dc	
Pseudoechinolaena polystachya (H.B.K.) Stapf	Gramineae	h	a	gro	3	egf,da,sg	gr,ls	550	1525	oc-nv	nv-dc	my-dc	flowers
Saccharum arundinaceum Retz.	Gramineae	h	pe	gro, wee	3	da, sg	gr,ls	500	1525	sp-dc	nv-ja	ja-dc	flowers
Saccharum spontaneum L.	Gramineae	h	pe	gro, wee	3	da, sg	gr, ls	400	1525	sp-dc	nv-ja	ja-dc	flowers
Sacciolepis indica (L.) A. Chase	Gramineae	h	a	gro, wee	3	da, sg	gr	900	1525	sp-dc	nv-ja	my-dc	flowers
Schizachyrium brevifolium (Sw.) Nees	Gramineae	h	a	gro	3	da,sg	gr	1000	1400	nv-dc	nv-dc	jn-dc	flowers, fruits
Setaria palmifolia (Koen.) Stapf var. *palmifolia*	Gramineae	h	pe	gro	3	da	gr, ls	1000	1525	ag-fb	sp-fb	ja-dc	flowers
Setaria parviflora (Poir.) Kerg.	Gramineae	h	a	gro, wee	3	eg/bb, da, sg	gr	1000	1525	sp-oc	oc-nv	my-dc	flowers
Themeda triandra Forssk.	Gramineae	h	pe	gro, wee	3	da, sg	gr, ls	500	1525	sp-oc	oc-nv	ja-dc	flowers
Thysanolaena latifolia (Roxb. *ex* Horn.) Honda	Gramineae	h	pe	gro, wee	3	da,sg	gr, ls	500	1525			ja-dc	

Table 5 (continued)

Bambusa balcooa Roxb.	Gramineae, Bambusoideae	h	pe	gro	3	streams in eg/bb cliffs	gr, ls	1100	1425	jl-ag	ag-sp	ja-dc	flowers
Dendrocalamus giganteus (Wall.) Munro	Gramineae, Bambusoideae	h	pe	gro	4	rocks in eg/bb	ls	1300	1425			ja-dc	
Dendrocalamus hamiltonii Nees & Arn. *ex* Munro	Gramineae, Bambusoideae	h	pe	gro	3	eg/bb	gr	1100	1300			ja-dc	
Dendrocalamus membranaceus Munro	Gramineae, Bambusoideae	h	pe	gro	4	eg/bb,da	gr	400	1500	nv-dc	ja-dc	ja-dc	flowers
Dendrocalamus nudus Pilg.	Gramineae, Bambusoideae	h	pe	gro	4	eg/bb,da	gr	900	1200	nv-fb	ja-mr	ja-dc	flowers
Dinochloa maclellandii (Munro) Gamb.	Gramineae, Bambusoideae	h	pe	gro	4	egf, eg/bb, da, sg	gr	1100	1450			ja-dc	
Gigantochloa apus (Schult.) Kurz	Gramineae, Bambusoideae	h	pe	gro	3	bb/df, eg/bb	gr, ls	500	1500			ja-dc	
Melocanna baccifera (Roxb.) Kurz	Gramineae, Bambusoideae	h	pe	gro	2	streams in mxf, eg/bb	gr	1000	1300			ja-dc	
Urochloa ruziziensis (Germ. & Evr.) Morr. & Zul.	Gramineae	h	pe	gro, int, nat, wee	3	da, sg	gr	800	1200	oc-ja	nv-fb	ja-dc	flowers

Table 6. List of other plant species arranged in morphological family surveyed at Doi Tung, Chiang Rai Province

Species	Family	Habit	Aped	Life mode	Abundance	Habitat	Bedrock	Lower	Upper	Flowering	Fruiting	Leafing	Collected
								Elevation (m)		Months			
Gymnospermae													
Pinus kesiya Roy. *ex* Gord.	Pinaceae	t	pe	gro also cul	2	eg/pine	gr	1200	1500	fb-mr		ja-dc	
Cephalotaxus griffithii Hk. f.	Cephalotaxaceae	t	pe	gro	2	egf	ls	1375	1400		jl-dc	ja-dc	fruits
Pteridophyta													
Lycopodium cernuum L.	Lycopodiaceae	h	pe	gro	3	egf,da,sg	gr	600	1300	ja-dc	ja-dc	ja-dc	strobili
Selaginella helferi Warb.	Selaginellaceae	v, h	a	gro	3	eg/bb, da	gr	500	1150	oc-fb	oc-fb	my-ja	sporangia
Selaginella involvens (Sw.) Spr.	Selaginellaceae	h	pd	epi,epl	3	rock in mxf, eg/bb	ls	1300	1425	jl-sp	jl-sp	my-dc	sporangia
Selaginella kurzii Bak.	Selaginellaceae	h	a	epl	3	rocks in bb/df cliffs	ls	400	800	sp-oc	sp-oc	jn-dc	sporangia
Selaginella minutifolia Spr.	Selaginellaceae	h	a	gro	3	eg/bb	ls	1100	1300	oc-nv	oc-nv	my-nv	sporangia

Table 6 (continued)

Selaginella roxburghii (Hk. & Grev.) Spr. var. *roxburghii*	Selaginellaceae	h	a	epl	3	rocks in mxf, egf, eg/bb cliffs	ls	1300	1400	sp-nv	sp-nv	my-dc	sporangia
Selaginella tenuifolia Spr.	Selaginellaceae	h	a	gro	3	egf, da	gr	900	1450	sp-nv	sp-nv	my-dc	sporangia
Equisetum debile Roxb. *ex* Vauch.	Equisetaceae	h	pe	gro	2	wet areas in bb/df	gr, ls	400	800			ja-dc	
Ophioglossum petiolatum Hk.	Ophioglosaceae	h	pd	gro, epi	2	egf, da	gr, ls	950	1375	jn-oc	jn-oc	my-dc	sori
Angiopteris evecta (Forst.) Hoffm.	Marattiaceae	h	pe	gro	3	streams in egf,eg/bb	gr	1100	1400	ja-dc	ja-dc	ja-dc	sori
Dicranopteris curranii Copel.	Gleicheniaceae	h	pe	gro	3	da	gr	1200	1350	jl-sp		ja-dc	sori
Dicranopteris linearis (Burm. f.) Underw. var. *linearis*	Gleicheniaceae	h	pe	gro	3	da	gr	600	1525	jn-sp		ja-dc	sori
Lygodium flexuosum (L.) Sw.	Schizaeaceae	v	pd	gro	3	eg/bb, da	gr	500	1500	sp-oc	sp-oc	my-dc	sori
Lygodium polystachyum Wall. *ex* Moore	Schizaeaceae	v	pe	gro	3	bb/df, eg/pine, eg/bb	gr	700	1100	ap-jl	ap-jl	ja-dc	
Hymenophyllum polyanthos (Sw.) Sw.	Hymenophyllaceae	h	pe	epi	2	egf	ls	1200	1375	sp-nv	sp-nv		sori
Cibotium baromtez (L.) J. Sm.	Dicksoniaceae	h	pe	gro	3	egf, da	ls	1200	1500	sp-oc	sp-oc	ja-dc	sori
Microlepia speluncae (L.) Moore	Dennstaedtiaceae	h	pe	gro	3	eg/bb, da	gr	1200	1500	ja-dc	ja-dc	ja-dc	sori
Pteridium aquilinum (L.) Kuhn *ssp. aquilinum* var. *wightianum* (Ag.) Tyr.	Dennstaedtiaceae	h	pe	gro	4	da, sg	gr, ls	1000	1525			ja-dc	
Sphenomeris chinensis (L.) Maxon var.*chinensis*	Lindsaeaceae	h	pe	gro	3	egf,da	gr	1100	1400	ja-dc	ja-dc	ja-dc	sori
Araiostegia imbricata Ching	Davalliaceae	h	pd	epi	3	rocks in mxf, eg/bb cliffs	ls	1300	1425	jl-sp	jl-sp	my-dc	sori
Davallia trichomanoides Bl. var. *lorranii* (Hance) Holtt.	Davalliaceae	h	pd	epi	3	egf	gr	1000	1300	jl-sp		my-dc	sori
*Davallodes membranulosum (*Wall. *ex* Hk.) Copel.	Davalliaceae	h	pd	epi, epl	3	rocks in bb/df, mxf, cliffs	ls	1300	1425	jl-sp	jl-sp	my-dc	sori
Leucostegia immersa Presl	Davalliaceae	h	pd	epi, epl	3	rocks in mxf, eg/bb cliffs	gr, ls	1300	1425	jl-sp	jl-sp	my-dc	sori
Oleandra undulata (Willd.) Ching	Oleandraceae	h	pd	gro	3	eg/pine, eg/bb	gr	1100	1400	ag-oc	ag-oc	my-dc	sori
Adiantum philippense L.	Parkeriaceae	h	pd	gro, epl	3	mxf, egf, eg/bb	gr, ls	500	1250	sp-dc	sp-dc	my-dc	sori

Table 6 (continued)

Adiantum zollingeri Mett. *ex* Kuhn	Parkeriaceae	h	pd	epl	3	rocks in bb/df, mxf, eg/bb cliffs	gr, ls	500	1500	ag-oc	ag-oc	my-dc	sori
Cheilanthes fragilis Hk.	Parkeriaceae	h	pd	epl	3	rock in mxf, eg/bb cliffs	ls	1300	1425	jl-ag		my-dc	sori
Cheilanthes pseudoargentea (S.K.Wu) K. Iw.	Parkeriaceae	h	pd	gro	3	rocks in mxf, cliffs	ls	1375	1400	fb-ap	fb-ap	jn-ap	sori
Pityogramma calomelanos (L.) Link	Parkeriaceae	h	pe	gro	2	egf,da,sg	gr	1100	1200	oc-dc	oc-dc	ja-dc	sori
Pteris biaurita L.	Pteridaceae	h	pe	gro	3	mxf, da	gr, ls	500	1500	sp-oc	sp-oc	ja-dc	
Pteris longipes D. Don	Pteridaceae	h	pe	gro	2	streams in egf	gr, ls	1200	1350			ja-dc	
Pteris subquinata Wall. *ex* Ag.	Pteridaceae	h	pd	epl	3	rocks in egf cliffs	ls	1200	1400	sp-nv	sp-nv		sori
Pteris venusta O. K.	Pteridaceae	h	pe	gro	2	eg/bb, da	ls	1100	1350	ag-oc	ag-oc	ja-dc	
Asplenium cheilosorum Kunze *ex* Mett.	Aspleniaceae	h	pe	epl	3	rocks and streams in egf	gr	1100	1325	nv-fb	nv-fb	ja-dc	sori
Asplenium greviellei Wall. *ex* Hk. & Grev.	Aspleniaceae	h	pe	epl	3	rocks in eg/bb, mxf,cliffs	ls	1300	1400	sp-nv	sp-nv	ja-dc	sori
Asplenium interjectum Christ	Aspleniaceae	h	pd	gro	3	rocks in egf,eg/bb cliffs	ls	1300	1425	jl-sp	jl-sp	my-dc	sori
Asplenium obscurum Bl.	Aspleniaceae	h	pe	epl	2	streams in eg/bb	gr	1050	1200	ja-dc	ja-dc	ja-dc	
Blechnum orientale L.	Blechnaceae	h	pe	gro	3	streams in egf, wet areas in eg/bb	gr	500	1500	jn-nv	jn-nv	ja-dc	sori
Brainea insignis (Hk.) J. Sm.	Blechnaceae	h, l	pe	gro	3	egf, eg/pine	gr	1200	1450			ja-dc	sori
Woodwardia japonica (L. f.) Sm.	Blechnaceae	h	pe	gro	2,3	eg/bb, egf	gr, ls	1100	1400	jl-dc	jl-dc	ja-dc	sori
Bolbitis sinensis (Bak.) K. Iw. var. *sinensis*	Lomariopsidaceae	h	pe	epl	3	streams, wet areas in egf	gr, ls	900	1350	nv-ja	nv-ja	ja-dc	sori
Bolbitis virens (Wall. *ex* Hk. & Grev.) Schott var. *virens*	Lomariopsidaceae	h	pe	epl	2	rocks, streams in egf	gr,ls	1000	1325			ja-dc	
Blechnum orientale L.	Dryopteridaceae	h	pe	gro	3	streams in egf	gr, ls	1100	1300	dc-fb	dc-fb	ja-dc	sori
Brainea insignis (Hk.) J. Sm.	Dryopteridaceae	h	pe	gro	3	eg/bb,da	gr	1100	1400	nv-dc	nv-dc	ja-dc	sori
Dryopteris cochleata (D. Don) C. Chr.	Dryopteridaceae	h	pe	gro	3	eg/bb,da	gr	1100	1400	nv-dc	nv-dc	ja-dc	sori

Table 6 (continued)

Polystichum lindsaefolium Scort. *ex* Ridl.	Dryopteridaceae	h	pe	epl	3	mxf, egf	ls	1300	1425	sp-nv	sp-nv	ja-dc	sori
Pteridrys cnemidaria (Christ) C. Chr. & Ching	Dryopteridaceae	h	pe	gro	2	streams in mxf	sh	500	700	nv-ja	nv-ja	ja-dc	sori
Tectaria decurrens (Presl) Copel.	Dryopteridaceae	h	pe	gro	3	streams in egf	gr, ls	1100	1300	dc-fb	dc-fb	ja-dc	sori
Tectaria herpetocaulos Holtt.	Dryopteridaceae	h	pe	gro	3	egf, eg/bb	gr, ls	550	1375	sp-nv	sp-nv	ja-dc	sori
Thelypteris nudata (Roxb.) Mort. var. *nudata*	Thelypteridaceae	h	pe	gro	3	mostly streams, wet areas in eg/bb, egf	gr, ls	1100	1500	jl-oc	jl-oc	ja-dc	sori
Thelypteris parasitica (L.) Fosb.	Thelypteridaceae	h	pe	gro	3	egf,da,sg	gr	1100	1500	ja-dc	ja-dc	ja-dc	sori
Thelypteris subelata (Bak.) K. Iw.	Thelypteridaceae	h	pe	gro	3	egf,eg/bb	ls	1125	1400	sp-nv	sp-nv	ja-dc	sori
Thelypteris terminans (Hk.) Tag. & K. Iw.	Thelypteridaceae	h	pe	gro	3	eg/bb	gr,ls	800	1250	ag-dc	ag-dc	ja-dc	sori
Thelypteris truncate (Poir.) K. Iw.	Thelypteridaceae	h	pe	gro	2	streams in egf, eg/bb	gr	1000	1200	ja-dc	ja-dc	ja-dc	sori
Aniscocampium cumingianum Presl	Athyriaceae	h	pd	gro	3	bb/df, eg/bb	gr, ls	550	1100	sp-nv	sp-nv		sori
Athyrium anisopterum Christ	Athyriaceae	h	pd	gro	3	bb/df, eg/bb	gr	1000	1400	jl-sp		my-dc	sori
Diplazium esculentum (Retz.) Sw.	Athyriaceae	h	pe	gro	3	streams in bb/df, wet areas in eg/bb	gr	700	1150	ja-fb	ja-fb	ja-dc	sori
Diplazium muricatum (Mett.) v. A. v. Ros.	Athyriaceae	h	pe	gro	3	rocks in egf,eg/bb	ls	1125	1400	oc-nv	oc-nv	ja-dc	sori
Aglaomorpha coronans (Wall. ex Mett.) Copel.	Polypodiaceae	h	pe	epi	2	eg/bb	ls	1100	1325			ja-dc	
Drymoglossum piloselloides (L.) Presl var. *piloselloides*	Polypodiaceae	h, cr	pe	epi, epl	3	rocks in mxf, egf	ls	1100	1400	ag-oc	ag-oc	ja-dc	sori
Drynaria propinqua (Wall. *ex* Mett.) J. Sm. *ex* Bedd.	Polypodiaceae	h	pd	epi	2	egf, eg/bb	gr, ls	1000	1500	jl-sp	jl-sp	my-ja	sori
Drynaria rigidula (Sw.) Bedd.	Polypodiaceae	h	pd	epi	3	eg/bb	gr	1000	1400	my-jl	my-jl	my-dc	sori
Lepisorus nudus (Hk.) Ching	Polypodiaceae	h	pe	epi	3	egf, eg/pine	gr, ls	1200	1525	ag-oc	ag-oc	ja-dc	sori
Leptochilus ellipticus (Thunb.) Noot.	Polypodiaceae	h	pe	gro	2	streams in egf, eg/bb	gr, ls	1100	1350	ag-oc	ag-oc	ja-dc	sori

Table 6 (continued)

Loxogramme involuta (D. Don) Presl	Polypodiaceae	h	pe	epi,epl	3	rocks in mxf cliffs	ls	1300	1425	sp-nv	sp-nv	ja-dc	sori
Microsorum zippelii (Bl.) Ching	Polypodiaceae	h	pd	epi, epl	3	rocks and streams in egf, mxf, eg/bb cliffs	gr,ls	1000	1425	sp-ja	sp-ja	jn-fb	sori
Phymatosorus lucidus (Roxb.) P.S.	Polypodiaceae	h	pe	epl	3	rocks in mxf cliffs	ls	1200	1425	dc-ap	dc-ap	ja-dc	sori
Platycerium wallichii Hk.	Polypodiaceae	h	pd	epi	2	dof, eg/bb	gr	500	1050	ag-oc	ag-oc	jn-dc	
Polypodium mamneiense H.Christ	Polypodiaceae	h	pd	epi, epl	3	egf	ls	1100	1400	jl-sp	jl-sp	jn-dc	sori
Pyrrosia lingua (Thunb.) Far. var. *heteractis* (Mett. *ex* Kuhn) Hoven.	Polypodiaceae	h	pe	gro, epl	3	rocks in mxf cliffs	ls	500	1425	sp-dc	sp-dc	ja-dc	sori
Pyrrosia porosa (Wall. *ex* Presl) Hoven. var. *tonkinensis* (Gies.) Hoven.	Polypodiaceae	h	pe	gro, epi, epl	3	rocks in mxf, egf cliffs	gr, ls	1200	1425	sp-dc	sp-dc	ja-dc	sori
Bryophyta													
Anthocerotopsida													
Phaeoceros laevis (L.) Prosk.	Anthocerotaceae	h	pe	gro	2	eg/bb	gr	1100	1500	sp-oc	sp-oc	ja-dc	sporophyt e
Hepaticopsida													
Dumortiera hirsuta (Sw.) Nees	Marchantiaceae	h	pe	epl	3	rocks, streams in egf, eg/bb	gr	1100	1200	oc-nv	oc-nv	ja-dc	sporophyt e
Bryopsida													
Brachymenium nepalense Hk.	Bryaceae	h	pe	epi	3	eg/pine	gr	1450	1525	sp-oc	sp-oc	ja-dc	capsules
Brachymenium	Bryaceae	h	pe	epl	3	rocks in eg/pine	gr	1450	1525	sp-oc	sp-oc	ja-dc	capsules
Rhodobryum giganteum (Schwaegr.) Par.	Bryaceae	h	pe	epl	3	rocks in eg/bb, cliffs	ls	1200	1425	ag-oc	ag-oc	ja-dc	
Entodon macrocarpus (Hedw.) Mitt.	Entodontaceae	h	pe	epi	3	eg/pine	gr	1300	1450	my-ag	my-ag	ja-dc	capsules
Entodon macropodus (Medw.) Mitt.	Entodontaceae	h	pe	epl	3	rocks in egf, mxf	ls	1300	1425	sp-oc	sp-oc	ja-dc	capsules
Entodon plicatus C. Muell.	Entodontaceae	h	pe	epi	3	rocks in egf, eb/bb	ls	1200	1400	sp-nv	sp-nv	ja-dc	capsules

Table 6 (continued)

Fissidens nobilis Griff.	Fissidentaceae	h	pe	epl	2	rocks, streams wet areas in egf	gr, ls	1200	1325			ja-dc	
Hypopterygium flavolimbatum Mull. & Hal.	Hypoterygiaceae	h	pe	epl	3	rocks in egf, cliffs	ls	1200	1400			ja-dc	
	Leskeaceae	h	pe	epi	3	egf	ls	1300	1425			ja-dc	
Leucobryum aduncum Dozy & Molk. var.*scalare* (C. Muell. *ex* Fleisch.) A. Eddy	Leucobryaceae	h	pe	epi	3	eg/bb	gr	1100	1400	jl-nv	jl-nv	ja-dc	capsules
Meteoriopsis squarrosa (Hk.) Fleish. var. *squarrosa*	Meteoriaceae	h	pe	epi, epl	4	rocks, cliffs	ls	1200	1425			ja-dc	
Papillaria semitorta (C. Muell.) Jaeg.	Meteoriaceae	h	pe	epi	4	rocks in mxf, cliffs	ls	1300	1425			ja-dc	
Plagiomnium succulentum (Mitt.) Kop.	Mniaceae	h	pe	epl	3	rocks in mxf, egf, cliffs	ls	1200	1400			ja-dc	
Himantocladium plumula (Nees) Fleisch.	Neckeraceae	h	pe	epi	3	egf, cliffs	ls	1300	1425			ja-dc	
Stereophyllum	Plagiotheciaceae	h	pe	epi	3	egf, eg/pine	gr	900	1200	jl-sp	jl-sp	ja-dc	capsules
Pogonatum neesii (C.Muell.) Dozy	Polytrichaceae	h	pe	gro	4	eg/bb	gr	1100	1400	oc-nv	oc-nv	ja-dc	capsules
Hyophila involuta (Hk.) Jaeg.	Pottiaceae	h	pe	epl	3	rocks in eg/pine	gr	1450	1525	sp-oc	sp-oc	ja-dc	capsules
Racopilum orthocarpum Wils. *ex* Mitt.	Racopiliaceae	h	pe	epi	3	egf	gr, ls	1100	1400	my-ag	my-ag	ja-dc	capsules
Rhytidium	Rhitidiaceae	h	pe	epi	3	eg/pine	gr	1450	1525	sp-oc	sp-oc	ja-dc	capsules
Targionia hypophilla L.	Targioniaceae	h	pe	epl	3	rocks in egf, cliffs	ls	1300	1425			ja-dc	
Thuidium orientale Mitt. *ex* Dix.	Thuidiaceae	h	pe	epi	3	mxf, egf, cliffs	ls	1200	1400			ja-dc	

Table 7. The distribution of plants surveyed in Doi Tung, Chang Rai, Province

Division	Family	Species, ssp. var.
Angiospermae, Dicotyledonae	111	742
Angiospermae, Monocotyledonae	17	176
Gymnospermae	2	2
Pteridophyta	22	71
Bryophyta	18	22
TOTAL	**170**	**1013**

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Full Paper

Nickel-aluminium complex: a simple and effective precursor for nickel aluminate ($NiAl_2O_4$) spinel

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Abstract: A reaction of aluminium hydroxide, nickel nitrate and triethanolamine in ethylene glycol provided, in one step, a simple and effective nickel-aluminium complex precursor for $NiAl_2O_4$ spinel. On the basis of ^{1}H-, ^{13}C-NMR spectroscopy, and mass spectrometry, the possible structure of the complex was proposed as a trimetallic double alkoxide consisting of two four-coordinate TEA-Al (alumatrane) moieties linked via a bridging TEA group enfolding the Ni^{2+} cation. Transformation of the nickel-aluminium complex to pure spinel occurred when the complex precursor was pyrolysed at 1000°C for 5 h. The BET surface area of the pyrolysed product was found to be 31 m^2/g. In addition, the morphology of the powder product was examined by SEM.

Keywords: nickel complex, nickel aluminate, spinel, one-pot process

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Introduction

Nickel aluminate spinel ($NiAl_2O_4$) has received attention as a catalyst solid support due to its stability, strong resistance to acids and alkalis, and high melting point [1]. The ceramic material possesses a unique structure consisting of grains, grain boundaries, surfaces and pores, making it suitable for use as catalyst support when its microstructures are controlled [2].

Recently, the development of $NiAl_2O_4$ for advanced applications, especially as a solid support for metal catalysts, has been carried out. Salagre et al. studied the synthesis of $NiAl_2O_4$ for use as nickel catalyst support for the hydrodechlorogenation of 1,2,4-trichlorobenzene in the gas phase [1]. Rodeghiero et al. reported the transformation of Ni/Al layered double hydroxides to Ni/Al_2O_3 and Ni/$NiAl_2O_4$ composites which have found utility as methanation catalysts in the treatment of carbon monoxide rich gases [3]. Jin et al. focused on a new looping material based on the addition of the new binder, $NiAl_2O_4$, and applied it to chemical looping combustion [4]. Cesteros et al. discussed the effect of preparation conditions for nickel aluminium hydroxide gels and calcination temperatures on the final structure of the $NiAl_2O_4$. The obtained spinel may be consequently used in catalytic system of hydrogenation reactions and in preparation of more resistant reduced catalysts [5]. Joo and co-workers observed the effect of calcination temperatures on the catalytic activity and the stability of Ni/Al_2O_3 catalysts for CH_4 dry reforming [6]. However, for producing advanced ceramics, chemical routes offer many advantages over traditional methods, including control of homogeneity and purity of product, processing at lower temperatures, and control of the size, shape and distribution of the ceramic particles. Moreover, chemical techniques are often used for producing thin films and fibres [7-8].

Up to now, various synthetic routes for spinel have been reported, such as co-precipitation of hydroxides, sol-gel formation method, and solid-solid reaction [9-11]. However, the cost of starting materials, the homogeneity and purity, including processing temperatures are the most important disadvantages for these synthetic routes. A wide variety of inexpensive preceramic polymers derived directly from metal hydroxides and oxides has been therefore developed. One of the simple and straight- forward methods is the "oxide one-pot synthesis (OOPS)" process [12]. This method was applied to prepare $MgAl_2O_4$ spinel [13].

Recently, Laobuthee et al. studied the ceramic oxide of magnesium aluminate ($MgAl_2O_4$) spinel prepared via OOPS process for use as a humidity sensing material [14-16]. The obtained $MgAl_2O_4$ exhibited a similar performance compared to those prepared by other methods. The humidity responses of the spinel exhibited good linear relationship between the logarithm of resistance and the relative humidity (RH). The considerably high sensitivity and reproducibility of this spinel was also observed [14-16].

Due to the advantages of one-pot process as mentioned above and $NiAl_2O_4$ also having the same structure as $MgAl_2O_4$, in this research work the nickel-aluminium complex precursor of $NiAl_2O_4$ was then synthesised by the same procedure as the OOPS process. In our study, nickel nitrate was, however, employed as starting material in place of nickel oxide for preparing the nickel-aluminium complex.

Materials and Methods

Materials

Aluminium hydroxide hydrate, [$Al(OH)_3.xH_2O$] and nickel nitrate, [$Ni(NO_3)_2.6H_2O$] were purchased from Aldrich Chemical Co. Inc (USA) and Carlo Erba (Barcelona), respectively. They were used as received. Ethylene glycol [$HOCH_2CH_2OH$] was purchased from Carlo Erba (Barcelona), and distilled prior to use. Triethanolamine [TEA, $N(CH_2CH_2OH)_3$, 98% purity] was obtained from Carlo Erba (Barcelona) and used as received.

Instrumental

The complex precursor was characterised by ^1H- and ^{13}C-NMR (INOVA VARIAN NMR Spectrometer 400 MHz). The NMR spectrometer operating in the quadrature mode was used to obtain ^1H- and ^{13}C-NMR spectra. Typical ^1H-NMR spectrum consisted of 16 transients of 23,954 data points over a 6.39 kHz bandwidth using a 3.2 μs at 45° pulse. Typical ^{13}C-NMR spectrum consisted of 25,600 transients of 30,144 data points over a 25.16 kHz bandwidth using a 7.25 μs at 45° pulse. Deuterated dimethylsulfoxide (DMSO-d_6) was used as solvent for the complex precursor. Mass spectrum was obtained from ESI-MS (Bruker Esquire mass spectrometer). Methanol was used as a solvent to prepare a complex solution for MS measurement. The mass range of a complex was set from m/z 100 to 1000. The decomposition phenomena and weight loss of the complex was studied by thermogravimetric analysis (TGA) (Perkin-Elmer TGA 7). A sample (10 mg) was heated at a rate of 5°C/min in N_2 (20 psi) from 27-1000°C. The TGA balance flow meter was set at 20 psi N_2, while the purge flow meter was adjusted at 20 psi of synthetic air.

The pyrolysed sample was characterised by X-ray diffraction (XRD) (Phillips P.W.1830 diffractometer). The powder sample was spread on double-sided sticky tape and mounted on glass microscope slides. Diffraction patterns were recorded over a range of 2θ angles from 15 to 80° and the crystalline phase was identified from the Joint Committee on Powder Diffraction Standards (JCPDS) file No. 10-0339 [1-2, 5]. Fourier Transform infrared spectra of $NiAl_2O_4$ were obtained on a Perkin-Elmer 2000-FTIR. Potassium bromide (KBr), powdered with an agate mortar and pestle, was used as non-absorbing media. Samples (0.3-0.5 wt%) were rigorously mixed with the KBr powder to prepare pellet specimens for identifying the spinel phase. Scanning electron micrographs (SEM) were obtained with a JEOL JSM-6301F scanning microscope operating at an acceleration voltage of 20 kV, a work distance of 15 mm and magnification values in 10,000x to identify the powder sample microstructures. Samples were mounted on alumina stubs using a liquid carbon paste and then sputter coated with Au to avoid particle charging. The Brunauer-Emmett-Teller (BET) surface area was calculated from the nitrogen adsorption isotherms at 77 K using a Micromeritics ASAP 2020 surface analyser and a value of 0.162 nm^2 for the cross-section of the nitrogen molecule. Samples were degassed at 350°C under high vacuum for 20 h before measurement.

Methods

The nickel-aluminium complex for $NiAl_2O_4$ spinel was prepared via one pot process as follows. Aluminium hydroxide hydrate, [$Al(OH)_3.xH_2O$ (63.2% as Al_2O_3 16.10 g, 100 mmol)], nickel nitrate hydrate [$Ni(NO_3)_2.6H_2O$ (29.07 g, 100 mmol)], 3 mol equivalent of triethanolamine (TEA, 40.0 ml, 300 mmol) and 60 ml of ethylene glycol (EG) as solvent, were added into a round bottomed flask. The mixture was then heated to 140°C to distill off EG and the water by-product produced during the reaction. The reaction mixture was continuously distilled for approximately 7 h. The homogeneous products obtained were characterised by ESI-MS, TGA, ^1H- and ^{13}C-NMR.

The nickel-aluminium complex was pyrolyzed in the horizontal tube furnace at 500°C for 5 h and then 1000°C for 5 h. The product was ground in an alumina mortar and then characterised by XRD, BET, and SEM.

Results and Discussion

In this present work, nickel nitrate was used instead of nickel oxide because it was easily dissolved in solvent as compared to nickel oxide. The reaction temperature for preparing the complex was consequently decreased to 140^o C. The reaction of $Al(OH)_3$, $Ni(NO_3)_2$, and TEA was complete in 7 h resulting in a clear and black-green color solution. The product solution became a black-green viscous product when EG was removed. The product showed a good solubility in water and alcohols, such as, ethanol, n-propanol, and iso-propanol.

The structure of nickel-aluminium complex was determined by electrospray ionization (ESI) technique. The major peak as the protonated parent ion appeared at m/z = 554. The possible structure of product was proposed to be a trimetallic species, consisting of one TEA ligand per metal center (Figure 1). To minimise the charge separation for the most stable structure of the dipositive cation complex, it was assumed that the Ni^{2+} ion is enfolded by the third TEA, whose oxygen and nitrogen atoms can donate electrons to complex with the nickel ion as shown in Figure 1 [13-15].

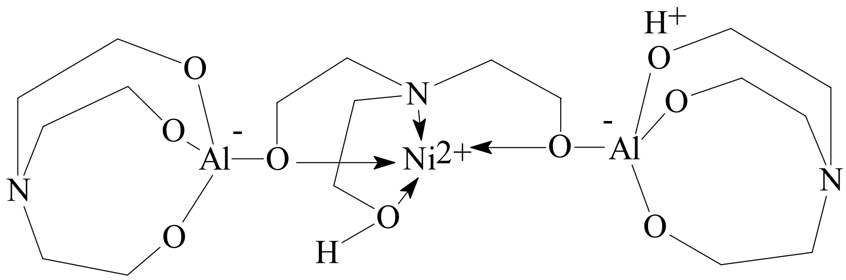

Figure 1. The proposed structure of nickel-aluminium complex (m/z =554)

The ^{1}H-NMR result for the nickel-aluminium complex is presented in Table 1. It was found that the peaks for methylene groups adjacent to oxygen and nitrogen atoms, occurred at chemical shifts of 3.452 ppm (triplet), and 2.637 ppm (triplet), respectively. Both peak positions shift 0.08 and 0.15 ppm respectively to downfield position compared to the free TEA.

Table 1. ^{1}H-NMR peak positions and assignments for nickel complex precursor

Peak position (ppm)	**Assignment**
2.49 (t)	$N(C\mathbf{H_2}CH_2OH)_3$, free TEA
3.37 (t)	$N(CH_2C\mathbf{H_2}OH)_3$, free TEA
4.45 (br)	OH of TEA either coordinated to Ni^{2+} or free TEA
2.64 (t)	$NC\mathbf{H_2}CH_2OAl$
3.45 (t)	$NCH_2C\mathbf{H_2}OAl$

The [13]C-NMR spectrum of the nickel-aluminium complex consists of four different peaks. The peaks at 54.759 and 59.646 ppm are assigned to the carbons of ethyleneoxy groups bound to Al while the peaks at 59.867 and 60.914 ppm are the most probable positions for the bridging TEA ligand (Table 2).

Table 2. [13]C-NMR peak positions and assignments for nickel complex precursor

Peak position (ppm)	Assignment
54.31	N(**C**$H_2CH_2OH)_3$, free TEA
54.76	N**C**H_2CH_2OAl
59.87	Bridging N**C**H_2CH_2O
59.65	NCH_2**C**H_2OAl
60.91	Bridging NCH_2**C**H_2O
63.45	N(CH_2**C**$H_2OH)_3$, free TEA

The results also showed that it is not easy to distinguish between the free ethyleneoxy and the bridging groups. It might be due to the fact that the carbon peak (and proton) positions of the free ethyleneoxy group are close to those of the two bridging groups. However, the retained free TEA could be burned out during the pyrolysis.

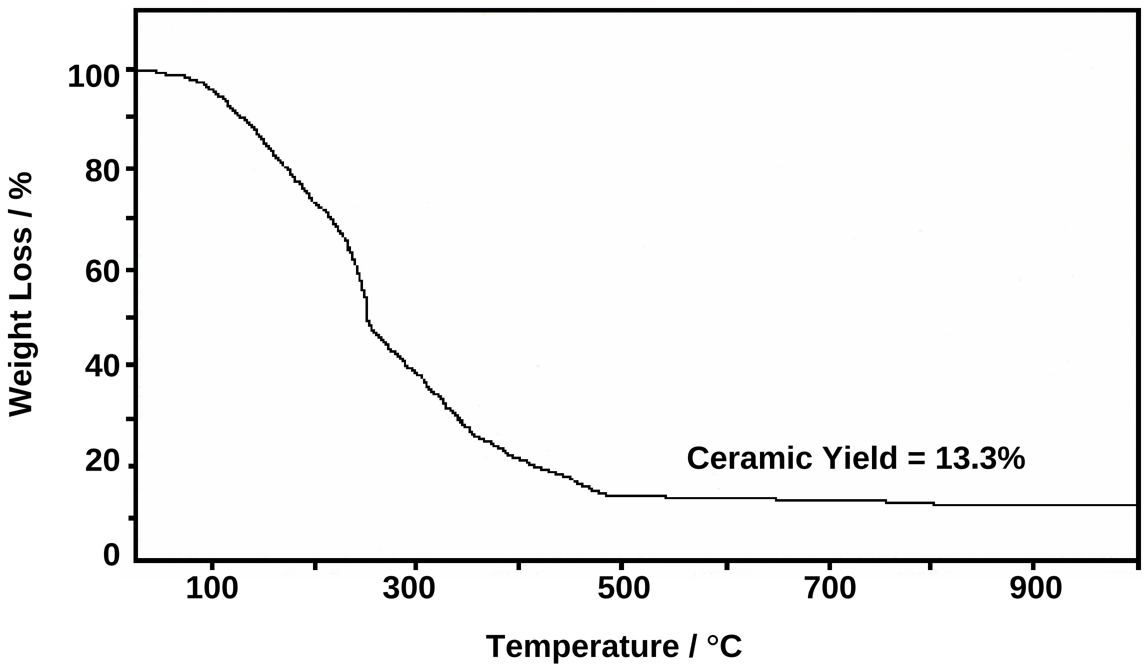

Figure 2. TGA thermogram of nickel-aluminate complex

To obtain $NiAl_2O_4$, the nickel-aluminium complex was then studied by TGA. The thermogram (Figure 2) shows three regions of mass loss. The first mass loss occurring between 100° and 250°C involved the decomposition of the organic ligand. In this step, volatiles and char were generated [13-15]. The char obtained was then oxidised during continuous heating from 250° to 500°C as shown in the region of second mass loss (Figure 2). The final mass loss occurred at 500-800°C. It should be noted that in the final mass loss, some $NiCO_3$ was formed. The formation of $NiCO_3$ during ligand decomposition could be confirmed by the FTIR result which shows a broad peak of low intensity and broad peak at approximately 1508 cm^{-1} (Figure 3).

After pyrolysing the complex at 500°C for 5 h and then at 1000°C for another 5 h, the obtained product had a blue colour. As the nickel-aluminium complex was a highly viscous liquid, the decomposition products, such as CO, CO_2, H_2O and volatile hydrocarbons produced during the pyrolysis of the complex were difficult to escape and retained in the resulting product. Consequently, a gas-filled and foam-like structure was obtained [13-15].

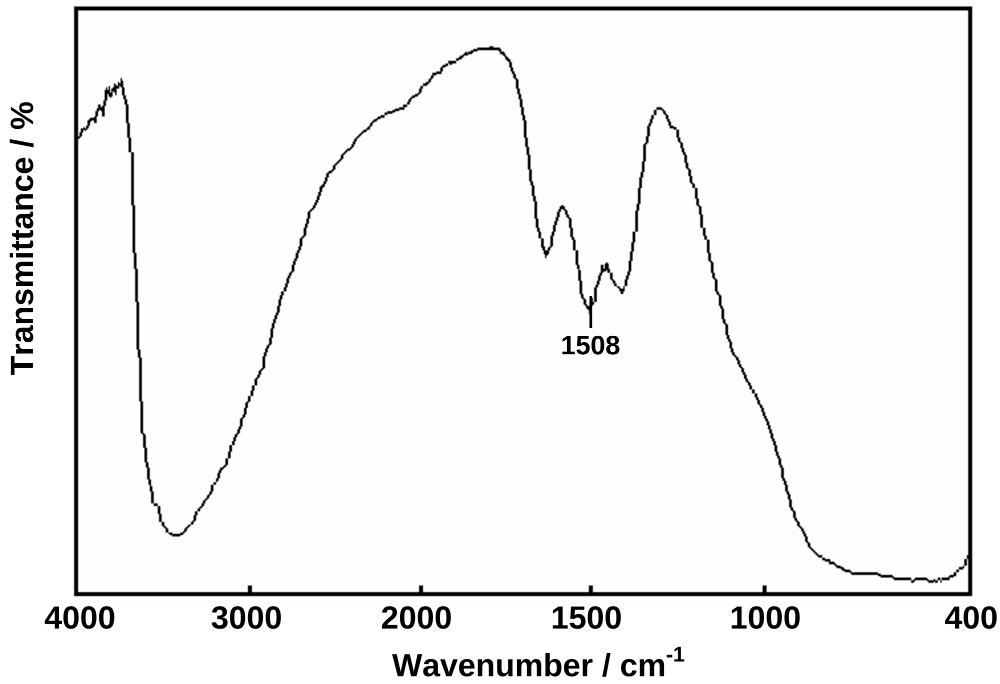

Figure 3. FTIR spectrum of the spinel precursor pyrolysed at 600°C for 5 h

Figure 4 shows the powder X-ray diffraction pattern of the $NiAl_2O_4$ obtained by calcination at 500°C for 5 h and then at 1000°C for another 5 h. All peak positions were identified by comparing with JCPDS file No. 10-0339. The major peaks for spinel were the *hkl* reflection of 311, 400 and 440. The diffraction peaks in Figure 4 indicate the phase purity of the $NiAl_2O_4$ spinel.

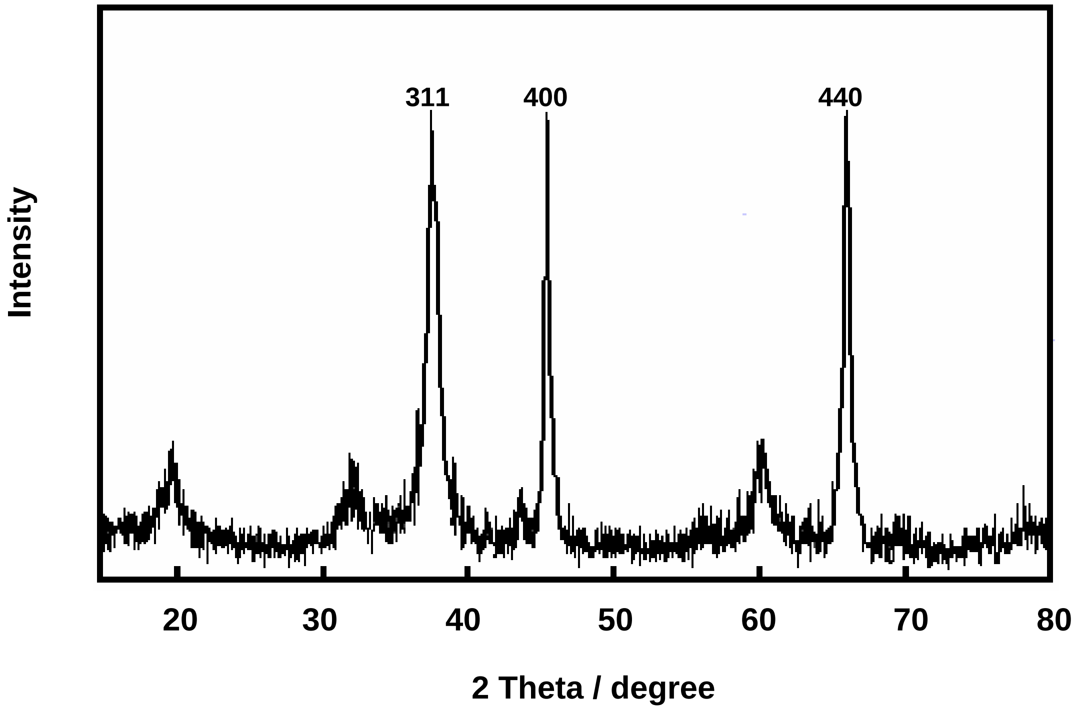

Figure 4. Powder X-ray diffraction pattern of the $NiAl_2O_4$

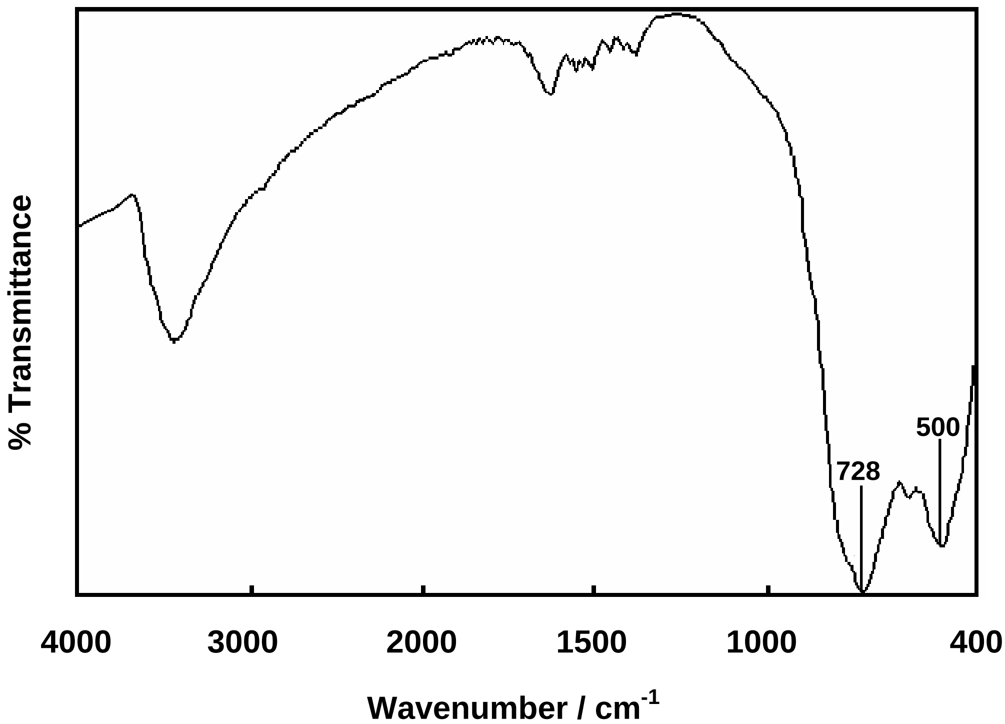

Figure 5. FTIR spectrum of the spinel precursor pyrolysed at 500°C for 5 h and then at 1000°C for 5 h

FTIR spectrum (Figure 5) shows two characteristic peaks of the spinel phase at approximately 728 and 500 cm^{-1}. The peak at 728 cm^{-1} is associated with the lattice vibrations of tetrahedrally coordinated Al-O. The peak at 500 cm^{-1} is associated with stretching vibration mode of Al-O for the octahedrally coordinated aluminium ion [17-18]. The broad peak at 3447 cm^{-1} represents the hydroxyl peak from either physisorbed water or hydrogen-bonded hydroxyl groups on the spinel surface.

The surface area of $NiAl_2O_4$ measured by BET analysis was 31 m^2/g while the pore volume examined by single point adsorption analysis was 0.10 cm^3/g and the pore size determined by adsorption average pore width analysis was 13 nm.

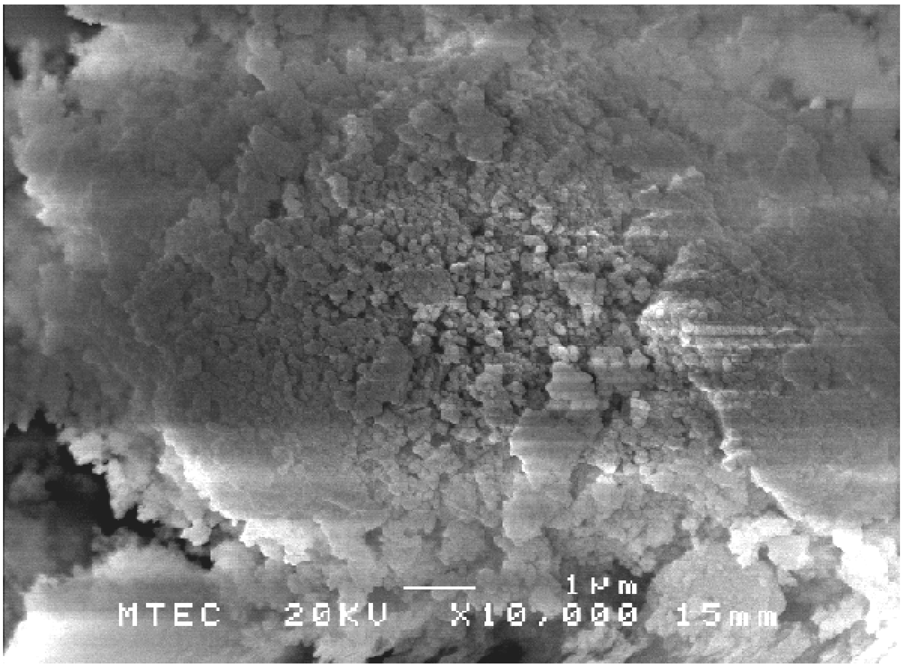

Figure 6. Scanning electron micrograph of $NiAl_2O_4$ (magnification x10,000)

The SEM micrograph of the $NiAl_2O_4$ powder is shown in Figure 6. The powder was irregularly shaped with blocky particles possibly due to the agglomeration generated during the precursor pyrolysis. The results from BET and SEM indicated that the powder obtained did not have a large surface area. However, the $NiAl_2O_4$ from the one-pot process was a highly pure compound compared with those from other previous methods [1-6].

Conclusion

The product obtained from the one-pot process was found to be a simple nickel-aluminium complex which was effective for use as a precursor for preparing pure $NiAl_2O_4$. Thus the "One Pot" process offers an inexpensive, straightforward alternative to solid-solid reaction, co-precipitation and other chemical techniques of ceramic processing, and retains the advantages of purity, homogeneity, low processing temperatures. In addition, owing to the ease of preparation and the process capability, the one- pot process may be used to prepare $NiAl_2O_4$ for catalyst applications.

Acknowledgements

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References

1. Y. Cesteros, P. Salagre, F. Medina, and J. E. Sueiras, "Synthesis and characterization of several Ni/$NiAl_2O_4$ catalysts active for the 1,2,4-trichlorobenzene hydrodechlorination", *J. Appl. Catal.*, **2000**, *25*, 213-227.
2. Y. Cesteros, P. Salagre, F. Medina, and J. E. Sueiras, "Simple synthesis and characterization of several nickel catalytic precursors", *J. Chem. Educ.*, **2002**, *79*, 489-491.
3. E. D. Rodeghiero, J. Chisaki, and E. P. Giannelis, "In situ microstructural control of Ni/Al_2O_3 and Ni/$NiAl_2O_4$ composites from layered double hydroxides", *J. Chem. Master.*, **1997**, *9*, 478-484.
4. H. Jin, T. Okamoto, and M. Ishida, "Development of a novel chemical-looping combustion: synthesis of a solid looping material of Ni/$NiAl_2O_4$", *J. Ind. Eng. Chem. Res.*, **1999**, *38*, 126-132.
5. Y. Cesteros, P. Salagre, F. Medina, and J. E. Sueiras, "Preparation and characterization of several high-area $NiAl_2O_4$ spinels: study of their reproducibility", *J. Chem. Master.*, **2000**, *12*, 331-335.
6. O-S. Joo and K-D. Jung, "CH_4 dry reforming on alumina-supported nickel catalyst", *Bull. Korean Chem. Soc.*, **2002**, *23*, 1149-1153.
7. G. L. Messing, S-C. Zhang, and G. V. Jayanthi, "Ceramic powder synthesis by spray pyrolysis", *J. Am. Ceram. Soc.*, **1993**, *76*, 2707-2726.
8. A. Gurav, T. Kodas, T. Pluym, and Y. Xiong, "Aerosol processing of materials", *Aerosol Sci. Technol.*, **1993**, *19*, 411-452.
9. R. J. Bratton, "Coprecipitates yielding $MgAl_2O_4$ spinel powders", *Am. Ceram. Soc. Bull.*, **1969**, *48*, 759-762.
10. Y. Ning and C. Li, "Structural inhomogeneity and crystallization behavior of aerosol-reacted $MgAl_2O_4$ powders", *Mater. Lett.*, **1992**, *15*, 84-88.
11. G. Gusmano, P. Nunziante, E. Traversa, and G. Chiozzini, "The mechanism of $MgAl_2O_4$ spinel formation from the thermal decomposition of precipitated hydroxide", *J. Eur. Ceram. Soc.*, **1991**, *7*, 31-39.
12. R. M. Laine, B. L. Mueller, and T. Hinklin, "Neutral and mixed neutral/anionic polymetallooxanes", U.S. Patent No. 5,418,298, May 23, **1995**.
13. K. F. Waldner, R. M. Laine, S. Dhumrongvaraporn, S. Tayaniphan, and R. Narayanan, "Synthesis of a double alkoxide precursor to spinel ($MgAl_2O_4$) directly from $Al(OH)_3$, MgO and triethanolamine and its pyrolytic transformation to spinel", *Chem. Mater.*, **1996**, *8*, 2850-2857.
14. A. Laobuthee, "Synthesis of $MgAl_2O_4$ spinel and its application as a humidity sensing element", *MSc. Thesis*, **1997**, Chulalongkorn University, Thailand.
15. A. Laobuthee, S. Wongkasemjit, E. Traversa, and R. M. Laine, "$MgAl_2O_4$ spinel powders from oxide one pot synthesis (OOPS) process for ceramic humidity sensors", *J. Eur. Ceram. Soc.*, **2000**, *20*, 91-97.

16. S. Wongkasemjit and A. Laobuthee, “3 Ways to $MgAl_2O_4$ spinel powders used as humidity sensor”, *J. Metals, Materials and Minerals*, **2001**, *10*, 13-27.
17. J. Preudhomme and P. Tarte., “Infrared studies of spinel, III: Normal II-III spinels”, *Spectrochim. Acta.*, **1971**, *27A*, 1817-1922.
18. N. M. Grimes, “Interpretation of the infrared spectrum of spinels”, *Spectrochim. Acta.*, **1973**, *28A*, 2217-2225.

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Full Paper

An investigation of a defensive chitinase against *Fusarium oxysporum* in pepper leaf tissue

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Abstract: Plant chitinase is classified as a PR-protein involved in a defense mechanism against a pathogen. This research aims to investigate a specific type of chitinase which is produced by pepper in response to an early defense against *Fusarium oxysporum*, which causes wilt disease. The changes of chitinase isozyme patterns in the inter- and intracellular fluids in the leaf of four cultivars of pepper (*Capsicum annuum* L.) at day 1, 3, 5, 7 and 10 from fungal inoculation were analysed using SDS-PAGE in polyacrylamide gel supplemented with glycol chitin as a substrate. The levels of disease severity in the four varieties of pepper were also compared with the isozyme patterns. The results showed that the resistance of pepper to *F. oxysporum* attack corresponded to the expression of ~70 kDa chitinase band (Chi-3) in the intercellular fluid. Therefore, such chitinase could possibly be used as a protein marker to identify the tolerant line and as a springboard for further study of wilt disease control.

Keywords: chitinase, isozyme, Fusarium oxysporum, PR-proteins, Capsicum annuum

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Introduction

Pepper (*Capsicum annuum* L.) is an economic crop in Thailand. The major problem of pepper plantation is mostly caused by fungal pathogen. The widespread of Fusarium wilts, provoked by *Fusarium oxysporum*, has been reported to be hardly controlled. Although the host plants are removed from the farm, the fungus may be left in the soil and re-infect the plants on the next cultivation [1]. To control such disease with a chemical pesticide can cause an environmental problem. Therefore, an investigation of a biological control method to inhibit the growth of this pathogen is a challenge.

Chitinase (EC 3.2.14) is an enzyme which catalyses the hydrolysis of chitin, the major cell wall component of many fungal pathogens [2]. Plant chitinase is characterised as one of the pathogenesis-related (PR) proteins. These proteins are induced by plants when they are infected by a pathogen. They form a protective barrier against the pathogen by collecting at infection sites and act to decrease the susceptibility of the plant [3]. Many studies have reported the success of fungal pathogen inhibition by chitinase isolated from plants [4, 5]. Transgenic plants with plant chitinase gene also show more resistance to pathogen infection [6].

Up to now, the biological control of *F. oxysporum* by chitinase isolated from pepper plant has not yet been reported. Generally, there are many types of chitinases in plants [7]. An investigation of the chitinase involved in the defense against *F. oxysporum* is therefore pertinent to the effectiveness of chitinase application. In this study, we focused on the investigation of the defensive chitinase in pepper plant by comparing the changes of the isozyme patterns with the disease severity in four cultivars of *C. annuum* L.

Materials and Methods

Chemicals and reagents

Tris(hydroxymethyl)-aminoethane-HCl (Tris-HCl) and sodium dodecyl sulfate (SDS) were purchased from GE Healthcare Bio-Sciences (Piscataway, NJ, USA). Phenylmethyl-sulfonyl fluoride (PMSF), bovine serum albumin (BSA), calcofluor white M2R, and standard proteins (high molecular weight) were obtained from Sigma-Aldrich (St. Louis, MO, USA). Unless stated otherwise, all other reagents and chemicals were obtained from Merck (Bangkok, Thailand). All chemicals were of analytical grade.

Plants

Pepper (*Capsicum annuum* L.) cultivars (cv.) used in this study were Huay Sri Ton, T2006, Chiwalee and Hithot obtained from Known-You Seed Co. Ltd. (43 Ratchaphuek Rd., Changpuak, Muang, Chiang Mai 53000, Thailand). The seeds were disinfected with 10% sodium hypochlorite for 15 min, and followed by 30 min rinses in sterile water. Seeds were germinated in plastic pots filled with sterilised clay loam. Pots were kept in a greenhouse at 30-35°C with a 14 h photoperiod. Water was supplied daily. Sampling was done at different time intervals as required. Six-week-old pepper seedlings were used for pathogen inoculation.

Fusarium oxysporum culture

F. oxysporum used in this study was isolated from *C. annuum* by the plant pathology research group from Plant Protection Research and Development Office, Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand. The culture was maintained on Potato Dextrose Agar (PDA, Himedia) at 35°C. Routine subculture was achieved by transferring a mycelial plug onto a fresh PDA plate.

Plant inoculation and disease assessment

The conidial suspension of *F. oxysporum* was prepared from the 7 day-old culture by washing the surface of colonies with sterile distilled water and scraping with a scalpel, then filtering through two layers of cheesecloth to remove mycelial fragments. The number of conidia in the suspension was adjusted to 10^7/ml following counting with a haemacytometer. The plants were inoculated by stem inoculation modified by the method of Sharma [8]. The stem was vertically cut (1 to 1.5 cm long) at 2 cm above the soil line with sterile sharp scalpel and then inoculated with 1 ml of *F. oxysporum* conidia suspension. After inoculation, the wound was sealed with a wet cotton swab and then covered with a plastic strip. For control, distilled water was used instead of conidia suspension. The inoculated and healthy plants were grown in a greenhouse under the condition described above.

The disease severity of Fusarium wilts in pepper plants was rated after inoculation of the fungus based on the following scale: 0 = no disease observed, 1 = slight stunting, 2 = slight stunting and chlorosis of leaves, 3 = $\leq$10% of the leaves showing chlorosis and/or 10% of the plant with wilt symptoms, 4 = 11-25% of the plant with wilt symptoms, 5 = 26-50% of the plant with wilt symptoms, 6 = 51-100% of the plant with the wilt symptoms or plant death [9]. The disease severity data were derived from the means of 10 inoculated plants. All experiments were repeated with similar results. Data are presented from one experiment only.

Preparation of intercellular fluid (IF) and intracellular fluid (In)

The leaves of infected and control plants were harvested at day 1, 3, 5, 7 and 10 after inoculation. Individual leaves from similar position on each plant were collected and pooled at each sampling time to account for variation in chitinase levels. The isolation of intercellular fluid (IF) of pepper leaves was carried out according to De Wit and Spikman [10], with slight modification. Briefly, a gram of harvested leaves was washed with distilled water three times and then submerged in 100 ml of a mixture of ice-cold 25 mM Tris-HCl, 10 mM $CaCl_2$, 10 mM $MgCl_2$, and 10 mM PMSF pH 7.8 in a vacuum flask under vacuum for 5 min. The leaves were gently blotted dry using paper towels and transferred into a 3 ml plastic syringe barrel. The syringe barrel was then sat on an eppendorf tube (without a lid). After centrifugation at 4000 rpm for 15 min at 4°C, the IF was recovered in the eppendorf tube and used immediately or stored at -80°C. The entire IF-free leaves were then frozen in liquid nitrogen and ground in a mortar containing 0.1 M sodium acetate buffer pH 5.2 (2.0 ml/g fresh weight) and sand. The homogenate was centrifuged for 10 min at 3000 rpm, followed by 20 min at 10000 rpm (4°C). The supernatant (intracellular fluid, In) was collected and used immediately or stored at -80°C.

Determination of protein concentration

The protein concentration of In and IF was determined using the method described by Bradford [11] with BSA as a standard.

Separation and detection of chitinase isoenzymes by SDS-PAGE

The In and IF of infected or control leaves were analysed by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) in 10% separating gel containing 0.04% (w/v) glycol chitin under non-reducing conditions as described by Trudel and Asselin [12]. Samples (15 μg protein) were denatured by boiling for in the denaturing buffer for 5 min. After electrophoresis, gels were incubated for 20 h in 100 mM sodium acetate buffer (pH 5.0) containing 1% (v/v) Triton X-100 to remove SDS from proteins and gels. Chitinase activities on gels were revealed by fluorescent staining using 0.01% (w/v) calcofluor white M2R in 50 mM Tris-HCl (pH 8.9) for 5 min, then washing with distilled water several times and destaining in distilled water for 2 h at room temperature. Gels were visualised under UV light; bands with lytic activity appeared as dark zones under UV light. To determine the apparent molecular weights of chitinase bands, the gels were further stained with Coomassie brilliant blue R-250. Bands with lytic activity appeared as white zones with blue background under daylight and were then compared with standard proteins (high molecular weight).

Results and Discussion

External symptoms of Fusarium wilt disease

To determine the resistance and susceptibility of pepper cultivars used in this study, disease severity was examined. The disease progress curves for pepper plants inoculated with conidia suspension of *F. oxysporum* are shown in Figure 1. Disease symptoms appeared 3 days after inoculation in all cultivars and directly increased with time. The development of disease symptoms in cv. Hithot was highest followed by cv. Chiwalee, T2006 and Huay Sri Ton. These results suggest that Huay Sri Ton was the best disease tolerant cultivar. In contrast, the most susceptible cultivar to pathogen attack was Hithot.

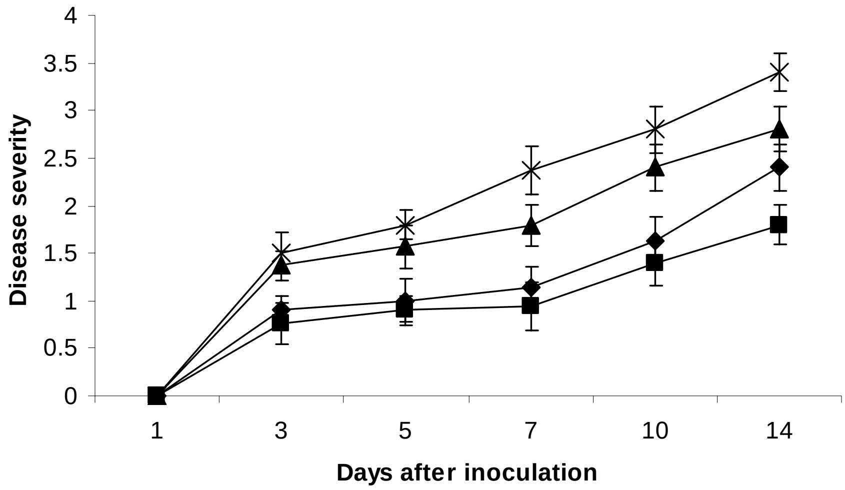

Figure 1. Disease severity of pepper plants after inoculation with *F. oxysporum*: ◆, T2006; ■, Huay Sri Ton; ▲, Chiwalee; ×, Hithot. Each bar represents a mean ± standard deviation from three replicates.

Chitinase isozyme of SDS-PAGE gels

IF and In protein extracts prepared from pepper leaves were separated on non-reducing SDS-PAGE. Glycol chitin was supplemented in the gel to detect bands of chitinase activity. Bands showing chitinolytic activity but differing in molecular weight are definded as chitinase isozyme. The chitinase isoenzyme patterns were examined at 0, 1, 3, 5, 7 and 10 days after inoculation because the early defense by chitinase in plant after pathogen inoculation has been reported [13]. In order to investigate the occurrence of chitinase in response to *F. oxysporum* in pepper plant, the changes of chitinase isozyme in inoculated plants were compared with the control. The SDS-PAGE results of each cultivar are shown in Figures 2-5.

Chitinolytic activity bands were detected at the day of inoculation in all cultivars. Although a plant may have never been infected, it nevertheless usually produces chitinase in order to protect itself from pathogen invasion [14]. The number of chitinolytic bands detected in IF and In of un-inoculated pepper plant varied. In IF, four chitinolytic bands were detected in cv.T2006 while the rest showed three chitionolytic bands. In contrast to IF, three chitinolytic bands were detected in In of cv.Huay Sri Ton, while the rest showed four chitinolytic bands.

However after inoculation with *F. oxysporum*, the change in the number of chitinolytic bands was found in cv.Huay Sri Ton. Interestingly, one band (ChiH-3) was significantly induced in both IF and In at 1 day after inoculation. Although no change of chitinolytic bands occurred in cv.T2006, Chiwalee or Hithot, the induction of Chi-3 was observed. Table 1 summarises the induction of Chi-3 detected on the gel of each cultivar. It can be seen that the disease severity was related to the induction of Chi-3 particularly in IF. This evidence was also observed in resistant cultivar of sorghum in response to fungal infection [15]. Liao *et. al.* [16] explained that the early defense against pathogen infection in plant mostly involve PR-protein found in IF.

Table 1. Induction of Chi-3 in intercellular fluid (IF) and intracellular fluid (In) of pepper cultivars after inoculation with *F. oxysporum*

Cultivar	Disease severity	Source	Induction of Chi-3	Day of appearance
Huay Sri Ton	1	IF	++	1
		In	+	1
T2006	2	IF	++	7
		In	+	7
Chiwalee	3	IF	-	-
		In	+	1
Hithot	4	IF	-	-
		In	-	-

Note: Level of induction is indicated by number of +. No induction of Chi-3 is shown by -.

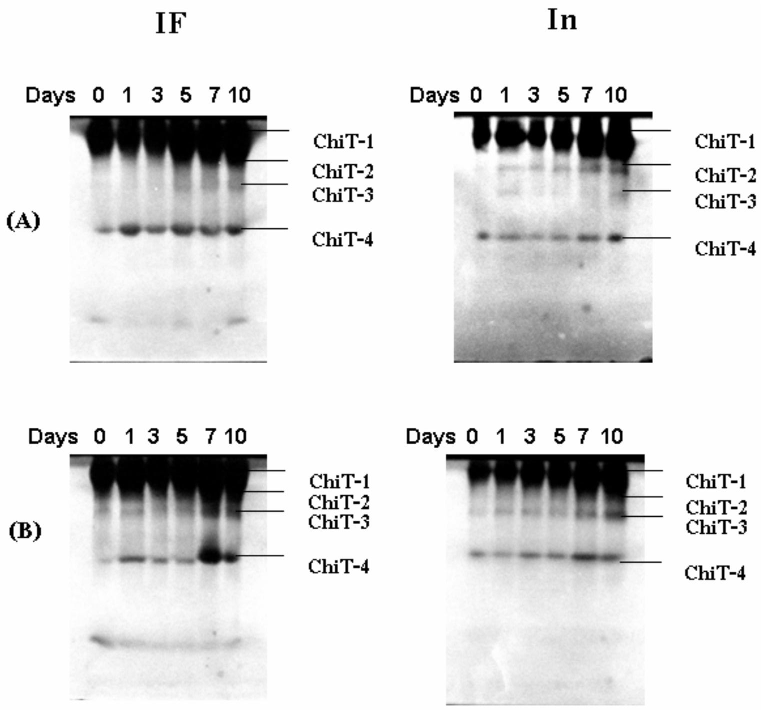

Figure 2. Chitinase isozyme patterns of intercellular fluid (IF) and intracellular fluid (In) from pepper leaves (cv.T2006) at 0, 1, 3, 5, 7 and 10 days after inoculation with *F. oxysporum* (B) comparing with water-treated control (A). All lanes were loaded with 15 μg proteins. Proteins were separated on 10% SDS-PAGE supplemented with glycol chitin. Bands with chitinase activity are indicated.

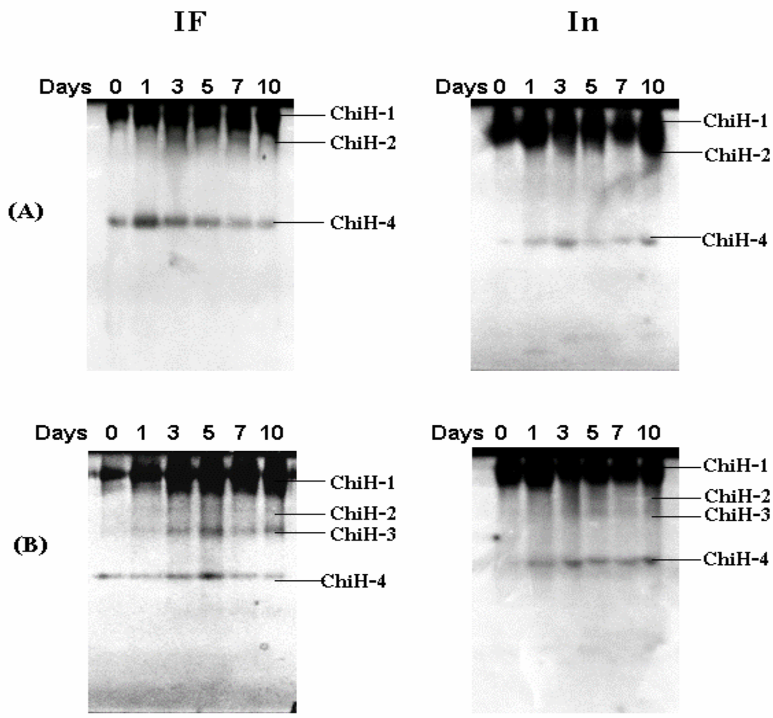

Figure 3. Chitinase isozyme patterns of intercellular fluid (IF) and intracellular fluid (In) from pepper leaves (cv. Huay Sri Ton) at 0, 1, 3, 5, 7 and 10 days after inoculation with *F. oxysporum* (B) comparing with water-treated control (A). Proteins were separated as stated above. Bands with chitinase activity are indicated.

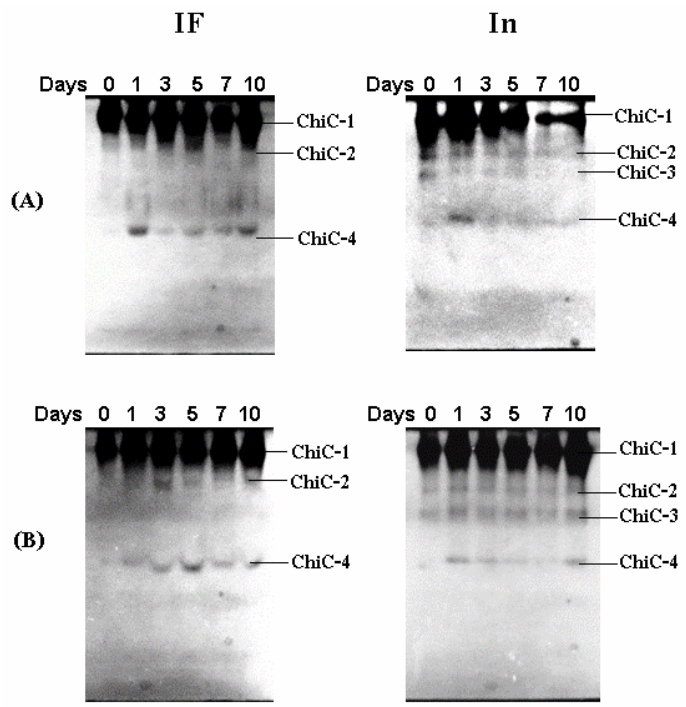

Figure 4. Chitinase isozyme patterns of intercellular fluid (IF) and intracellular fluid (In) from pepper leaves (cv. Chiwalee) at 0, 1, 3, 5, 7 and 10 days after inoculation with *F. oxysporum* (B) comparing with water-treated control (A). All lanes were loaded with 15 μg proteins. Proteins were separated on 10% SDS-PAGE supplemented with glycol chitin. Bands with chitinase activity are indicated.

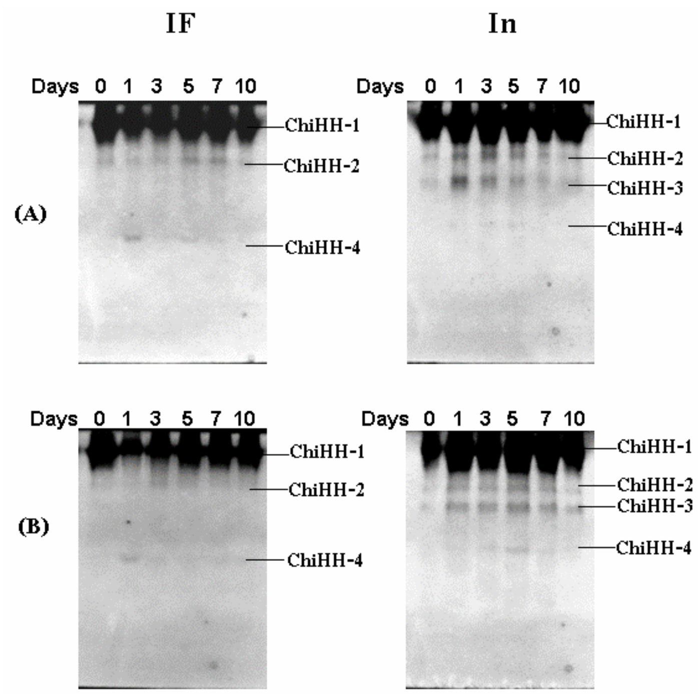

Figure 5. Chitinase isozyme patterns of intercellular fluid (IF) and intracellular fluid (In) from pepper leaves (cv. Hithot) at 0, 1, 3, 5, 7 and 10 days after inoculation with *F. oxysporum* (B) comparing with water-treated control (A). Proteins were separated as stated above. Bands with chitinase activity are indicated.

To determine the molecular weight of Chi-3, Coomassie staining was conducted. The result shows that the molecular weight of Chi-3 is approximately 70 kDa (data not shown). This protein could possibly be used as a protein marker to distinguish between resistant and susceptible cultivars of pepper plant. The chitinase band (~30 kDa) detected from chitinase isozyme was reported to successfully determine the *A. solani* resistant cultivar of tomato [17]. To use Chi-3 as a biological control agent, the study of *F. oxysporum* inhibition by this chitinase needs to be further carried out.

Conclusions

A chitinase responded in defense against *F. oxysporum* in pepper plant (*C. annuum* L.) was investigated by comparing the chitinase isoenzyme patterns in the intercellular and intracellular fluids obtained from the leaves of inoculated and un-inoculated plants. Disease symptoms in four cultivars of pepper plants were also evaluated. The result suggests that a chitinase (~70 kDa) in the intercellular fluid might be responsible for a defense against *F. oxysporum* in pepper plant.

Acknowledgements

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References

1. D. Fravel, C. Olivain, and C. Alabouvette, "*Fusarium oxysporum* and its biocontrol", *New Phytologist*, **2003**, *157*, 493-502.
2. S. Yuying and D. W. M Leung, "Elevation of extracellular β-1,3-glucanase and chitinase activities in rose in response to treatment with acibenzolar-S-methyl and infection by *D. rose*", *J. Plant Pathol*., **2001**, *158*, 971-976.
3. L. D. Huang, and D. Backhouse, "Analysis of chitinase isoenzymes in sorghum seedlings inoculated with *Fusarium thapsinum* or *F. proliferatum*", *Plant Sci*., **2006**, *171*, 539-545.
4. M. V. Gomes, A. E. A Oliveira, and J. Xavier-Filho, "A chitinase and a β-1,3-glucanase isolated from seeds of cowpea (*Vigna unguiculata* L. Walp) inhibit the growth of fungi and insect pests of the seed", *J. Sci. Food Agri*., **1996**, *72*, 86-90.
5. S. Karasuda, S. Tanaka, H. Kajihara, Y. Yamamoto, and D. Koga, "Plant chitinase as a possible biocontrol agent for use instead of chemical fungicides", *Biosci. Biotech. Biochem*., **2003**, *67*, 221-224.
6. K. Kishimoto, Y. Nishizawa, Y. Tabei, T. Hibi, M. Nakajima, and K. Akutsu, "Detailed analysis of rice chitinase gene expression in transgenic cucumber plants showing different levels of disease resistance to gray mold (*Botrytis cinerea*)", *Plant Sci*., **2002**, *162*, 655-662.
7. M. Legrand and B. Fritig, "Biological function of pathogenesis-related proteins: four tobacco pathogenesis-related proteins are chitinase", *PNAS*, **1987**, *84*, 6750-6754.
8. N. D. Sharma, L. K. Joshi, and S. C. Vyas, "A new stem inoculation technique for testing Fusarium wilt of pigeon-pea", *Indian Phytopathol*., **1977**, *30*, 406-407.

9. W. H. Elmer and R. J. McGovern, “Efficacy of integrating biologicals with fungicides for the suppression of Fusarium wilt of cyclamen”, *Crop Prot.*, **2004**, *23*, 909-914.
10. P. J. G. M. De Wit and G. Spikman, “Evidence for the occurrence of race- and cultivar-specific elicitors of necrosis in intercellular fluids of compatible interactions of *Cladosporium fulvum* and tomato”, *Physiol. Plant Pathol.*, **1982**, *21*, 1-11.
11. M. Bradford, “A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding”, *Anal. Biochem.*, **1976**, *72*, 248-254.
12. J. Trudel and A. Asselin, “Detection of chitinase activity after polyacrylamide gel electrophoresis”, *Anal. Biochem.*, **1989**, *178*, 362-366.
13. Y. Zhange and Z. K. Punja, “Induction and characterization of chitinase isoforms in cucumber (*Cucumis sativus* L.): effect of elicitors, wounding and pathogen inoculation”, *Plant Sci*., **1994**, *99*, 141-150.
14. Y. Suo and D. W. M. Leung, “Accumulation of extracellular pathogenesis-related proteins in rose leaves following inoculation of in vitro shoots with *Diplocarpon rosae*”, *Sci. Hort*., **2002**, *93*, 167-178.
15. S. Krishnaveni, S. Muthukrishnan, G. H. Liang, G. Wilde, and A. Manickam, “Induction of chitinases and β-1,3-glucanases in resistant and susceptible cultivars of sorgum in response to insect attack, fungal infection and wounding”, *Plant Sci.*, **1999**, *144*, 9-16.
16. Y. C. Liao, F. Kreuzaler, R. Fischer, H. J. Reisener, and R. Tiburzy, “ Characterization of a wheat class 1b chitinase gene differentially induced in isogenic lines by infection with *Pucciniagraminis*”, *Plant Sci*., **1994**, *103*, 177-187.
17. C. B. Lawrence, M. H. A. J Joosten, and S. Tuzun, “Differential induction of pathogenesis-related proteins in tomato by *Alternaria solani* and the association of a basic chitinase isozyme with resistance”, *Physiol. Mol. Plant Path*., **1996**, *48*, 361-377.

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Full Paper

Phytoremediation of kitchen wastewater by *Spirulina platensis* (Nordstedt) Geiteler: pigment content, production variable cost and nutritional value

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Abstract: Phytoremediation of domestic wastewater by *Spirulina platensis* was carried out using kitchen wastewater. A complete randomised design (CRD) was created for the experiment which was performed on modified Zarrouk's medium (Zm), 100% kitchen wastewater (100%Kw) and 90% kitchen wastewater (90%Kw). Water quality, biomass production, pigment content and nutritional value of *Spirulina platensis* were determined from cultures harvested every 5 days for a period of 15 days. The physico-chemical properties of cultivated wastewater were: water temperature 27-28 ^{o}C, pH 8.73-9.77 and DO 0.20-7.20 mg L^{-1}. The 100%Kw and 90%Kw produced lower BOD, COD, TP, NH_3-N, ON, TKN, NO_3-N, NO_2-N, TON and TN compared to Zm with $p< 0.05$. After cultivation, the treated kitchen wastewater met the standards for safe discharge in Thailand. The highest level of β-carotene of *S. platensis* was achieved in Zm (0.29 mg g^{-1}) and 100%Kw (0.29 mg g^{-1}) while the highest levels of C-phycocyanin were obtained in 100%Kw (17.95 mg g^{-1}) and 90%Kw (16.31 mg g^{-1}). The highest production variable cost for dry weight of *S.*

platensis was in Zm (310.6 Baht kg $^{-1}$) and 90%Kw (303.6 Baht kg $^{-1}$) as compared to 100%Kw (276.6 Baht kg $^{-1}$), with $p<0.05$. The highest biomass production of *S. platensis* was achieved in Zm (0.84 g L^{-1}) and 100%Kw (0.82 g L^{-1}), with protein content of 54.44% and 35.86%, respectively. Implications for the use of *S. platensis* for phytoremediation and C-phycocyanin production using of 100%Kw and 90% Kw are discussed.

Keywords: kitchen wastewater, nutritional value, pigment content, production variable cost, *Spirulina platensis*

Introduction

Remediation of wastewater to remove unwanted nutrients using microorganisms has been widely applied throughout the world. Some of the important advantages of using microalgae such as *Spirulina platensis* include the relative safety of the microorganism, the efficient removal of the primarily nitrogen- and phosphorous-containing nutrients, its rapid growth rate, and the ability to utilise the resulting algae as a food source for fish or farm animals. Kitchen wastewater has received relatively little attention although it can make a significant contribution to the polluted stream, especially from dining facilities in large institutions such as universities. It is rich in nutrients (nitrogen, phosphorous, fats, proteins, carbohydrates, etc.) and has relatively few toxic components that need to be removed owing to its origin in the food processing environment.

The conventional nitrogen sources for *S. platensis* are ammonia nitrogen (NH_3-N) and nitrate nitrogen (NO_3-N) [1]. Interesting research work has been carried out using animal wastes, wastewater and urban effluents as low-cost nitrogen sources [2]. In batch and fed-batch cultures, large *S. platensis* biomass production was demonstrated along with elevated pigment content [3-4]. Culturing *S. platensis* for animal feed purposes using inorganic culture media is relatively expensive because of the need to provide a full complement of nutrients. Low-cost alternatives such as wastewater should be evaluated as a more cost-effective method of producing this important nutritional product. In addition, production of *S. platensis* can improve water quality, as demonstrated in a recent study in Mexico involving use of 50% swine waste in a suspended system [5]. Significant biomass levels were obtained and wastewater nutrient levels were dramatically reduced.

Another study [6] achieved 96% total nitrogen (TN) and 54% total phosphorus (TP) removal by *S. platensis* in an outdoor raceway by treating 2% diluted anaerobic effluents from pig wastewater containing almost the same amount of nitrogen and phosphorus as in the experiment carried out as described in the present study. These studies, along with the present work on kitchen wastewater, clearly demonstrate that *S. platensis* cultivation can be considered as a promising approach to nitrogen and phosphorus removal from wastewater [2,7].

The improvement to effluents (lower N, P) from a pig manure biogas digester by *S. platensis* was described in 1999 [8-9]. The *S. platensis* biomass produced during the experiment could be used later as a dietary protein supplement in aquatic farming. All experimental ponds were continuously aerated. Water and algal samples were collected every 3 days over a culture period of 30 days. Over 98.99% of the NH_3-N was removed in all treatments and dilutions of different effluents, thus meeting the pollution control standards in Thailand. The COD was reduced by 97.13% in the 30% effluent dilution. The COD concentration after 30 days was also lower than the effluent standard of Thailand [26]. The highest biomass production (0.32 g L^{-1} as dry-weight) was achieved in the 50% effluent, where the chlorophyll-a content was between 38.6 and 69.2 μg L^{-1}[9]. However, the COD actually increased for this mixture.

Many studies have been carried out to examine microorganisms as a source of protein for human consumption and animal feed. Among these is the microalga *S. platensis*, one of the phytoplankton in the division Cyanophyta [10]. This organism has a protein content that ranges from 60 to 72% (dry weight) and contains 18% C-phycocyanin, 1.7% β-carotene, 1.6% chlorophyll-a, and 26-30% gamma linoleic acid (as percentage of total fatty acids) [11]. *S. platensis* has a low nucleic acid concentration and the amino acid content is similar to that recommended for human or animal consumption by the international Food and Agriculture Organization (FAO) [12]. C–phycocyanin is one of the major biliproteins of *S. platensis*, a blue green alga, with antioxidant and radical scavenging properties. It is also known to exhibit anti-inflammatory and anti-cancer properties.

The main objective of this study is to investigate the efficiency of *S. platensis* in improving the water quality of the effluent from kitchen wastewater and to determine the production variable cost of the resulting alga, as well as its content of β-carotene, C-phycocyanin and other nutritional components.

Materials and Methods

Kitchen wastewater preparation

One hundred litres of wastewater from the day's food and dish washing at the cafeteria kitchen in the Department of Biology, Chiang Mai University, were collected every Friday. This wastewater was placed in 100-L cement tanks and allowed to ferment for 3 weeks for microorganisms to break down the solid organic wastes. The liquid portion in each tank was then filtered through an 80-micron plankton net filter. The filtrate was taken for determination of temperature, pH, dissolved oxygen (DO) and BOD by azide modification, COD by closed reflux, NH_3-N by direct nesslerisation, NO_3-N by phenoldisulphonic acid, NO_2-N by diazotisation, TN by the macro Kjeldahl method, and TP by persulfate digestion/stannous chloride [13-14]. This filtrate, or "100%" solution (100%Kw), was diluted to 90% with tap water to make an additional starting solution (90%Kw). Greater dilutions were found to produce significantly lower growth rates, so only 100% and 90% solutions were used in this study [15].

S. platensis stock culture preparation

Stock Zm: *S. platensis* was cultured in modified Zarrouk's medium (Zm) in a 5-litre bottle and allowed to grow for 2 weeks until the optical density at 560 nm reached 1 (OD_{560nm}=1).

Modified Zarrouk's medium (Zm) [8]: this medium is composed of 2 g L^{-1} of $NaHCO_3$ (Qingdao Co., LTD, China), 1 g L^{-1} of NaCl (Purity Salt Industry, Co., LTD, Thailand), 1 g L^{-1} of $MgSO_4$ (UTIDS Enterprise Co., LTD, Thailand), 0.5 g L^{-1} of $NaNO_3$ (Qingdao) and 1 g L^{-1} of N:P:K (16:16:16, YARA International ASA Co., Ltd, Norway), adjusted to pH 10 $\pm$ 0.5 using NaOH.

Stock Kw: *S. platensis* from stock Zm was cultured in fermented 100%Kw in 50 L glass tanks and allowed to grow for 2 weeks until the optical density (OD) at 560 nm reached 1 ($OD_{560\ nm\ =\ 1}$). This stock Kw would then be used as "*S. platensis* inoculum" for the experiments in 100-L cement ponds.

Experimental design

A complete randomised design (CRD) was carried out using 3 treatments, each performed in triplicate. Initial physico-chemical properties were measured on the media before inoculation. *S. platensis* was obtained by first filtering 30 L of the stock solution (stock Kw) to give the "raw *S. platensis*." The control tanks consisted of the raw *S. platensis* added to 100 L of Zm. The treated tanks were 90% (90%Kw) and 100% (100%Kw) wastewater inoculated with raw *S. platensis*. The initial optical density of each tank was 0.30. All experimental tanks were cultured for 15 days with continuous aeration. Samples were collected every 5 days from each tank and analysed for their physico-chemical properties viz. temperature, pH, DO, BOD, COD, TP, NH_3-N, organic nitrogen, total Kjeldahl nitrogen (TKN), NO_3-N, NO_2-N, total oxidised nitrogen (TON) and TN. Algal biomass concentration was also determined by filtration using a 120- μm plankton net. Samples of *S. platensis* were analysed for production variable cost, nutritional content (protein, fat, ash, fiber, moisture), β-carotene and C-phycocyanin [16-18].

β-Carotene and C-phycocyanin analysis

The β-carotene concentration (mg g^{-1}, dry weight) in *S. platenisis* was determined by HPLC (Mightysil RP-18 GP, 5 µm, 150 x 4.6 mm ID column, Kanto Reagent Co., Ltd, Japan). The algal sample (0.75 g, dry weight) was homogenised in a homogeniser with hexane as extracting solvent, then filtered and the filtrate collected and evaporated to dryness. The residue was dissolved in methanol : chloroform (4:1) before injection. The mobile phase flow rate and the measured wavelength were 1 mL min^{-1} and 456 nm respectively. Authentic β-carotene (Sigma, USA) was run through the same procedure as described above [16]. The C-phycocyanin concentration (mg g^{-1}, dry weight) in *S. platenisis* was determined by HPLC (Agilent Technologies, USA) using a reverse phase ZORBAX Eclipse XDB-C-18 (5 µm, 150 x 4.6 mm) column. Approximately 1g (dry weight) of *S. platensis* was suspended in 10 ml of phosphate buffer solution (PBS), pH 7.2, and maintained in the dark at 4 ^{0}C for 16 h. The crude extract was then centrifuged at 10,000 rpm for 15 min at 4 ^{0}C to separate cell debris. The volume was adjusted to 10 ml with PBS. Then other components in the supernatant were precipitated by addition of solid ammonium sulfate (25% w/v final composition). The resulting C-phycocyanin-containing solution was evaporated to dryness. The solid residue was dissolved in 10 mL of a methanol:water mixture (1:1) prior to analysis by HPLC. The mobile phase was methanol:water (1:1), the flow rate was 0.50 mL/min, and the detector wavelength was 214 nm. Authentic C-Phycocyanin (Sigma Aldrich, USA) was run through the same procedure as described for the *S. platensis* samples [17].

Production variable cost and nutritional value

The production variable cost was calculated from the cost of *S. platensis* culture plus the variable costs, viz. nutrient cost, stock *S. platensis* cost, labour cost, and electricity and water cost [19]. Samples of *S. platensis* were analysed for their nutritional content (protein, fat, ash, fiber and moisture) [18].

Statistical analysis

Data were presented as mean values ± standard deviation. Comparison of mean values was made by one-way analysis of variance (ANOVA), followed by Duncan's multiple range test (DMRT) at a significance level of $p<0.05$ (SPSS Inc., Chicaco, USA, Ver.15).

Results and Discussion

Water quality

The water quality values for the kitchen wastewater filtrate are summarised in Table 1 and the progress of their changes is illustrated in Figure 1. After completing the 15-day experimental period, it was found that the physical and chemical properties of the water changed significantly (Table 1). All media showed an increase in pH during the period, consistent with the usual behaviour of blue green algal cultures. In the commercial growth of *S. platensis* the media employed have high pH (9.5-12) and high salinity and they are particularly selective for this organism, an important factor in preventing contamination of the reactor by bacteria, algae and protozoa [20]. A large increase in dissolved oxygen (DO) occurred for both preparations of kitchen waste media as a result of aeration. The optimum level of DO for algal cultures in water is normally more than 5 mg L^{-1} [21], thus the final solutions under aeration had adequate levels (6.12-7.20 mg L^{-1}). The initial level in the Zm medium was high since it was prepared using tap water containing considerable DO, and 90%Kw contained 10% tap water, resulting in a slightly elevated DO level compared to 100%Kw.

For 100%Kw and 90%Kw, the BOD decreased by 72.74 % and 71.08 % respectively. The chemical composition of Zm resulted in a low BOD initially since it contained no significant amount of biodegradable organic compounds such as protein, carbohydrate or fat. The present study showed a slightly larger decrease in BOD using kitchen wastewater than the 70% decrease during the cultivation of *S. platensis* in the 40% dormitory effluent from Maejo University [22]. With 100%Kw and

90%Kw the COD value decreased dramatically (72.6% and 73%), but somewhat less than in the cultivation of *S. platensis* in wastewater from the production of sago starch as reported by Canizares [5], where COD decreased by 98.00 %, and in the cultivation of *S. platensis* in 30% effluents from pig manure biogas digester reported by Promya and Traichiyaporn [9], where COD decreased by about 97% using different waste sources.

Improvement in water quality is often assessed by the ability of a process to reduce nutrient matter, especially nitrogen and phosphorous. Cultivating algae in water with high nutrient matter can dramatically reduce nitrogen and phosphorous levels and, at the same time, produce a useful product, such as algae for animal feed. Kitchen wastewater generally has a high level of nutrients and large quantities are produced every day at commercial and residential sites, so it is especially noteworthy that the experiment described in this work showed dramatic improvement in water quality, sufficient to meet the standard for discharge, and produced significant amounts of useful algal material.

Total phosphorous levels in all three media (Zm, 100%Kw and 90%Kw) were initially high (3.83-4.35 mg L^{-1}) and decreased by nearly the same percentages (50, 50.4 and 50.4 %, respectively). These are similar to those in other studies where 54-55% reductions were achieved [6, 23-25]. Ammonia nitrogen (NH_3-N) was not added to Zm, so the measured levels were near the detection limit. However, there were significant levels of NH_3-N initially in the kitchen wastewater (7.03 and 5.75 mg L^{-1} for 100%Kw and 90%Kw, respectively). Algae prefer to use NH_3-N than NO_3-N, and the optimum concentration range of nitrogen for algal growth is 1.3 - 6.5 mg L^{-1} [14]. After 15 days of cultivation, the NH_3-N levels dropped dramatically by 98.0 and 97.8 % for 100% Kw and 90% Kw respectively, to those within the allowable discharge limit for NH_3-N (<1.1 mg L^{-1}) [26]. Total Kjeldahl nitrogen (TKN) is the sum of organic nitrogen and ammonia nitrogen [27]. Since Zm contained neither ammonia nor organic nitrogen, the initial and final levels were very low (0.07 and 0.05 mg L^{-1}, respectively). Kitchen wastewater contained a significant amount of both organic and ammonia nitrogen, so the initial TKN was high (22.56 and 20.3 mg L^{-1} for 100%Kw and 90%Kw, respectively). Culturing *S. platensis* in kitchen wastewater resulted in 97% decrease in TKN for both 100%Kw and 90%Kw, and the resulting water was improved to within the discharge limit of <100 mg L^{-1} [26]. Since organic nitrogen is derived from TKN by subtracting with NH_3-N, similar decrease (near 97%) was observed.

NO_3-N was the sole source of nitrogen for Zm, so the initial level was very high (30.73 mg L^{-1}). Cultivation of *S. platensis* reduced this by 94.2%. The lower starting levels in 100%Kw and 90%Kw (3.8 and 3.47 mg L^{-1}) were also dramatically reduced by 99.2% for each medium. Again, all media after cultivation were within the discharge limit for NO_3-N (<0.5 mg L^{-1}) [26]. NO_2-N in all media was very low (0.003 – 0.008 mg L^{-1}) as anticipated, since neither Zm nor the kitchen wastewater had an identifiable source of this nutrient. Total oxidised nitrogen is the sum of NO_3-N and NO_2-N, so this quantity is dominated by the effect of NO_3-N (<0.5 mg L^{-1}) [26]. Total nitrogen is the sum of TKN and total oxidised nitrogen and the resulting values are summarised in Table 1. A reduction of 94-97% was achieved in all media after 15 days of cultivation of *S. platensis*.

Table 1. The statistical summary (mean ± SD) of water quality and percentage removal in wastewater culture of *S. platensis* after15-days (Boldface numbers indicate the largest changes.)

Chemistry Parameter	Zm			100% Kw			90%Kw			Standard Limits	References
	Zm before culture	Final culture after 15 days	% Removal	Filtrate before culture	Final culture after 15 days	% Removal	Filtrate before culture	Final culture after 15 days	% Removal		
Air tem .(^{o}C)	30	29	-	30	29	-	30	29	-	-	
Water tem. (^{o}C)	28.1	27.9	-	28.2	27.93	-	28.1	27.97	-	< 40 ^{o}C	26
pH	8.73	9.7	-	9.3	9.71		9.54	9.77	-	5.5 - 9	26
DO (mg L^{-1})	3.73 ± 0.15^{a}	7.20 ± 0.10^{a}	-	0.2 ± 0.05^{b}	6.12 ± 0.12^{b}	-	0.3 ± 0.05^{b}	7 ± 0.26^{a}	-	> 5 (mg L^{-1})	28
BOD (mg L^{-1})	9.99 ± 0.5^{a}	6.11 ± 0.10^{c}	38.8 ± 2.1^{b}	18.71 ± 0.61^{a}	5.15 ± 0.11^{a}	72.74 ± 0.1^{a}	16.84 ± 0.55^{b}	4.87 ± 0.10^{b}	71.08 ± 0.1^{a}	< 20 (mg L^{-1})	26
COD (mg L^{-1})	13.21 ± 1.00^{c}	$7.20 \pm .25^{ab}$	45.1 ± 3.8^{b}	28.07 ± 0.64^{a}	7.69 ± 0.35^{a}	72.6 ± 1.2^{a}	25.26 ± 0.58^{b}	6.93 ± 0.32^{b}	73 ± 1^{a}	< 120 (mg L^{-1})	26
TP (mg L^{-1})	4.35 ± 0.39^{a}	2.17 ± 0.06^{a}	50 ± 6^{ns}	4.25 ± 0.13^{ab}	2.11 ± 0.14^{a}	50.4 ± 1.8^{ns}	3.83 ± 0.12^{b}	1.9 ± 0.13^{b}	50.4 ± 1.9^{ns}	< 0.4 (mg L^{-1})	26
NH_3-N (mg L^{-1})	0.03 ± 0.01^{c}	0.01 ± 0.006^{b}	67 ± 18^{b}	7.03 ± 0.06^{a}	0.14 ± 0.006^{a}	98.0 ± 0.1^{a}	5.75 ± 0.14^{b}	0.13 ± 0.005^{a}	97.8 ± 0.1^{a}	< 1.1 (mg L^{-1})	26
Org. N (mg L^{-1})	0.04 ± 0.00^{c}	0.02 ± 0.004^{c}	0	15.53 ± 0.50^{a}	0.54 ± 0.014^{a}	96.52 ± 0.02^{a}	14.55 ± 0.36^{b}	0.48 ± 0.015^{b}	96.7 ± 0.02^{a}	< 10 (mg L^{-1})	29
TKN (mg L^{-1})	0.07 ± 0.01^{c}	0.05 ± 0.01^{b}	70 ± 16^{b}	22.56 ± 0.56^{a}	0.68 ± 0.02^{a}	97.0 ± 0.2^{a}	20.3 ± 0.50^{b}	0.61 ± 0.02^{a}	97 ± 0.2^{a}	< 100 (mg L^{-1})	26
NO_3-N (mg L^{-1})	30.73 ± 1.00^{a}	1.78 ± 0.07^{a}	94.2 ± 0.2^{b}	3.8 ± 0.9^{b}	0.03 ± 0.01^{b}	99.2 ± 0.3^{a}	3.47 ± 0.69^{b}	0.027 ± 0.01^{b}	99.2 ± 0.2^{a}	< 0.5 (mg L^{-1})	26
NO_2-N (mg L^{-1})	0.003 ± 0.001^{b}	0.001 ± 0.001^{b}	67 ± 33^{ns}	0.009 ± 0.001^{a}	0.003 ± 0.001^{b}	65 ± 15^{ns}	$0.008 \pm 0 .001^{a}$	0.002 ± 0.001^{b}	73 ± 15^{ns}	-	-
TON (mg L^{-1})	30.73 ± 1.00^{a}	1.78 ± 0.07^{a}	94.18 ± 0.07^{b}	3.809 ± 0.901^{b}	0.033 ± 0.011^{b}	99.15 ± 0.09^{a}	3.478 ± 0.691^{b}	0.029 ± 0.011^{b}	99.19 ± 0.16^{a}	< 0.5 (mg L^{-1})	26
TN (mg L^{-1})	30.8 ± 1.01^{a}	1.83 ± 0.08^{a}	94.03 ± 0.10^{b}	26.37 ± 1.46^{b}	0.713 ± 0.031^{ab}	97.30 ± 0.04^{a}	23.778 ± 1.191^{c}	0.639 ± 0.031^{b}	97.31 ± 0.01^{a}	< 4 (mg L^{-1})	26

<u>Note:</u> The means $\pm$ SD in the same row with different superscripts are significantly different ($p < 0.05$).

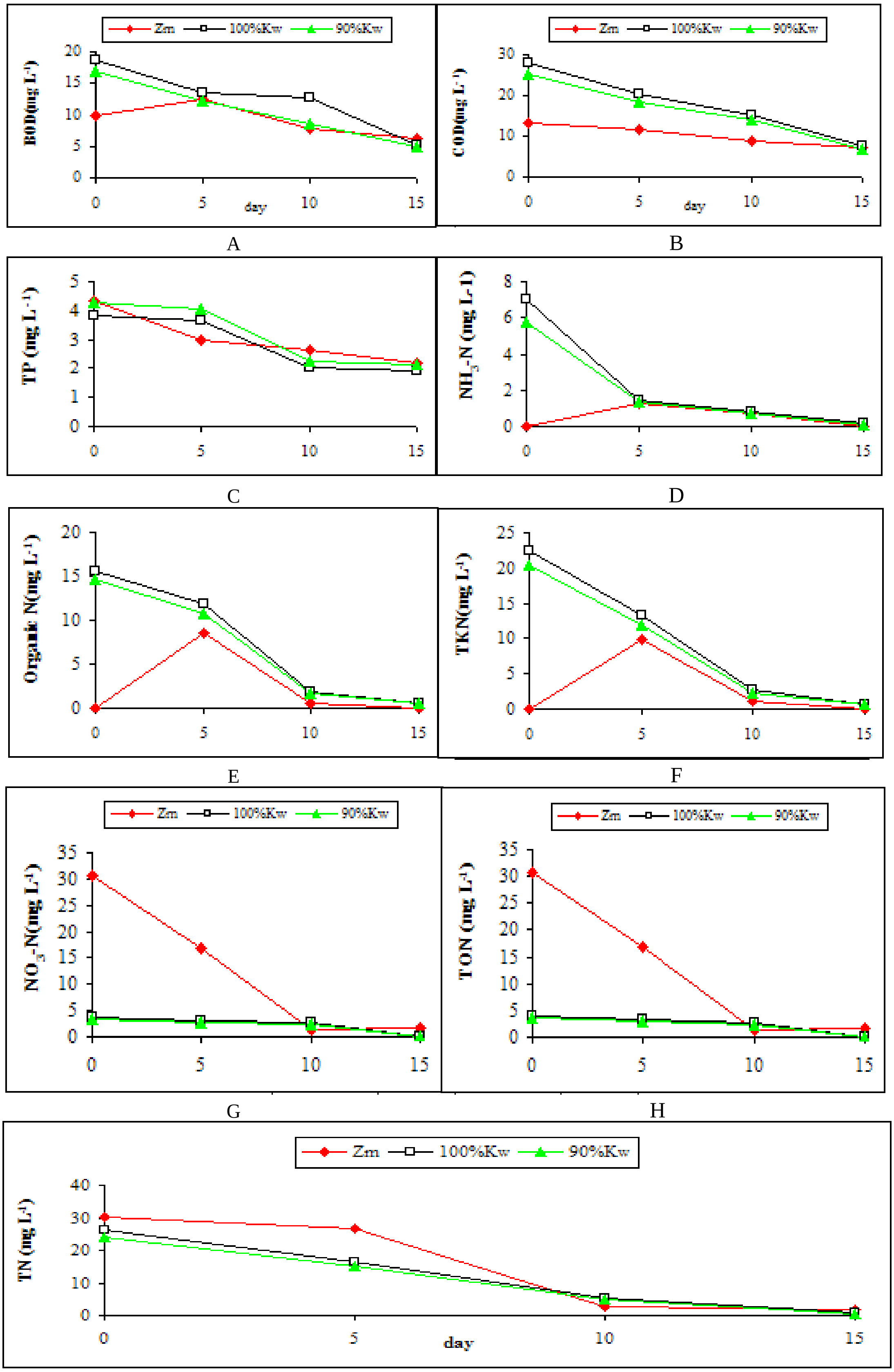

Figure 1. Changes of nutrients: A) BOD, B) COD, C) TP, D) NH_3-N, E) ON, F) TKN, G) NO_3-N, H) TON, and I) TN in the experimental wastewater

Pigment content

The content of *β*-carotene of *S. platensis* cultured in Zm, 100%Kw, and 90%Kw was 0.29, 0.29, and 0.26 mg g^{-1} respectively, while that of C-phycocyanin was 6.94, 18.44, and 16.31 mg g^{-1} respectively (Table 2). The present study utilised a modified Zarrouk's medium (Zm) with substantially fewer nutrients compared to the standard Zarrouk's medium, so substantially lower levels of *β*-carotene and C-phycocyanin were anticipated. (*S. platensis* cultured outdoors using standard Zarrouk's medium had 1.5 mg g^{-1} and 60.70 mg g^{-1} of *β*-carotene and C-phycocyanin, respectively [30].) Although fewer nutrients were utilised in Zm, they were sufficient to maintain the *S. platensis* culture. Also, with fewer nutrients, the production cost using Zm was lower than that using the standard Zarrouk's medium (see below). In this study, the 100%Kw and 90%Kw had a lower level of dissolved oxygen than Zm, but *β*-carotene and C-phycocyanin levels were 2.5 to 3 times higher. Other researchers [31] have also observed that the lowest dissolved oxygen (anaerobic) environment was more conducive to the accumulation of C-phycocyanin as compared to the aerobic environment.

Table 2. Statistical summary (mean ± SD) for analysis of *β*-carotene and C-phycocyanin in *S. platensis* culture in modified Zarrouk's medium (Zm), kitchen wastewater (100%Kw) and kitchen wastewater (90%Kw)

Pigment (mg g^{-1})	**Zm**	**100%Kw**	**90%Kw**
β-Carotene	0.29 ± 0.02^{a}	0.29 ± 0.02^{a}	0.26 ± 0.02^{b}
C-Phycocyanin	6.94 ± 1.69^{b}	18.44 ± 1.09^{a}	16.31 ± 1.10^{a}

Note: The means ±SD in the same row with different superscripts are significantly different ($p< 0.05$).

Production variable cost

The total production variable cost was calculated on a Baht kg^{-1} dry weight basis of *S. platensis*. The 100%Kw medium, which possessed the lowest variable cost of 276.6 Baht kg^{-1}, yielded considerable cost saving (10.9%) compared to the modified Zarrouk's medium (Zm). The 90%Kw was only slightly less expensive (2.6%) than Zm. The 100%Kw was nearly as effective as Zm in the biomass production (0.82 and 0.84 g L^{-1}, respectively); both gave a higher production than 90%Kw (0.73 g L^{-1}) (Table 3). Similar cultivation of *S. platensis* in wastewater arising from the digested pig waste yielded a biomass production of 0.77 g L^{-1} [32]. The biomass production in this study was more than that obtained from a 50% effluent from the pig manure biogas digester (0.32 g L^{-1}) [9].

Nutritional value

As can be seen from Table 3 and Figure 2, percent protein content was nearly 60% higher for the culture in Zm compared to that in either Kw medium. The protein content of *S. platensis* in 100% Kw was 35.86% (dry weight). However, the fat content of the 100% Kw culture was 60% higher than the Zm culture as expected since the kitchen wastewater contained several types of fat from the cooking process. The fibre content of both Kw cultures was more than 4 times higher than that of the Zm culture, probably because the kitchen wastewater was rich in carbon source (carbohydrate and fat/oil) compared to the sole carbon source, sodium bicarbonate, in Zm. The high ash content present in the alga grown in kitchen wastewater (up to 7 fold increase from Zm alga) is unexpected but could be due to the presence of some unidentified inorganic components present in Kw (e.g. those added in the detergent) which could generally enhance the mineral content in algae.

Table 3. Statistical summary (mean ± SD) for analysis of production variable cost and nutritional value of *S. platensis* cultures in Zm and kitchen wastewater (100%Kw and 90%Kw)

Item	Zm	100%Kw	90%Kw
Production variable cost (baht kg^{-1})	310.6 ± 7.6^{a}	276.6 ± 9.6^{b}	303.6 ± 14.7^{a}
Biomass production (dry weight, g L^{-1})	0.84 ± 0.05^{a}	0.82 ± 0.02^{a}	0.73 ± 0.02^{b}
Crude protein (%)	54.44 ± 0.63^{a}	35.86 ± 1^{c}	32.27± 0.91^{d}
Fat (%)	1.93 ± 0.16^{c}	3.13 ± 0.02^{a}	2.82 ± 0.02^{b}
Fibre (%)	2.31 ± 0.27^{e}	10.65 ± 0.79^{a}	9.58 ± 0.71^{b}
Moisture (%)	10.95 ± 0.61^{a}	7.72 ± 0.24^{b}	6.95 ± 0.21^{c}
Ash (%)	3.94 ± 0.15^{c}	27.94 ± 1.56^{a}	25.2 ± 1.4^{ab}

Note: The means ± SD in the same row with different superscripts are significantly different ($p < 0.05$).

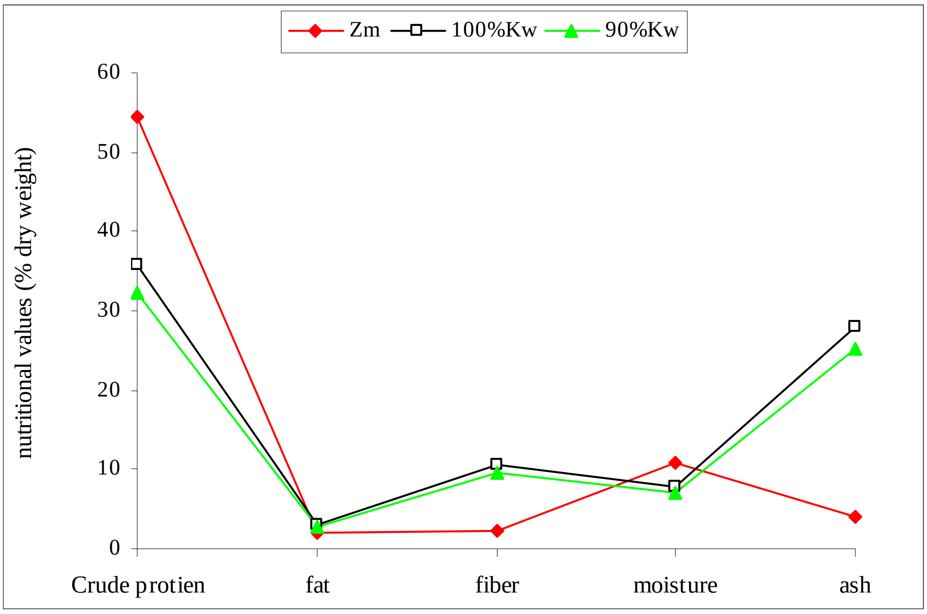

Figure 2. Comparative nutritional value of *S. platensis* cultures in Zm and kitchen wastewater (100%Kw and 90%Kw)

The biomass of *S. platensis* was evaluated as a recommended good protein source for fish, especially *Oreochromis* sp. (Tuptim tilapia). Young tilapias are easily weaned and grow fast to market size when fed the formulated diet [33]. Fast growth rates are common when fish are fed foodstuffs containing levels of 20-30% protein for fish. Future studies should concentrate on detailed nutrient analysis of the kitchen wastewater although considerable variation is expected, depending on source and food/waste processing procedure.

Conclusions

Phytoremediation of domestic wastewater by *S. platensis* was carried out on kitchen wastewater. Water quality, biomass production, production variable cost, pigment content and nutritional value of *S. platensis* were determined in cultures harvested every 5 days for a period of 15 days. A higher % decrease of BOD, COD, TP, NH_3-N, ON, TKN, NO_3-N, NO_2-N, TON and TN was observed in the treated wastewater (100%Kw and 90%Kw) compared to that in the modified Zarrouk's medium (Zm). The highest level of β-carotene (0.29 mg g^{-1}) in *S. platensis* was achieved when cultured in Zm and 100%Kw, while the higher levels of C-phycocyanin were obtained using 100%Kw (17.95 mg g^{-1}) and 90%Kw (16.31 mg g^{-1}). The 100%Kw medium yielded considerable cost saving (10.9 %; 276.6 baht kg^{-1}) compared to the Zm (310.6 baht kg^{-1}). The higher biomass production of *S. platensis* was achieved in Zm (0.84 g L^{-1}) and 100%Kw (0.82 g L^{-1}), where the protein content was 54.44% and 35.86%, respectively. This study provides strong support for the use of *S. platensis* for phytoremediation of kitchen wastewater as well as C-phycocyanin production in this medium.

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References

1. U.G. Schlfsser, "Sammlung von Algenkulturen", *Ber. Dtsch. Bot. Ges.*, **1982**, *95*, 181– 276.
2. E. J. Olguyn, S. Galicia, O. Angulo-Guerrero, and E. Hernandez, "The effect of low light flux and nitrogen deficiency on the chemical composition of *Spirulina* sp. *(Arthrospira)* grown on digested pig waste", *Bioresour. Technol.*, **2000**, *77*, 19– 24.
3. D. Stanca, and E. Popovici, "Urea as nitrogen source in modified Zarrouk's medium", *Rev. Roum. Biol.*, **1996**, *41*, 25–31.
4. C. O. Rangel-Yagui, E. D. G. Danesi, J. C. M. Carvalho, and S. Sato, "Chlorophyll production from *S. platensis*: cultivation with urea addition by fed-batch process", *Bioresour. Technol.*, **2004**, *92*, 133–141.
5. R. O. Canizares, "Free and immobilized cultures of *S. maxima* for swine waste treatment in Mexico", *Biotechnol. Lett.*, **1993**, *15*, 321–326.

6. M. E. Martinez, S. Sanchez, J. M. Jimenez, E. I. Yous, and F. L. Munoz, "Nitrogen and phosphorus removal from urban wastewater by the microalga *Scenedesmus obliquus*", *Bioresource Technol.*, **2000**, *73*, 263–272.
7. B. Chuntapa, S. Powtongsook, and P. Menasveta, "Water quality control using *S. platensis* in shrimp culture tanks", *Aquaculture*, **2003**, *220*, 355– 366.
8. J. Promya, "The mass culture of *S. platensis* in effluent from pig manure biogas digester", *MSc Thesis*, **2000**, Chiang Mai University, Thailand.
9. J. Promya, and S. Traichaiyaporn, "Water quality improvement of effluent from pig manure biogas digester by the culture of *S. platensis* (Nordstedt) Geiteler", *J. Sci. Fac. CMU*, **2003**, *30*, 95-101.
10. H. C. Bold and M. J. Wynne, "Introduction to the Algae Structure and Reproduction", 2nd Edn., Prentice-Hall, Englewood Cliff., **1985**.
11. H. Nakamura, "*S. platensis* : Food for Hungry World, a Pioneer's Story in Aquaculture", University of the Tree Press, California, **1982**.
12. A. Richmond, "*S. platensis*", in "Microalga Biotechnology", (Eds. M. A. Borowitzka and L. J. Borowitzka), Cambridge University Press, Cambridge, **1998**, pp. 85-119.
13. APHA, AWW and WPCF, "Standard Methods for Examination of Water and Waste Water", 16th Edn., American Public Heath Association, Washington DC, **1985**.
14. S. Traichaiyaporn, "Water quality analysis" (a textbook in Thai), Department of Biology, Faculty of Science, Chiang Mai University, **2000**.
15. J. Promya, S. Traichaiyaporn, and R. L. Deming, "Phytoremediation of domestic and industrial wastewater by *S. platensis* (Nordstedt) Geiteler", *Proc. 40th Western Reg'l. Meeting, Am. Chem. Soc.*, 22-25 January 2006, California, **2006**.
16. A. H. Simonne, N. R. Green, and D. I. Bransby, "Consumer acceptability and ß-carotene content of beef as related to cattle finishing diets", *J. Food Sci.*, **1996**, *61*, 1254-1256.
17. D. S. Berns, H. L. Crespi, and J. J. Katz, "Isolation, amino acid composition and some physico-chemical properties of the protein deuterio-phycocyanin", *J. Am. Chem. Soc.*, 1963, *85*, 8-14
18. AOAC, "Methods of Analysis", 14th Edn., Arlington, Virginia, **1984**.
19. S. S. De Silva, R. M. Gunasekera, and C. Keembiyahetty, "Optimum ration and feeding frequency in *Oreochromis niloticus* young", (Eds. J. L. Maclean, L. B. Dizon, and L. V. Hosillos), *Proc. The First Fisheries Forum, Asian Fisheries Society*, Manila, **1986**, pp. 559-564.
20. M. R. Walach, M. Bazin, and J. Pirt, "Computer control of carbon–nitrogen ratio in *S. platensis*", *Biotechnol. and Bioengineering*, **1987**, *29*, 520–528.
21. F. Marquez, "Inhibitory effect of oxygen accumulation on the growth of *S. platensis*", *Biotechnol. Lett.*, **1995**, *17*, 225-228.
22. J. Promya and S. Traichaiyaporn, "Improvement of the dormitory effluent by *S. platensis* (Nordstedt) Geiteler", *Proc. 4th Asia-Pacific Phycological Forum*, Bangkok, **2005**.
23. P. Siew-Moi, M. S. Miah, B. G. Yeoh, and M. A. Hashim, "*S. platensis* production in a high rate pond treating sago starch factory wastewater", *Proc. 4th Asia-Pacific Conference on Algal Biotechnology*, Hong Kong, **2000**.

24. L. E. Gonzales, R. O. Canizares, and S. Baena, "Efficiency of ammonia and phosphorus removal from a Colombian agroindustrial wastewater by the *S. platensis*", *Bioresource Technol.*, **1997**, *60*, 259–262.
25. J. Y. An, S. J. Sim, J. S. Lee, and B. K. Kim, "Hydrocarbon production from secondarily treated piggery wastewater by the green alga *Botryococcus braunii*", *J. Appl. Phycol.*, **2003**, *15*, 194–199.
26. Pollution Control Department, "Laws and Standards on Pollution Control in Thailand", 3rd Edn., Ministry of Science Technology and Environment, Bangkok, **1994**.
27. W. Stumm and J. J. Morgan, "Aquatic Chemistry. Chemical Equilibria and Rates in Natural Waters", 3rd Edn., Wiley-Interscience, New York, **1996**.
28. N. S. Clair, M. L. Perry, and F. P. Gene, "Chemistry for Environmental Engineering and Science", 5th Edn., McGraw-Hill, New York, **2003**.
29. G. B. Jackson, "Applied Water and Spent Water Chemistry", Van Nostrand Reinhold, New York, **1993**.
30. J. Carlos, B. R. Cossio, D. Lablla, and F. X. Niell, "The feasibility of industrial production of *S. platensis* in Southern spain", *Aquaculture*, **2003**, *217*, 179-190.
31. G. A. Armstrong, B. S. Hundle, and J. E. Hearst, "Evolutionary conservation and structural similarities of carotenoid biosynthesis gene products for photosynthetic and non photosynthetic organisms", *Meth. Enzymol.*, **1993**, *214*, 297–311.
32. J. Eugenia, O. S. Galicia, O. A. Guerrero, and E. Hernandez, "The effect of low light flux and nitrogen deficiency on the chemical composition of *Spirulina* sp. (*Arthrospira*) grown on digested pig waste", *Bioresource Technol.*, **2002**, *77*, 19-24.
33. G. Mahajan and M. Kamat, "γ-Linolenic acid production from *S. platensis*", *Appl. Microbiol. Biotechnol.*, **1995**, *43*, 466– 469.

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Full Paper

Stopped-flow injection method for determination of phosphate in soils and fertilisers

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Abstract: A stopped-flow injection system for the determination of phosphate has been developed. It involves the phosphate-molybdate-ascorbic acid reactions in the molybdenum blue method. The system is controlled by a semi-automatic stopped-FI analyser with a light emitting diode (LED)-colorimeter for monitoring the absorbance change relating to the concentration of a reaction product formed during the stopping period while the injected zone of a standard or sample is being in the flow cell. The slope of the FIAgram obtained is linearly proportional to the reaction rate, which depends on the phosphate concentration. Effects of concentration of reagents, viz. sodium molybdate, ascorbic acid and nitric acid, on the slope of the FIAgram were studied. The suitable concentration is 0.02 M, 0.25 %w/v and 0.15 M, respectively. A linear calibration graph in the range of 0.3-6.0 mg P L^{-1} was employed for the determination of phosphate in soil and fertiliser samples. The results obtained agree well with those from a standard spectrophotometric method.

Keywords: phosphate, stopped-flow injection, molybdenum blue, fertiliser, soil

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Introduction

Phosphorus is an element which is widely distributed in nature. It is never found in a free or uncombined state because of its great affinity for oxygen [1]. The common species of phosphorus are phosphate (PO_4^{3-}), phosphorus trioxide (P_2O_3) or phosphorus oxide (P_4O_6), phosphorus tetraoxide

(P_2O_4 or PO_2), and phosphorus pentoxide (P_2O_5 or P_4O_{10}). A condensed phosphate is formed by the combination of oxides of phosphorus and water [2].

In agriculture, phosphorus is one of the essential elements for plants. It is absorbed by plants preferably in the form of a phosphate ion (HPO_4^{2-} or $H_2PO_4^-$). Under acidic conditions the latter is the dominant ion of the soil system. Plants need this nutrient for cell division, transformation of starch to sugar, seed germination, fruiting and flowering [3]. Thus, knowing the amounts of phosphate in soils or fertilisers is useful for monitoring the amounts of phosphorus for plants. Various methods for determination of phosphate have been reported such as ion chromatographic [4], batch [5], and flow injection (FI) [6-10] methods. Ion chromatography can quantitate different anions simultaneously at low concentration levels, but it requires an expensive and complicated instrument. Batch and FI spectrophotometric methods are used popularly for determination of phosphate by employing different chemical reactions such as molybdenum blue formation [10], complexation of orthophosphate with alizarin red sulphonate [11], malachite green ion association [12], and molybdate-crystal violet-phosphate reaction [13]. Both of the methods can provide simplicity and rapidness of analysis, but they suffer from interferences and low sensitivity. In order to improve sensitivity and selectivity of analysis, a stopped FI method is proposed in this research for determination of phosphate employing molydenum blue reaction.

The stopped FI method can increase sensitivity of the measurement by increasing the residence (reaction) time, the elapsed time after sample and reagent are mixed together prior to detection of the reaction product. By stopping the flow the residence time can be prolonged without increasing the length of the reaction coil, thus avoiding an increase of dispersion [14]. The absorbance signal due to the phosphomolybdenum blue product is continuously recorded during the stopping period. Improvement of selectivity is another advantage, since the response of an analyte increases with time whereas the background signal remains unchanged during the stopped-flow period. Therefore, by using the slope of the signal profile during the stopping period for analysis, interferences from coloured and colloidal substances present in the sample, which is a serious problem in the batch or normal FI method, can be eliminated.

Materials and Methods

Chemicals

Deionised water (Milli RX, Millipore) was used throughout. All reagents were of analytical grade, unless otherwise stated. Potassium dihydrogen phosphate (Merck) was used to prepare a stock standard solution of 1000 mg P L^{-1}, by dissolving 0.2197 g of the chemical in water, making up to a volume of 500 mL in a volumetric flask. Acidic molybdate reagent was prepared by dissolving sodium molybdate dihydrate (Fisher Scientific) (2.4195 g) in water. Then 5.4 mL of nitric acid was added before making up to a volume of 500 mL with water. Ascorbic acid (0.25 %w/v) was prepared freshly by dissolving 1.25 g of ascorbic acid in 500 mL water.

Sample preparation

Soil samples were collected from different areas in Chiang Mai. Each sample was collected from at least 15 points by digging at the depth of 6 inches (15 cm) then combining together. The sample was air- dried and ground to less than 300 μm particle diameter. A portion of 10 g of each sample was extracted with 25 mL of 0.8 M acetate buffer (pH 4.8) by shaking for 30 min and the mixture filtered through a filter paper and the final volume of the filtrate adjusted to 50 mL with water prior to analysis.

Fertiliser samples were obtained from local suppliers. An appropriate amount of the sample was dissolved with water prior to determination of available phosphate. The solution was filtered before analysis.

Stopped FI setup

The stopped FI system used is illustrated in Figure 1. A lab-built semi-automatic stopped-FI analyser as reported previously [10] was employed. It consists of a peristaltic pump (MP-3, Eyela, Japan), a 6-port injection valve (Upchurch, USA), a home-made colorimetric detector, a recorder (Philip, The Netherland) and a microcontroller for timing control of the pump and valve. The colorimeter had a light emitting diode (LED) as the light source and a photodiode as the light sensor. All tubings used were PTFE tubing with inner diameter of 0.5 mm, except for Tygon pump tubing (Saint-Gobain Performance Plastics, USA).

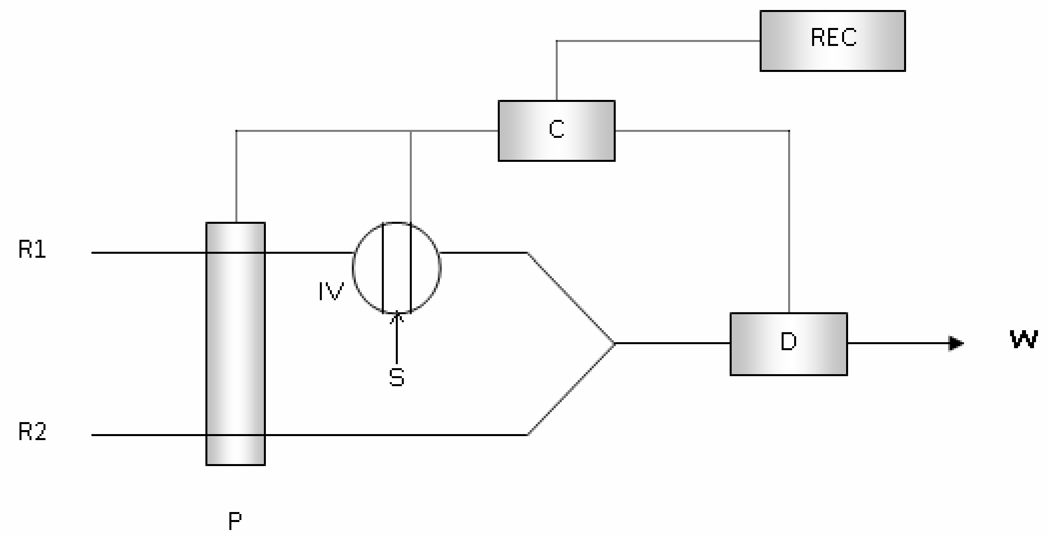

Figure 1. Stopped FI manifold for determination of phosphate: R1 = 0.02 M sodium molybdate in 0.15 M nitric acid, R2 = 0.25%w/v ascorbic acid, S = sample, P = Peristaltic pump, C = controller, IV = six-port injection valve, D = colorimetric detector, REC = recorder, W = waste

Procedure

A standard or sample (55 μl) was injected into a stream of 0.02 M sodium molybdate, which was then merged with a stream of 0.25%w/v ascorbic acid and flowed further to a colorimetric flow cell (see Figure 1). The flow rate of each stream was 2.0 mL min^{-1}. After injection, the injected zone was travelled for 3 s (travelling time) before being stopped for a period of 10 s (stopping time) in the flow cell at the detection point of the detector by stopping the pump. During this period, the colour intensity of the phosphomolybdenum blue product increased continuously, and the absorbance at about 630 nm was recorded as a stopped FI profile (FIgram). Then the flow was started again to propel a bolus of the solution mixture out of the flow cell for a period of 8 s (washing time). The slope of stopped-FIgram was used for phosphate determination by plotting slope versus phosphate concentration. A linear calibration graph was obtained, which could be utilised for the determination of phosphate in a sample. The whole cycle took about 40 s, with a consumption of 0.4 mL of each reagent.

Results and Discussion

The stopped-flow injection system for the determination of phosphate involves the phosphate-molybdate-ascorbic acid reaction to form a molybdenum blue product as shown [15].

$$PO_4^{3-} \quad + \quad \text{Acidic molybdate} \quad \rightarrow \quad \text{Heteropoly acid}$$

$$\text{Heteropoly acid} \quad + \quad \text{Ascorbic acid} \quad \rightarrow \quad \text{Molybdenum blue}$$

Ascorbic acid is selected as a reducing agent because it is efficient and more friendly to the environment. Tin (II) chloride can also be used, but it produces a heavy metal waste. With sodium sulfite as a reducing agent, the bubble of sulfur dioxide is evolved in the flow system, which may cause many problems.

In this work, a semi-automatic stopped FI-analyser was employed (see Figure 1). Via the controller, presetting values can be defined for travelling time (T), the period for sample to flow from the injection point to the detection point prior to the stopping of the flow and the monitoring of the reaction product. Also defined is stopping time (S), the period during which the flow is stopped, and washing time (W), the period during which the system is washed by restarting the flow (after stopping). Each operation cycle comprises these three periods. The analyser is on standby (the flow is halted) after each operation cycle is finished, ready for the user to start the next cycle. Due to the non-continuous flow, the stopped FI method consumes a smaller amount of reagent than the normal FI one.

During the stopping period, the change of absorbance due to the reaction product was recorded versus time, so that the kinetics of the reaction could be continuously monitored. Using the reagents mentioned above, the reaction of the phosphate was relatively fast compared to the silicate, and the kinetic data could be used for a discriminative determination of both of the species [10]. In this work, a stopping period of 10 s was selected in order to avoid interference from the silicate, which might be present in the soil extract at a high concentration. The stopped-FI signal profiles of standard solutions containing different concentrations of phosphate are illustrated in Figure 2. It can be noticed that the slope of the signal profile is linearly proportional to the phosphate concentration.

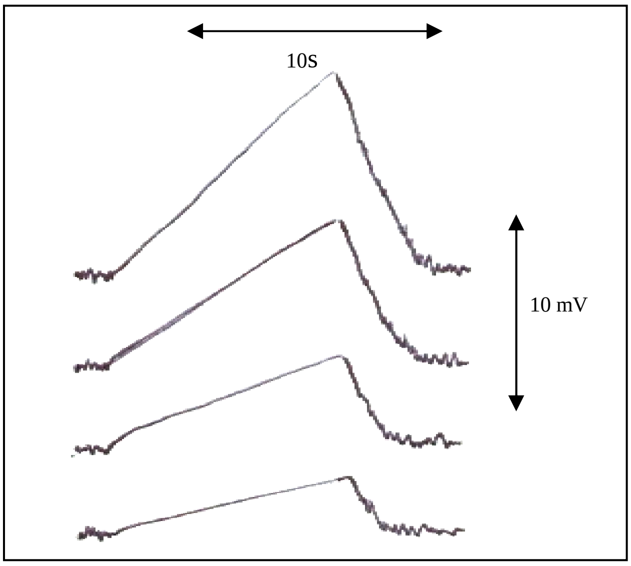

Figure 2. Stopped-FI profiles obtained with different concentrations of phosphate (0.3, 0.5, 1.0 and 2.0 mg P L^{-1}, respectively)

Effect of reagent concentration

1. Sodium molybdate

The sodium molybdate concentration was varied from 0.005 to 0.04 M while ascorbic acid and nitric acid concentration was fixed at 0.5% (w/v) and 0.08 M, respectively. A series of standard phosphate solutions was injected and calibration graphs (plot of slope of signal versus phosphate concentration) were constructed. A plot of slope of the calibration graph (sensitivity) versus concentration of sodium molybdate is illustrated in Figure 3, indicating that 0.02 M sodium molybdate should be selected.

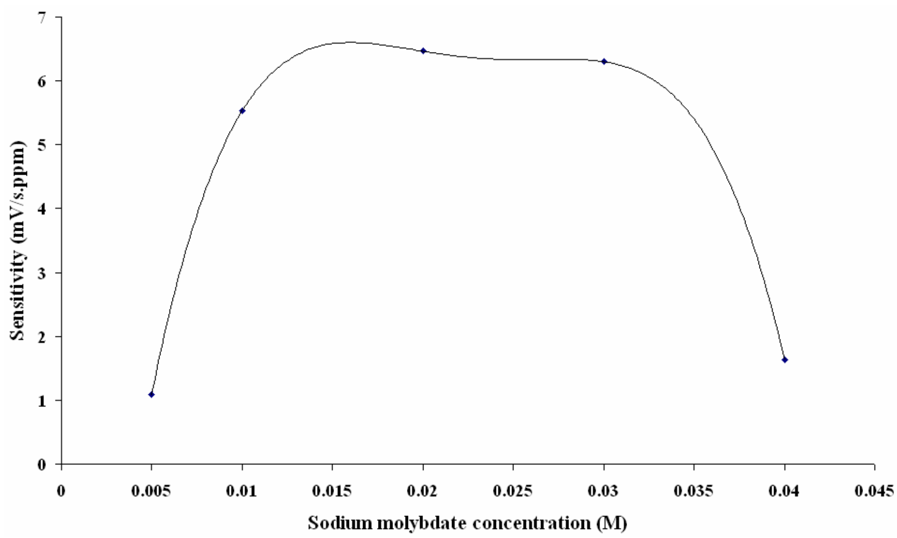

Figure 3. Effect of sodium molybdate concentration

2. Ascorbic acid

Ascorbic acid concentrations in the range of 0.05 to 2%w/v were tried while the sodium molybdate and nitric acid concentration was fixed at 0.02 and 0.08 M, respectively. The effect of ascorbic acid concentration on the slope of the calibration graph is illustrated in Figure 4. Although 1 and 2% w/v ascorbic acid provided higher sensitivity than 0.05, 0.25 and 0.5% w/v, both of these concentrations gave a high noise signal that caused difficulty in measuring the slope of stopped-FIAgrams. Thus, ascorbic acid of 0.25% w/v was chosen because it provided higher sensitivity than 0.05 and 0.5% w/v.

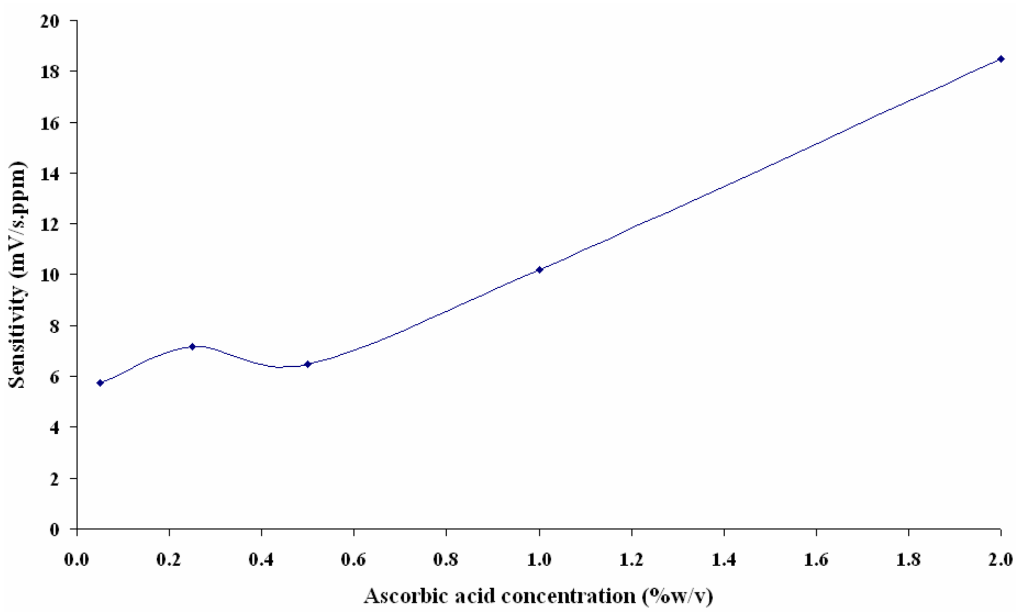

Figure 4. Effect of ascorbic acid concentration

3. Nitric acid

The effect of nitric acid concentration (0.05 to 0.4 M) was investigated while the sodium molybdate and ascorbic acid concentration was fixed at 0.02 M and 0.25% w/v, respectively. A sharp increase in sensitivity was observed when nitric acid concentration was increased up to 0.15 M, but at concentration higher than 0.15 M the sensitivity declined, as shown in Figure 5. In addition, when sulfuric acid of different concentrations was used, a similar trend was also observed, indicating that the reaction seemed to progress well in a narrow range of acid concentration.

Calibration graph and precision

Using the above selected conditions, a linear calibration graph in the range of 0.3 - 6 mg P L^{-1} ($y=10.091x + 5.5403$, $R^2=0.9987$) is obtained. The detection limit calculated from the calibration data is found to be 0.02 mg P L^{-1}. A relative standard deviation obtained for 10 replicated injections of 2 mg P L^{-1} is 2.6%. The method has a sample throughput of 90 h^{-1}, with a consumption of 0.4 mL of each reagent.

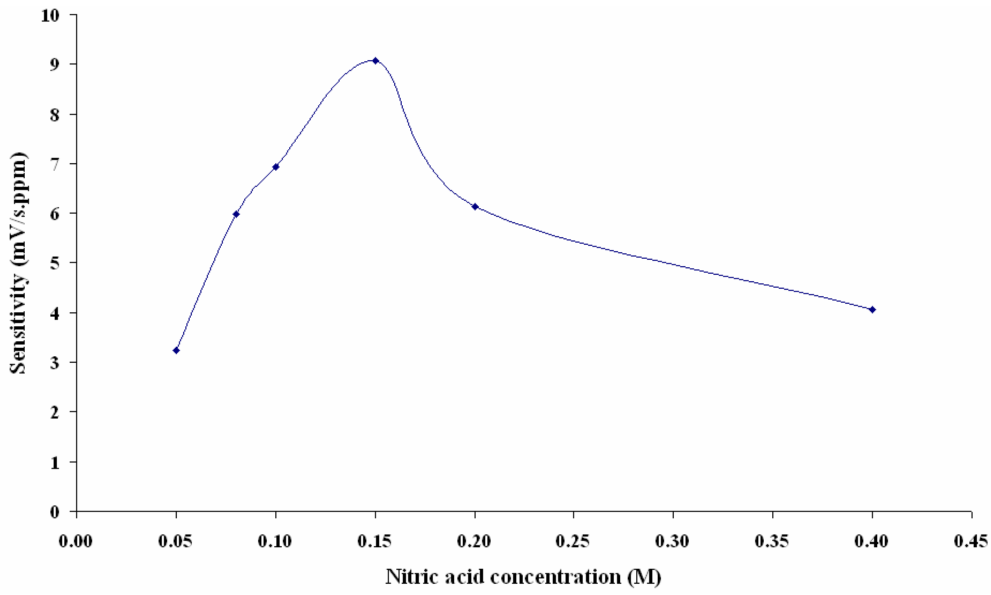

Figure 5. Effect of nitric acid concentration

Application to real samples

The developed method was applied to soil samples. The procedure for collecting and extracting soil has been described in the materials and methods section. The accuracy of the proposed method was determined by comparing results obtained with those from a batch spectrophotometric method [16]. Comparative analyses of the same samples were carried out on the same day and the results are summarised in Table 1. The phosphate contents obtained from the stopped-FI method (x) agree well with those obtained by the batch method (y), which is indicated by the value of the slope, the intercept and R^2 of the correlation graph between the two methods being closed to 1, 0 and 1, respectively ($y=1.0064x+0.0357$, $R^2=0.9997$). According to the t-test at 95 % confidence [17], these methods correlate to each other well.

The proposed method was also applied to the determination of soluble phosphate in fertilisers. The results are shown in Table 2. Again, according to the t-test at 95 % confidence, the two methods correlate well to each other.

The determination of phosphate in soil and fertiliser samples by the stopped-FI method seems to have more advantages than the batch method. The former method can reduce the effect of interferences from such species as silicate and arsenate, because their reaction rates in the molybdenum blue reaction are slower than that of the phosphate. By using the slope of FIAgram instead of peak height, the effect due to coloured and colloidal species usually found in these samples is also decreased. In addition, the stopped-FI technique is simple, inexpensive, rapid, and has a good sensitivity. Also, very small amounts of reagents and sample are consumed.

Table 1. Content of available phosphate in soil samples found by stopped-FI and batch method

Sample number	Physical appearance	[P] in soil sample (μg/g) [a]		% Difference [b]
		sFI method	Batch method	
1	Friable, wet	11.2 ± 0.3	11.2 ± 0.0	0.0
2	Friable, wet	11.1 ± 0.2	11.0 ± 0.2	0.9
3	Friable, wet	13.3 ± 0.3	13.5 ± 0.2	-1.5
4	Friable, wet	24.0 ± 1.2	24.1 ± 0.0	-0.4
5	Friable, wet	15.2 ± 0.7	15.0 ± 0.2	1.3
6	Laterite	7.4 ± 0.2	7.4 ± 0.1	-0.8
7	Friable, wet	12.8 ± 0.6	12.6 ± 0.1	1.6
8	Friable, wet	11.9 ± 0.5	11.8 ± 0.0	0.8
9	Black soil	120 ± 2	119 ± 1	0.8
10	Sand	42.0 ± 0.5	42.5 ± 0.0	-1.2
11	Friable, sand	12.4 ± 0.5	12.6 ± 0.0	-1.6
12	Friable, wet	5.7 ± 0.2	5.7 ± 0.1	0.0
13	Hard, dry	23.4 ± 1.2	23.6 ± 0.2	-0.8
14	Friable, wet	11.0 ± 0.5	10.9 ± 0.1	0.9
15	Friable, wet	5.1 ± 0.3	5.0 ± 0.1	2.0
16	Hard, dry	24.0 ± 2.4	24.2 ± 0.3	-0.8
17	Friable, wet	43.2 ± 0.6	43.1 ± 0.0	0.2
18	Friable, wet	14.5 ± 0.0	14.3 ± 0.0	1.4
19	Mud	3.0 ± 0.1	3.0 ± 0.0	0.0
20	Mud	5.0 ± 0.0	5.0 ± 0.1	0.5

[a] mean of triplicate results

[b] % difference = [(FIA value – batch value)/batch value] x 100

Table 2. Content of soluble phosphate in fertiliser samples found by stopped-FI and batch method

Sample number	$[P_2O_5]$ in fertiliser sample (mg/g)		% Difference[a]
	sFI method	Batch method	
1	85 ± 6	83 ± 2	3
2	69 ± 4	62± 1	10
3	50 ± 1	36± 1	37
4	396 ± 5	321 ± 0	23
5	63 ± 2	53 ± 2	19
6	76 ± 4	67 ± 2	13
7	98 ± 5	90 ± 2	8
8	136 ± 5	125 ± 2	9
9	0.7 ± 0.0	1.0 ± 0.0	-26
10	0.8 ± 0.0	0.7± 0.0	13

[a] % difference = [(FIA value – batch value)/batch value] x 100

Conclusions

The stopped FI method based on the phosphate-molybdate-ascorbic acid reaction (the molybdenum blue method) has been developed for the determination of phosphate in soil and fertiliser samples. The effect of concentration of reagents was investigated. The suitable concentration for sodium molybdate, ascorbic acid and nitric acid, is 0.02 M, 0.25 %w/v and 0.15 M, respectively. A linear calibration graph (plot of slope of the stopped-FIgram versus phosphate concentration) in the range of 0.3-6.0 mg P L^{-1} was employed for the determination of phosphate in samples. The developed method provides various advantages, including high sensitivity and selectivity, and a simple, fast and cheap analysis.

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References

1. W. H. Waggaman, “Phosphoric Acid, Phosphate and Phosphatic Fertilizers”, 2nd Edn., Hafner Publishing Company, New York, **1969**.

2. O. Tue-Ngeun, "Development of flow injection analysis system for determination of phosphate, nitrite, nitrate, chromium, and calcium, *MS. Thesis*, **1997**, Chiang Mai University, Thailand, p 4-5.
3. V. Sanchelli, "Chemistry and Technology of Fertilizers", Reinhold Publishing, New York, **1993.**
4. M. T. Galceran and M. Diez, "Column-switching techniques in the analysis of phosphate by ion chromatography", *J. Chromatogr. A*, **1994,** *675*, 141-147.
5. S. Motomizu, M. Oshima, and A. Hirashima, "Spectrophotometric determination of phosphorus in river water based on the reaction of vanadomolybdophosphate with malachite green", *Anal. Chim. Acta*, **1988**, *211*, 119-127.
6. J. M. Estela and V. Cerda, "Flow analysis techniques for phosphorus: an overview", *Talanta*, **2005**, *66*, 307-331.
7. H. Abderrazak, M. Dachraoni, and B. Lendl, "A novel flow injection procedure for determination of phosphate in industrial raw phosphoric acid", *Analyst*, **2000**, *125*, 1211-1213.
8. Z. Chen, P. Grierson, and M. A. Adams, "Direct determination of phosphate in soil extracts by potentiometric flow injection using a cobalt wire electrode", *Anal. Chim. Acta*, **1998**, *363*, 191-197.
9. R. J. Prieto and M. Silva, "Improved simultaneous reaction-rate determination of phosphate and silicate by use of the continuous addition of reagent technique", *Analyst*, **1998**, *123*, 2389-2394.
10. K. Grudpan, P. Ampan, Y. Udnan, S. Jayasvati, S. Lapanantnoppakhun, J. Jakmunee, G. D. Christian and J. Ruzicka, "Stopped-flow injection simultaneous determination of phosphate and silicate using molybdenum blue", *Talanta*, **2002**, *58*, 1319-1326.
11. A. M. Abdallah, M. E. Khalifa, and M. A. Akl, "Spectrophotometric determination of phosphate with alizarin red sulphonate", *Anal. Chim. Acta*, **1991**, *251*, 207-213.
12. K. L. Linge and C. E. Oldham, "Interference from arsenate when determining phosphate by the malachite green spectrophotometric method", *Anal. Chim. Acta*, **2001**, *450*, 247-252.
13. D. Thorburn Burns, D. Chimpalee, N. Chimpalee, and S. Ittipornkul, "Flow-injection spectrophotometric determination of phosphate using crystal violet", *Anal. Chim. Acta*, **1991**, *254*, 197-200.
14. J. Ruzicka and E. H. Hansen, "Flow Injection Analysis", 2nd Edn., John Wiley & Sons, New York, **1988**, p156-166.
15. A. I. Vogel, "Quantitative Inorganic Analysis", 3rd Edn., Longmans, London, **1968**.
16. M. A. H. Franson, "Standard Methods for the Examination of Water and Wastewater", 17th Edn., American Public Health Association, Washington, DC, **1989**.
17. F. W. Fifield and D. Kealey, "Principles and Practice of Analytical Chemistry", 4th Edn., Blackie Academic & Professional, Glasgow, **1995**.

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Full Paper

Simultaneous production of α-cellulose and furfural from bagasse by steam explosion pretreatment

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Abstract: Sugar cane bagasse was pretreated by steam explosion for the simultaneous production of furfural and α-cellulose pulp. The components of bagasse were fractionated after steam explosion. The details of the process are as follows. Bagasse was soaked in water for one night and steamed at temperatures varying between 206 and 223 °C for 4 minutes. The steam exploded pulp was strained and washed with hot water to yield a liquor rich in hemicellulose-derived mono- and oligosaccharides. The remaining pulp was delignified by alkali for 120 minutes at 170°C using, separately, NaOH load of 15, 20 and 25% of weight of the pulp. The delignified pulp was further bleached twice with 4% H_2O_2 charge of weight of the pulp to produce high α-cellulose pulp. The water liquor was evaporated and further hydrolysed and dehydrated with diluted H_2SO_4 in a stainless steel reactor to produce furfural. The result shows that the optimal pretreatment of steam explosion for 4 min at 218°C leads to the yield of α-cellulose pulp at 193-201 $g{\cdot}kg^{-1}$ of the original bagasse, and that furfural can be produced from xylose present in the liquor with a maximum conversion factor of 0.16.

Keywords: steam explosion, sugar cane bagasse, furfural, α-cellulose pulp, delignification

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Introduction

Bagasse is a waste product from the sugar industry, which is usually used as energy source in factory at present. However, the amount of bagasse left is still high enough for more value-added products. In Thailand, bagasse is used as forage and raw material for production of pulp for paper making and particle board. It has been reported that bagasse contains pentosan with concentration of 250-270 $g \cdot kg^{-1}$ of the original bagasse, which mainly consists of arabinoxylan [1]. Pentosan can be hydrolysed into xylose by acid treatment, then subsequently modified into more value-added chemical substances such as furfural and xylitol [2]. In addition, the residue after production of furfural or xylitol can be used as energy source or raw material for production of high α-cellulose pulp.

Furfural is a basic chemical which can be utilised in a variety of industries such as chemical industry, refining oil industry, food industry and agricultural industry. It is usually produced from agricultural wastes containing pentosan as the main component, notably corn cob, rice straw, bagasse and rice hull [3]. Usually, furfural can be produced by 2 processes. One is through a one-stage process in which pentosan is hydrolysed into xylose after which it is immediately dehydrated to furfural. In this one-stage process, both reactions simultaneously occur in same reactor. On the other hand, the two-stage process starts with hydrolysis of pentosan into xylose in one reactor. After that, the second stage of dehydration reaction is carried out in another reactor to obtain furfural. The advantage of the two-stage process is that the residue from the process can be further utilised for production of cellulose, glucose or ethanol while that from the one-stage process can be used only as fuel. Figure 1 shows the two-stage process for furfural production. Mansilla and coworkers [3] compared the efficiency of furfural production from rice hull between the one-stage and the two-stage process. The first process is conventional, but the yield of furfural is low. Another process is the two-stage process developed more recently and gives higher yield of furfural [2]. Furthermore, the residue arising from two-stage process can be either used as fuel or raw material for α-cellulose pulp production. Furfural is a colourless viscous liquid which becomes dark brown and more viscous in the presence of oxygen. Its boiling point is approximately 160°C. The process for preparing furfural from pentosan from agricultural residues is shown in Figure 1.

The α-cellulose pulp can be substituted for cotton as raw material for producing cellulose derivatives such as carboxymethylcellulose (CMC), cellulose acetate and rayon [4]. Among a variety of processes aiming at fractionation of biomass, steam explosion has been proposed and investigated [5]. Hydrolytic treatment of biomass by pressurised steam alone or with addition of small amount of an inorganic acid, followed by sudden decompression has been studied as a method of depolymerisation of macromolecules in the biomass [6]. Steam pretreatment is an effective way of hydrolysis of hemicellulose and partial decrystallisation of cellulose to facilitate enzymatic attack. The steam explosion process is run at high pressure and high temperature (usually between 180 and 230°C) in a short period of time. As a result, steam explosion technique is truly useful for the separation of cellulose, hemicellulose and lignin from raw materials. This is indicated by the study of the technique for production of α-cellulose from wheat straw [5], production of ethanol from bagasse [7], enzymatic hydrolysis of eucalyptus pulp after steam explosion pretreatment [8], simultaneous production of ethanol and kraft pulp from aspen [9], and treatment of olive stone to improve hemicellulose solubility and enzymatic cellulose hydrolysis [6].

The aim of this work is to evaluate the fractionation of bagasse by the process sequence based on controlled auto-hydrolysis at high temperature followed by hemicellulose extraction and alkali delignification. The work was carried out at the laboratory bench scale, and discusses the yield, chemical composition and recovery potential of cellulose and hemicellulose products.

Materials and Methods

Raw material and chemicals

The sugarcane bagasse with moisture content of 10.78% on receiving from Mitra Phol Sugar Co. Ltd. in Suphanburi Province, Thailand, was used in this study. Glucose, xylose, furfural, and limonene were purchased from Aldrich Chemical Co. Ltd.

The pulp to be used for rayon production was supplied from Thai Rayon Company, Angtong Province, Thailand.

Analytical methods

A part of the bagasse sample was ground with a Wiley mill (Kinematica AG Co. Ltd., Tokyo, Japan) to pass a 420μm sieve for chemical analyses. The content of the ethanol-benzene extractive, lignin, α-cellulose, pentosan and ash were determined using the Tappi Test Method [10]. Holocellulose content was determined by sodium chlorite method according to Browning [11]. The viscosity and brightness of α-cellulose pulp were determined following the Tappi Test Method [10].

Steam explosion fractionation

Fractionation of bagasse was performed by the procedure shown in Figure 1. The bagasse sample (150 g oven dry weight) was soaked in water, and placed in a stainless steel batch reactor of 2.5 L capacity (Nitto Kouatsu Co. Ltd., Tokyo, Japan). Heating was accomplished by direct steam injection into the reactor. The sample was treated for 4 min at the desired temperature from 206 to 223 °C. Explosive discharge of the digester content into a collecting tank was actuated by rapidly opening a pressure release valve. The pulp slurry was collected and extracted with hot water (80°C) with a ratio of fibre to water of 1:10 (w/v) for 15 min (Figure 1). The pulp was filtered, air-dried at room temperature and pulp yield was determined after overnight oven drying at 105ºC. The chemical composition of the pulp was analysed as described for the original bagasse. A part of the hot water extract was stored at 4°C for determination of glucose and xylose content by LC10A High Performance Liquid Chromatography (Shimadzu Co. Ltd., Kyoto, Japan) with RI detector and Aminex HPX-87C column, according to the method of Montane et al. [5].

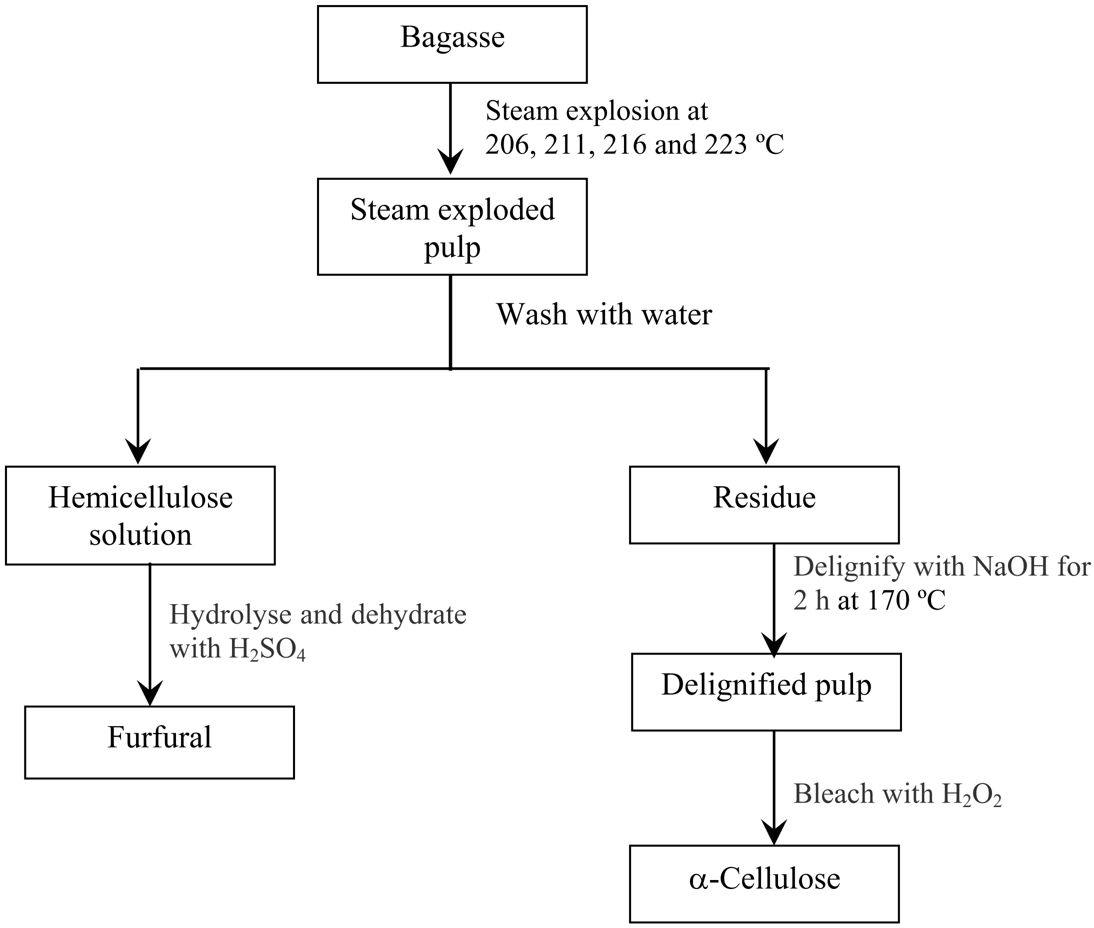

Figure 1. Steam explosion for two-stage production process of α-cellulose pulp and furfural from bagasse

Dehydration of authentic xylose and hot water extract of steam exploded pulp

Prior to the production of furfural from the hot water extract of the steam exploded pulp, authentic xylose was used as a substrate to assess the optimum dehydration condition. Xylose solution (60 $g \cdot l^{-1}$, 800ml) was placed in a stainless steel reactor (1 L capacity) and separately treated for 2 hr at 50, 170, 190 and 210°C. The reaction was catalysed by a series of H_2SO_4 concentrations of 0.05, 0.08, 0.10 and 0.125 mole/litre of the reaction mixture. The vapour evaporated from the reactor after 30, 60, 90 and 120 min was condensed with a condenser cooled by tap water. The optimum condition was then employed for the dehydration of the hot water extract after steam explosion to afford furfural. The hot water extract (8 litres) of the steam exploded pulp was concentrated 4-, 6-, 8- and 10-fold and then used as substrates to optimise the dehydration condition. The reaction was performed in a stainless steel reactor (1 L capacity) and catalysed by an appropriate H_2SO_4 solution to obtain furfural.

Furfural content was subsequently determined as follows. A part of the condensed liquid (5 ml) was extracted with toluene (2 x 5 ml). An aliquot of the toluene solution containing 10% limonene (Aldrich Co. Ltd.) as an internal standard was analysed by a gas chromatograph (Agilent Technologies A 6890N, USA.) with a FID detector. A capillary column, DB-WAX (30 m x 0.32 mm ID, 0.25 µm film thickness) (J&W Scientific, Folsom, California, USA) was used. Carrier gas was He at a flow rate of

1.4 ml·min^{-1} and split ratio of 50:1. Column temperature was kept at 45°C for 2 min and then programmed at 6°C·min^{-1} to 200°C. Temperature of injector and detector was maintained at 200 ºC.

Production of α-cellulose pulp

After steam explosion process, the pulp remaining after washing with hot water was delignified by digestion with NaOH (15, 20 and 25% w/w of oven-dried pulp) for 2 hr at 170°C using a ratio of pulp to liquid of 1:10 (w/v) to determine the optimum NaOH concentration for the delignification process. The delignified pulp was collected by filtration and washed with water several times until a colourless solution was obtained. A part of the delignified pulp was air-dried, and the yield was determined after oven drying at 105 ºC overnight. The chemical composition was determined as described for the original bagasse. The pulp was further subjected to a two-stage alkaline H_2O_2 bleaching starting with bleaching for 3 hr at 80°C using a ratio of pulp to liquor of 1:10 (w/v). The chemical load on the bleaching liquor was 4% H_2O_2, 3% NaOH and 0.5% $MgSO_4$ based on weight of oven-dried pulp. The pulp was filtered and thoroughly washed with distilled water before a second bleaching using the same condition as above. Following the two-stage bleaching, the brightness of resulting pulp fell in the same level as that of the commercially available Rayon. The bleached pulp was subsequently analysed for brightness using Technibrite^{TM} Micro TB–1C (Technidyne Co. Ltd., Indiana, USA), viscosity using a capillary viscometer (Tappi T230om-94) and 0.5 M cupriethylenediamine as a solvent, and chemical composition using the method as described for the original bagasse.

Results and Discussion

Results of the determination of the extractives, lignin, pentosan, holocellulose, α-cellulose and ash content of the original bagasse used in this investigation are 37, 199, 251, 664, 456, and 18 g·kg^{-1} respectively of the oven-dried bagasse. The content of α-cellulose is high enough to be applied to the α-cellulose pulp production process.

It is found that the pentosan content is significantly decreased by the steam explosion treatment from 251 g·kg^{-1} of raw material to 18-65 g·kg^{-1} of the steam exploded pulp (Table 1). This is in contrast with the contents of holocellulose (638-694 g·kg^{-1}), α-cellulose (459-501 g·kg^{-1}), and lignin (162-201 g·kg^{-1}), which are not truly affected by the steam explosion condition. It is concluded that the pentosan content in the pulp decreases significantly during the steam explosion process with removal efficiency from 84 to 96% of the original bagasse sample (Table 1). This is also consistent with the results by Ibrahim and his coworkers [4] that the pentosan in bagasse is hydrolysed during the prehydrolysis stage with 1.5% H_2SO_4 for 90 min at 140ºC, which is the optimum condition. However, it should be noted that the disadvantages of the acid hydrolysis are a lower % removal of pentosan and the requirement of a longer reaction period (90 min at 140ºC with 1.5% H_2SO_4) compared with the steam explosion. In addition, the use of H_2SO_4 causes corrosion of the reaction vessel. The yield of pulp is 600 g·kg^{-1} of the original bagasse and the removal efficiency of pentosan is 71.4%, which is significantly lower than that obtained by the steam explosion pretreatment (84-96%). These results suggest clearly that the acid prehydrolysis of lignocellulose should be substituted by steam explosion to obtain pentosan effectively.

Table 1. Pulp yield and chemical components in bagasse pulp after steam explosion

Steam temperature °C	Time min	Pulp yield [1] $g \cdot kg^{-1}$	Pentosan [2] $g \cdot kg^{-1}$	Lignin [2] $g \cdot kg^{-1}$	Holocellulose [2] $g \cdot kg^{-1}$	α-Cellulose [2] $g \cdot kg^{-1}$
206	4	606	65 (84.3)	162 (50.7)	682 (37.8)	501 (33.4)
211	4	594	58 (86.3)	186 (44.5)	694 (37.9)	499 (35.0)
218	4	571	32 (92.7)	201 (42.3)	693 (40.4)	479 (40.0)
223	4	568	18 (95.9)	192 (45.2)	638 (45.4)	459 (42.8)

[1] Based on bagasse; [2] Based on steam exploded pulp
Figure in bracket = % removal from the original bagasse by steam explosion treatment

It is found that the pulp yield decreases with rising temperature of the steam explosion process, from 606 to 568 $g \cdot kg^{-1}$ of the original bagasse sample. The condition at 223ºC for 4 min seems to be the best due to highest pentosan removal of 96% and pulp yield of 568 $g \cdot kg^{-1}$. However, this condition was not selected for the next step, because it was too severe and was not appropriate for α-cellulose pulp production. Thus the explosion condition of 4 minutes at 218°C was selected based on the pentosan removal (>92% of pentosan from the raw material) and pulp yield (571 $g \cdot kg^{-1}$) for producing furfural and α-cellulose pulp.

Results from chemical analysis of α-cellulose pulp after delignification and bleaching are shown in Tables 2 and 3. It is apparent that the contents of holocellulose and α-cellulose increase while delignified pulp yield and contents of pentosan, lignin and ash decrease with increase of NaOH dosage. This trends are good agreement with the results of Ibrahim et al.[4], although higher dosage (25%) of NaOH is required compared to this investigation (NaOH dosage of 15-20%) to obtain the same quality of the resulting pulp. Thus, it can be inferred that the pretreatment of lignocellulose such as bagasse with steam explosion can lead to a more effective removal of lignin than the acid hydrolysis pretreatment, probably because of an acid condensation of lignin during H_2SO_4 treatment being avoided.

Ibrahim et al. [4] used four successive chemicals for pulp bleaching, viz. chlorine, sodium hydroxide, sodium hypochlorite and sodium chlorite. Two-stage bleaching with 4% aqueous solution of H_2O_2 used in this experiment gave a pulp of similar quality. These data therefore seem to indicate that steam explosion is a more effective and environmentally friendly pretreatment of bagasse for α-cellulose pulp production.

The α-cellulose and pentosan contents of the resulting α-cellulose pulp from bagasse in this investigation are similar to those of the rayon pulp (Table 3), which is produced from cotton linter. However, brightness and viscosity of the bagasse α-cellulose pulp are lower, and residual lignin and ash contents are also higher than those of the rayon pulp. Low brightness and viscosity would probably be due to the presence of higher content of residual lignin in bagasse α-cellulose pulp. These disadvantages can be improved by additional bleaching step using ClO_2 or $NaClO_2$. This improvement has also been reported for α-cellulose production from rice straw by Montane et al. [5]. In the report, the rice straw was preliminarily treated by steam explosion and two-stage H_2O_2 bleaching. Then the pulp was bleached again with $NaClO_2$. The α-cellulose pulp obtained was demonstrated to be equivalent to the rayon grade pulp used in industry [5].

Table 2. Chemical components of pulp after delignification at different concentrations of NaOH

NaOH concentration % of SE pulp (w/w)	Pulp yield [1] $g \cdot kg^{-1}$	Holocellulose [2] $g \cdot kg^{-1}$	α-Cellulose [2] $g \cdot kg^{-1}$	Pentosan [2] $g \cdot kg^{-1}$	Lignin [2] $g \cdot kg^{-1}$	Ash [2] $g \cdot kg^{-1}$
15	227	944 (67.7)	932 (53.6)	18 (98.4)	51 (94.2)	10.1
20	220	959 (68.2)	948 (54.3)	16 (98.6)	37 (95.9)	6.5
25	199	971 (70.9)	961 (58.1)	16 (98.7)	22 (97.8)	6.1

[1] Based on the original bagasse; [2] Based on delignified pulp
Figure in bracket = % removal from the original bagasse by steam explosion treatment

Table 3. Chemical components of pulp after bleaching with 4% H_2O_2 at different concentrations of NaOH

NaOH concentration $g \cdot l^{-1}$	Pulp Yield [1] $g \cdot kg^{-1}$	Holo-Cellulose [2] $g \cdot kg^{-1}$	α-Cellulose[2] $g \cdot kg^{-1}$	Pentosan [2] $g \cdot kg^{-1}$	Lignin [2] $g \cdot kg^{-1}$	Ash[2] $g \cdot kg^{-1}$	Vis-cosity cp	Brightness %ISO
150	214	956 (69.2)	939 (55.9)	16 (98.6)	18 (98.1)	5.6	152.6	36.2
200	201	971 (70.6)	956 (57.9)	15 (98.8)	7.4 (99.3)	4.6	104.3	65.6
250	193	975 (71.7)	961 (59.3)	14 (98.9)	6.3 (99.4)	4.4	85.5	70.5
Rayon pulp	-	986	970	16	7.7	2.0	141.2	80.0

[1] Based on bagasse; [2] Based on bleached pulp
Figure in bracket = % removal from the original bagasse by steam explosion treatment

Prior to furfural production from the hot water extract of the steam exploded pulp, the monosaccharide composition was analysed by HPLC. It was found that the hot water extract of the steam exploded pulp was composed of xylose and glucose at the concentrations of 2.9 $g \cdot l^{-1}$ and 0.5 $g \cdot l^{-1}$, respectively (Table 4). The hot water extract was concentrated under reduced pressure to 1/4, 1/6, 1/8 and 1/10 volume to increase the concentration of xylose. These concentrated solutions were subsequently hydrolysed with 3% H_2SO_4 for 1 hr at 121°C according to Montane et al. [5] to determine the total glucose and xylose content in the hot water extract. The content of oligosaccharides containing glucosyl and xylosyl residues was calculated by subtraction of monomeric residues from those after hydrolysis of the hemicellulose solution. The result suggests that the hot water extract was composed mainly of xylosyl residues with a minor content of glucosyl residues. This result is similar to the amounts of pentosan and hexosan in the hot water extract from steam explosion treatment of eucalyptus wood [8].

Table 4. Total glucose and xylose in hemicellulose solution after hydrolysis with 3% H_2SO_4

Hemicellulose solution	Monosaccharide in hemicellulose solution		Oligosaccharide in hemicellulose solution		Total sugar in hemicellulose solution	
	Glucose $g \cdot l^{-1}$	Xylose $g \cdot l^{-1}$	Glucose $g \cdot l^{-1}$	Xylose $g \cdot l^{-1}$	Glucose $g \cdot l^{-1}$	Xylose $g \cdot l^{-1}$
Unconcentrated	0.5	2.9	0.6	3.2	1.1	6.1
Concentrated 4-fold	1.8	11.9	2.5	13.2	4.3	25.0
Concentrated 6-fold	2.2	19.6	1.9	14.4	4.1	34.1
Concentrated 8-fold	2.7	25.5	2.6	23.6	5.3	49.0
Concentrated 10-fold	5.1	28.9	4.6	29.3	9.7	58.2

The hot water extract was concentrated prior to furfural production. The concentrated solution was reacted for 2 hr at 190ºC with H_2SO_4 (0.08 mole/litre of solution) in a stainless steel reactor. Furfural produced by the dehydration reaction was quantified by gas chromatography. The molar conversion factor from the xylosyl residue to furfural was 0.16 for the 6-fold concentrated solution, which surprisingly was somewhat higher than that for the treatment of authentic xylose solution (0.12, Table 5). Also, it can be observed from Table 5 that there seems to be an optimum concentration for the hemicellulose solution which gives the highest conversion factor. As the hemicellulose solution is progressively concentrated, the conversion factor seems to increase to a maximum and then decrease. Since there were in the hemicellulose solution both xylosyl and glucosyl oligosaccharides as well as other extractives such as lignin decomposition products, this might have an effect of suppressing further modification of the furfural formed by consuming some excess acid catalyst. Also, the ratio of the substrate (hemicellulose) to the acid catalyst also progressively changes (increases) as the solution is increasingly concentrated. These may therefore be the causes of the conversion factor variation observed. A similar observation and assumption has been made by Currasco and Roy [1].

It has been demonstrated that the activation energy (Ea) for the first step from oligosaccharides to xylose is higher than for the second step from xylose to furfural [1,12], indicating that xylose can be converted to furfural faster than the hydrolysis of oligosaccharides to xylose. Therefore, separation of xylose from the mixture of xylose and xylooligosaccharides is not required prior to dehydration.

Table 5. Amount of furfural from hemicellulose solution at different concentrations of xylose

Solution	Xylose $mmol \cdot l^{-1}$	Furfural mmol	Conversion factor from xylosyl residue to furfural
Hemicellulose solution, concentrated 4- fold	167	25.3	0.152
Hemicellulose solution, concentrated 6- fold	227	36.5	0.160
Hemicellulose solution, concentrated 8- fold	327	40.2	0.123
Hemicellulose solution, concentrated 10- fold	388	29.5	0.076
Pure xylose solution	400	47.1	0.118

Conclusions

Bagasse was converted to high value added materials, viz. furfural and α-cellulose pulp by steam explosion pretreatment followed by fractionation of cell wall components. The yields of furfural and α-cellulose pulp depend on the temperature and the time period of steaming. The major components of the water-soluble fraction of the steam exploded pulp were xylooligosaccharides together with xylose. After concentration of the water-soluble fraction, the xylooligosaccharides could be directly converted into furfural without prehydrolysis to the xylose monomer. The highest conversion factor for the conversion of the xylosyl residue to furfural in the concentrated water-soluble fraction was 0.16.

In the other part of the work, the steam exploded bagasse pulp was delignified with alkali, and bleached with aqueous H_2O_2 to afford α-cellulose pulp, the quality of which is comparable to the rayon grade pulp. Production of α-cellulose pulp was performed by steam explosion pretreatment with less consumption of chemicals in the delignification and bleaching stages than that in the acid hydrolysis pretreatment. However, pulp brightness and viscosity was lower than that of rayon grade α-cellulose, probably because of higher residual lignin content in the bagasse α-cellulose. The ash content in the bagasse α-cellulose was also higher than that in the rayon grade α-cellulose. Further improvement such as additional bleaching stages using chlorine-containing agents would be required to produce better quality α-cellulose pulp from steam exploded pulp.

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References

1. F. Currasco and C. Roy, "Kinetic study of dilute acid prehydrolysis of xylan containing biomass", *Wood Sci.Technol.*, **1992**, *26*, 189-208.
2. J. R. Pessoa, A. I. M. Mancilka, and S. Sato. "Acid hydrolysis of hemicellulose from sugarcane bagasse", *Brazilian J. Chem. Eng.*, **1997**, *14*, 1-10.
3. H. D. Mansilla, J. Baezu, S. Urzua, G. Muturana, J. Villasenor, and N. Duran, "Acid-catalysed hydrolysis of rice hull: evaluation of furfural production", *Bioresource Technology*, **1998**, *66*, 189-193.
4. A. A. Ibrahim, A. M. A. Nada, U. Hagemann, and O. A. Elseoucl, "Preparation of dissolving pulp from sugar cane bagasse and its acetylation under homogeneous solution condition", *Holzforschung*, **1996**, *50*, 221-225.
5. D. Montane, X. Farriol, and J. Salvado, "Fractionation of wheat straw by steam explosion pretreatment and alkali delignification, cellulose pulp and byproducts from hemicellulose and lignin", *J. Wood Chem. Technol.*, **1998**, *18*, 171-191.
6. J. Fernandez-Bolunos, B. Felizon, A. Heredia, R. Rodriguez, R. Guillen, and A. Jimenez, "Steam explosion of olive stone: hemicellulose solubilization and enhancement of enzymatic hydrolysis of cellulose", *Bioresource Technol.*, **2001**, *79*, 53-61.
7. W. E. Kar, C. V. Gutierrez, and C. M. Kinoshita, "Steam explosion of sugarcane bagasse as a pretreatment for conversion to ethanol", *Biomass and Bioenergy*, **1998**, *14*, 1-9.
8. A. P. Nunes and J. Pourquie, "Steam explosion pretreatment and enzymatic hydrolysis of eucalyptus wood", *Bioresource Technol.*, **1996**, *57*, 107-110.
9. R. S. Martin, R. C. Perez, and R. Briones, "Simultaneous production of ethanol and kraft pulp from pine (*Pinus radiate*) using steam explosion", *Bioresource Technol.*, **1995**, *53*, 217-223.
10. Tappi Test Method, Tappi Press, Georgia, **1996**.
11. B. Browning, "Methods of Wood Chemistry", John Wiley and Sons, New York, **1967**.
12. G. Garrote and J. C. Parajo, "Non-isothermal autohydrolysis of eucalyptus wood", *Wood Sci. Technol.*, **2002**, *36*, 111-123.

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Full Paper

Effect of heavy metals induced toxicity on metabolic biomarkers in common carp (*Cyprinus Carpio* L.)

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Abstract: This research paper presents the pathological effects of a sub-lethal concentration of heavy metals (cadmium, lead, nickel, and chromium) on common carp (*Cyprinus carpio L.*). Total protein and levels of alkaline phosphatase (ALP), alanine aminotransferase (ALT), aspartate aminotransferase (AST) and lactate dehydrogenase (LDH) in the liver tissue were measured. Compared with the control group a significant decrease of total protein ($p < 0.001$) was ascertained in the experimental group. The ALP on the other hand was significantly higher ($p < 0.001$). The values of ALT, AST, and LDH significantly decreased in the first day and then progressively increased afterwards ($p < 0.001$). The above results on the biochemical profile indicate marked hepatotoxic effects of heavy metals in common carp.

Key words: marker enzymes, transaminases, metal toxicity, common carp, *Cyprinus carpio* L.

Introduction

Human activities have led to accumulation of toxic metals in the aquatic environment [1-2]. The adverse input of diverse industrial wastes has aggravated the problem of contamination, and sewage disposal has greatly enhanced the addition of heavy metals into the aquatic ecosystem. Trace element pollution of the sediment in rivers, lakes, estuaries and bays caused by industrialisation has been reported by many researchers around the world [3-5].

This problem has become complex because of the non-degradability of the inorganic pollutants. They are continuously released into the aquatic environment both from natural processes like volcanic activity and from rapid industrialisation. Heavy metals have received particular attention among the non-degradable toxic chemicals due to their adverse effects on aquatic life forms [6].

Heavy metals are the most noxious pollutants owing to their diverse effects. Some metals are soluble in water and readily absorbed into the living organisms. Metal ions of high toxicity are known to cause deleterious impact on organs and blood level in fish [7-8]. They form metal complexes with the structural proteins, enzymes and nucleic acids and interrupt their functions. For example, cadmium is a non essential, non-biodegradable element reported to be a major contaminant that causes adverse effects on the aquatic system [9-11]. Lead pollutant induces lipid peroxidation in tissues and causes an irreversible damage to the respiratory organs of fish [12-13]. Nickel induces a morphological transformation and chromosomal aberration in cells [14]. Nickel in combination with cobalt induces convulsions, DNA strand breakage and organ damage [15]. Hexavalent chromium is relatively mobile in the environment and is acutely toxic, mutagenic, teratogenic and carcinogenic to aquatic organisms [16].

Enzymes are necessary for normal cellular metabolism including that of the liver, and the degenerative changes due to the combined metal toxicity exhibited in the liver alter the level of a number of its enzymes. For example, lactate dehydrogenase (LDH) is released from the liver after its cellular damage and failure due to organophosphate insecticide intoxication [17]. LDH, spartate transaminase (AST), alanine transaminase (ALT), and alkaline phosphatase (ALP) are released in acute and chronic liver disorders. These enzymes are biomarkers of acute hepatic damage, thus their bioassay can serve as a diagnostic tool for assessing necrosis of the liver cells [18-19].

The aim of the present study is to determine the toxicity of combined heavy metals on the activity of the marker enzymes (AST, ALT, ALP and LDH) in order to measure the degree of organ damage in the liver of the common carp (*Cyprinus carpio* L.), an economically important species around the world.

Materials and methods

Freshwater common carps (10 – 13 cm long and weighing 35.70 ± 0.60 g) were collected from ponds of southern districts of Tamilnadu, India and were acclimatised to laboratory conditions for a week. Twenty to twenty five individuals were used for the experiment. They were kept in batches in 200L recirculating tanks filled with dechlorinated tap water under constant temperature (25 ± 1^{o}C) with a controlled photoperiod of 12:12-hour light-and-dark cycle and constant filtration. The physico-chemical characteristics of the tap water used in this study were as follows: pH 7.20, electrical conductivity 1255 µS/cm, TDS 815.75 mg/L, alkalinity 140.5 mg/L, total hardness 280.45 mg/L, Ca 120.25 mg/L, Mg 75.2 mg/L, Na 15 mg/L, K 8 mg/L, Cl^- 148.55 mg/L, SO_4^{2-} 68.65 mg/L and total NH_3 10.8 mg/L. The water in the control and experimental tank was changed every 3 days.

The fish were divided into two groups, with one group serving as control and the other as experimental group. The latter group was exposed to a concentration of 5 ppm of a combined (Cd + Pb + Cr + Ni) metal solution containing 1.25 ppm of each metal ion (1/10th of LC50/48h) for a period of 32 days. Analytical grade cadmium chloride, lead nitrate, potassium chromate, and nickel sulphate supplied by BDH were used as metal toxicants. The selected heavy metal concentration was based on preliminary results, which showed it to be sub-lethal after a 32-day period of exposure. No fish mortality was observed during the experiment.

The fish were fed with a commercially available fish feed at a daily rate of 3-4 % body weight throughout the experiment. The fish were starved for 24 hours before experimentation. Five specimens of the control and 5 specimens of the metal-exposed group were sacrificed during each exposure period of 1, 8, 16 and 32 days. The post-mitochondrial fraction from the pooled liver samples was washed in ice-cold 1.15% KCl solution, blotted and weighed. The tissues were homogenised in 4 volumes of homogenising buffer (50 mM Tris-HCL mixed with 1.15% KCl and the pH adjusted to 7.4) using a Teflon homogeniser. The resulting homogenate was centrifuged at 16,000g for 15 min at 0-4^{o}C a Beckman L5-50B centrifuge. The supernatant was decanted and stored at -20^{o}C until analysis.

The level of total protein in the liver tissue was assayed by the method of Lowry et al. [20]. The value of protein was expressed as g/L. Alkaline phosphatase activity was estimated by the method of Balasubramanium et al. [21]. The results were expressed as IU/L. Transaminases activity was estimated by the method outlined by Bergmeyer and Bernt [22] and Splittstoesser et al. [23]. The results were expressed as U/L. The enzyme lactate dehydrogenase activity was estimated by the method of King [24]. The enzyme activity was expressed as IU/L.

The data obtained from the experiments were analysed, and the results were expressed as mean ± S.D. The results were evaluated using Student's t-test. The values of $p < 0.001$ were considered statistically significant.

Results and Discussion

The levels of metabolic marker enzymes in the liver of the common carp (*Cyprinus carpio* L.) exposed to a combined heavy metal solution for a period of 1,8,16 and 32 days were determined. The level of total protein showed a significant decrease ($p < 0.001$) after several stages of exposure (Figure 1). The enzyme alkaline phosphatase in the liver was increased significantly after 1, 8, 16, and 32 days (Figure 2). Alanine aminotransferase and aspartate aminotransferase exhibited a significant decrease in the first day compared to control and then progressively increased in the successive exposure periods (Figures 3, 4). Lactate dehydrogenase activity showed a similar trend (Figure 5).

The mean values of total proteins were significantly decreased in the exposed fish compared to control (Figure 1). This implicates that the bioaccumulation of heavy metals triggers the oxidative stress in the liver cells by the generation of reactive oxygen species. The defensive surface proteins antagonise the toxic radicals resulting in elimination of protein from the liver cells. The lowered level of total protein in plasma, muscle and liver reflects the capacity of protein synthesis and denotes the osmolarity of the blood and liver impairments. Hence, it is a valuable indicator in the diagnosis of toxicity in fish.

In the present study the decrease in total protein might be due to several pathological processes induced by heavy metals including plasma dissolution, renal damage and protein elimination in the urine, a decrease in liver protein synthesis, and alteration in hepatic blood flow and/or hemorrhage into the peritoneal cavity and intestine. The present findings are in good agreement with previous reports of decreased level of soluble protein and RNA content in the liver [25].

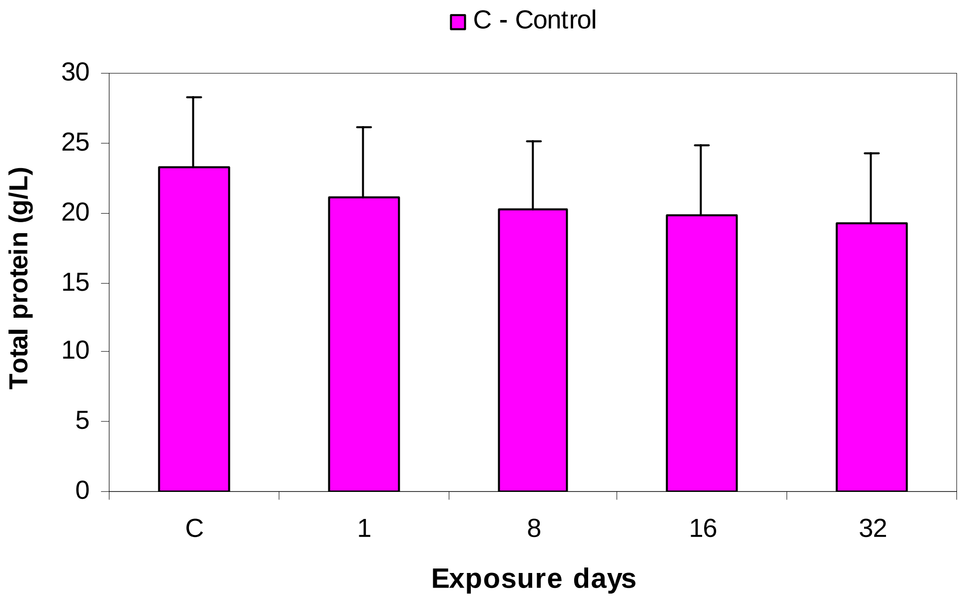

Figure 1. Level of total protein in liver

The alkaline phosphatase is composed of several isoenzymes that are present in practically all tissues of the body, especially in cell membranes. It catalyses the hydrolysis of monophosphate esters and has a wide substrate specificity. The functional activity of this enzyme was found to increase during the exposure with heavy metals as an adaptive response in mitigating the metal toxicity. Increased stimulation of alkaline phosphatase has previously been found in such pathological processes as liver impairment, kidney dysfunction and bone disease [26-27]. This supports our present study with increased activity of alkaline phosphatase in experimental fish when compared to the control (Figure 2).

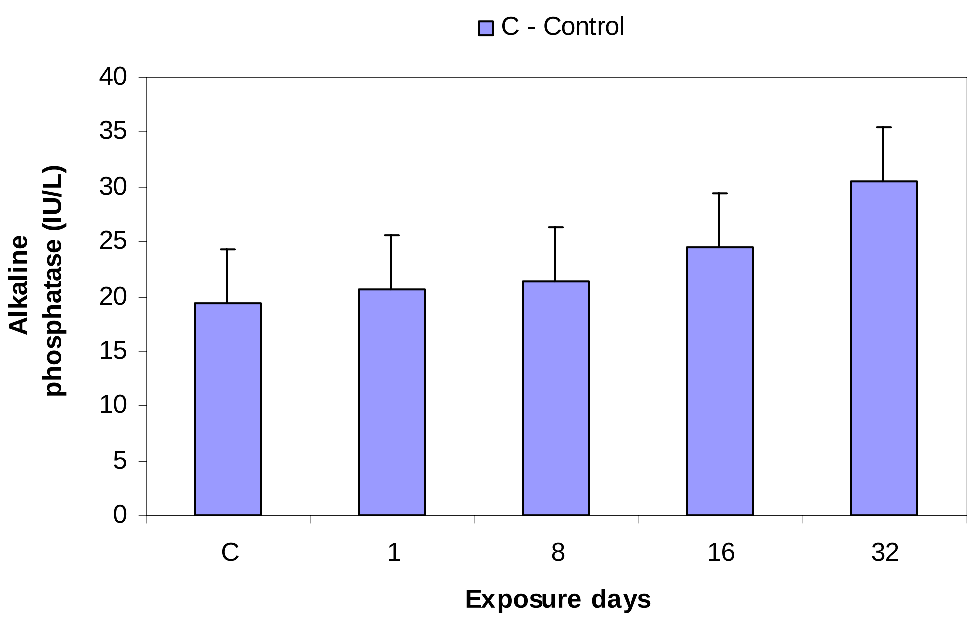

Figure 2. Level of alkaline phosphatase in liver

Transaminases play an important role in carbohydrate and amino acid metabolism in the tissues of fish and other organisms [28]. Alanine aminotransferase is a key metabolic enzyme released on the damage of hepatocytes. The enzyme shows a decreasing level in the first day and from then onwards its level increased steadily in the injured liver (Figure 3), indicating its adaptive response to its leakage into the blood stream due to the metal toxicity. Also, the alanine aminotransferase has a part in transforming protein to glycogen, which is the major reserve fuel of the body during the stress-induced toxicity in the liver .This result is in accordance with the results of previous investigators on fresh water fish [29]. The results indicate that under the influence of different heavy metals or in a state of stress, the damage of tissues and organs may occur with concomitant elevation and liberation of transaminases into the circulation.

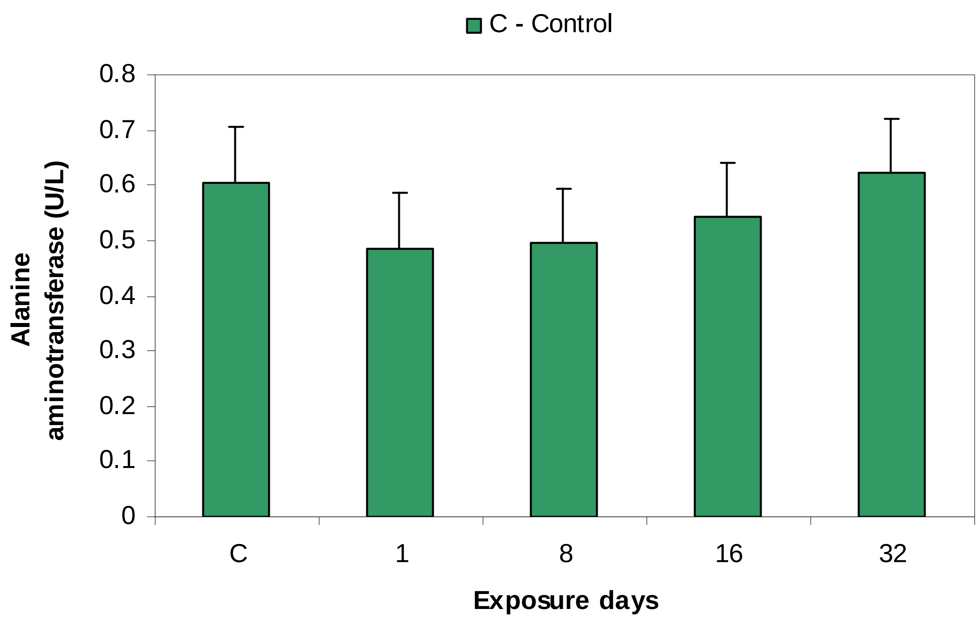

Figure 3. Level of alanine aminotransferase in liver

The aspartate aminotransferase belongs to the plasma non-functional enzymes which are normally localised within the cells of liver, heart, gills, kidneys, muscle and other organs. Monitoring of liver enzyme leakage into the blood has proved to be a very useful tool for toxicity studies in the liver. The present observation on the freshwater common carp revealed a slight decrease of the aspartate transaminase level in the liver during the first exposure day followed by a significant increase onwards (Figure 4). This is supported by a reported alteration in the enzyme activity due to the inhibitory effect of metals [30].

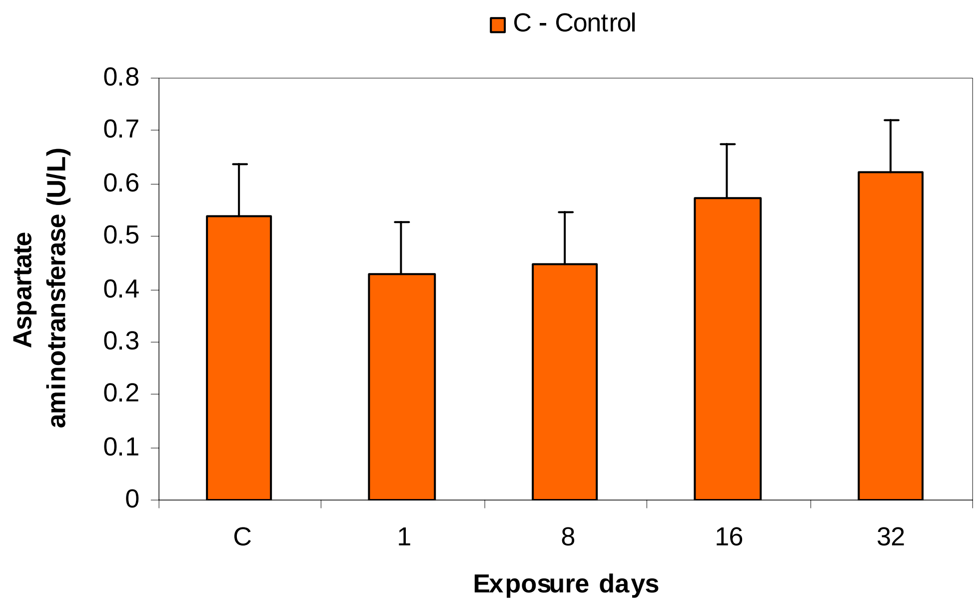

Figure 4. Level of aspartate transaminase in liver

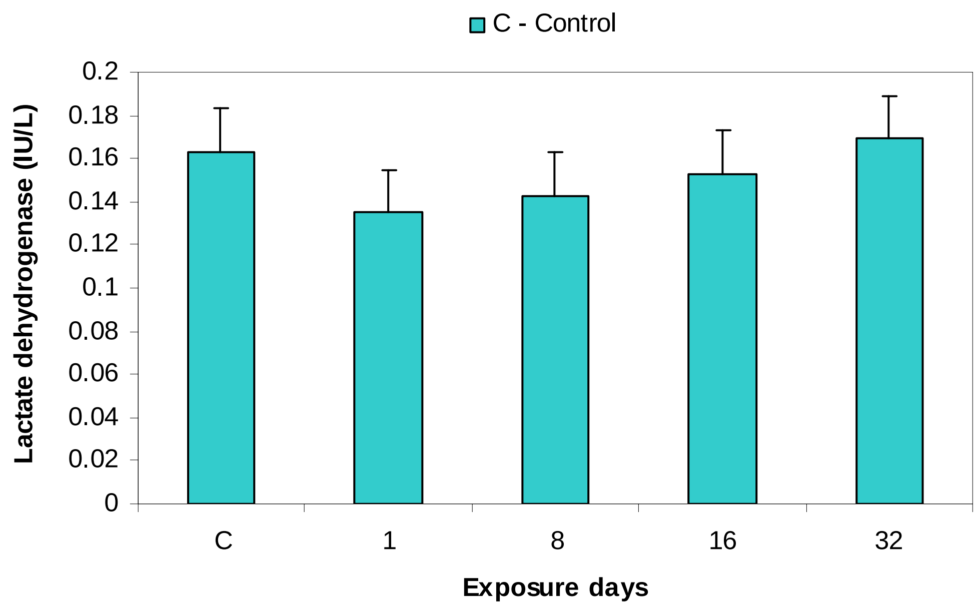

Figure 5. Level of lactate dehydrogenase in liver

The lactate dehydrogenase is an anaerobic enzyme involved in the conversion of pyruvate to lactate in the Embden Meyerhoff pathway. This enzyme shows an increasing activity during a strenuous muscle exercise. In this investigation the level of the lactate dehydrogenase in the liver homogenate was found to decrease in the one-day exposed fish with subsequent significant increase afterwards (Figure 5). The increased level of the lactate dehydrogenase may be due to an alternative anaerobic glycolytic pathway in conversion of lactate to pyruvate for the production of glucose, which is a major source of energy during stress induced by heavy metals. The variation of lactate dehydrogenase activity can thus be used as another sensitive index for assessing heavy metal toxicity.

Conclusions

It can be concluded that fishes show various stress responses comparable to other vertebrates. It is of interest to note that a significant rise in alkaline phosphatase in the liver and a drastic fall of total protein were observed in the present findings. Alanine aminotransferase, aspartate aminotransferases and lactate dehydrogenase exhibit a significant initial decrease in the first day before increasing progressively in the following 8th, 16th and 32nd day. This indicates that an exposure of common carp to a sub-lethal concentration of combined heavy metals causes liver damage. Continuous accumulation of toxic heavy metals by common carp may affect hepatic function and cause cellular degeneration. Furthermore, the results provide evidence that enzyme biomarkers can be used as sensitive indicators of aquatic pollution.

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References

1. H. Yang and N. L. Rose, "Distribution of Hg in the lake sediments across the UK", *Sci. Total Environ.,* **2003**, *304*, 391-404.
2. A. C. Heyvaert, J. E. Reuter, D. G.Sloton, and C. R. Goldman, "Paleolimnological reconstruction of historical atmospheric lead and Hg deposition at Lake Tahoe, California-Nevada", *J. Environ. Sci. Tech.,* **2000**, *34*, 3588-3597.
3. A. R. Karbassi, I. Bayati, and F. Moattar, "Origin and chemical partitioning of heavy metals in riverbed sediments", *Int. J. Environ. Sci. Tech.,* **2006**, *3*, 35-42.
4. M. S. Al-Masri, A. Aba, H. Khalil, and Z. Al-Hares, "Sedimentation rates and pollution history of a dried lake", *Sci. Total. Environ.,* **2002**, *293*, 177-189.
5. W. B. Coker, I. M. Kettles, and W. W. Shilts, "Comparison of mercury concentrations in modern lake sediments and glacial drift in the Canadian shield in the region of Ottawa/ Kingston to Georgian bay, Ontario, Canada", *Water. Air and Soil Poll.,* **1995,** *80*, 1025-1029.
6. N. Dirilgen, "Accumulation of heavy metals in freshwater organisms assessment of toxic interactions", *Tur. J. Chem.,* **2001**, *25*, 173-179.
7. A. Akahori, T. Gabryelak, Z. Jozwiak, and R. Gondko, "Zinc-induced damage to carp (Cyprinus carpio.L.) erythrocyte in vitro", *Biochem. Mol. Biol. Int.,* **1999**, *47*, 89-98.

8. V. Karan, S. Vitotovic, V. Tutundzic, and V. Poleksic, "Functional enzymes activity and gill histology of carp after copper sulfate exposure and recovery", *Ecotoxicol. Environ. Saf.,* **1998**, *40*, 49-55.
9. V. Filipovic and B. Raspor, "Metallothionein and metal levels in cytosol of liver, kidney and brain in relation to growth parameters of *Mullus surmuletus* and *Liza aurata* from the Eastern Adriatic Sea", *Water Research.,* **2003**, *37*, 3253-3262.
10. G. M. Adami, P. Barbieri, M. Fabiani, S. Piselli, S. Predonzani, and E. Reisenhofer, "Levels of cadmium and zinc in hepatopancreas of reared *Mytilus galloprovincialis* from the Gulf of Trieste (Italy)", *Chemosphere.,* **2002,** *48*, 671-677.
11. A. D. Rasmussen and O. Anderson, "Effects of cadmium exposure on volume regulation in the lungworm, *Arenicola marina*", *Aquat. Toxicol.,* **2000,** *48*, 151-164.
12. R. Jalali, H. Ghafourian, Y. Asef, S. J. Davarpanah, and S. Sepehr, "Removal and recovery of lead using non living biomass of marine Algae", *J. Hazard. Mat.,* **2002**, *B92*, 253-262.
13. T. K. Banerjee and R. Devi, "Toxicopathological impact of sub-lethal concentration of lead nitrate on the aerial respiratory organs of *Murrel channa striata* (Bloch Pisces)", *Iran. J. Environ. Health. Sci. Eng.,* **2007**, *4*, 249-256.
14. N. Coen, C. Mothersill, M. Kadhim, and E. G. Wright, "Heavy metals of relevance to human health induce genomic instability", *Pathol.,* **2001,** *195*, 293-299.
15. J. Xie, T. Funakoshi, H. Shimada, and S. Kojima, "Effects of chelating agents on testicular toxicity in mice caused by acute exposure to nickel", *Toxicology.,* **1995**, *103*, 147-155.
16. C. D. Palmer and R.W. Puls, "Natural attenuation of hexavalent chromium in ground water and soils", USEPA Ground Water Issue, EPA/540/5-94/505, U.S. Govt. Print. Office, Washington, D.C., **1994,** pp. 57-72.
17. J. J. Ceron, E. Sancho, M. D. Ferrando, C. Gutierrez, and E. Andreu, "Changes in carbohydrate metabolism in the eel *Anguilla anguilla* during short-term exposure to diazinon", *Toxicol. Environ. Chem.,* **1997**, *60*, 201-210.
18. E. H. Coles, "Veterinary Clinical Pathology", 4th Edn., Saunders, Philadelphia, **1989,** p. 486.
19. J. A. Coppo, N. B. Mussart, and S. A. Fioranelli, "Physiological variation of enzymatic activities in blood of bull frog, *Ranacatesbeiana* (Shaw, 1802)", *Rev. Vet.,* **2001-2002**, *12/13*, 22-27.
20. O. H. Lowry, N. J. Rosenbrough, A. L. Farr, and R. J.Randall, "Protein measurement with folin phenol reagent", *J. Biol. Chem.,* **1951**, *193*, 265-275.
21. M. P. Balasubramanian, S. Dhandayuthapani, K. Neelaiappan, and K. Ramalingam, "Comparative studies on phosphomonoesterase in helminthes", *Helminthologia.,* **1983**, *20*, 111-120.
22. H. U. Bergmeyer and E. Bernt, "Methods of Enzymatic Analysis" (Ed. H. U. Bergmeyer), 2nd Edn., New York, *Academic Press.,* **1974,** p.735.
23. W. E. Splittstoesser, M C Chu, S. A Stewart, and S. A. Splittstoesser, "Alanine aminotransferase from *Cucurbita moschata* cotyledons", *Plant. Cell. Physiol.,* **1976**, *17*, 83-89.
24. J. King, "The dehydrogenase of oxido reductase lactate dehydrogenase", in "Practical Clinical Enzymology" (Ed. D .Van), Nostrand Co., London, **1965,** pp. 83-93.

25. S. K. Jain, A. K. Raizada, S. Shrivastava, and K. Jain, "Protective effect of zeolite on the toxicity of lead to fresh water fish", *Fresenius Environ. Bull.,* **1996**, *5*, 466-468.
26. R. Kopp and J. Hetesa, "Changes of haemotological indices of juvenile carp (*Cyprinus carpio* L.) under influence of Natural population Cyanobacterial water blooms", *Acta. Vet. Brno.,* **2000**, *69*, 131-137.
27. J. L.Yang and H. C. Chen, "Serum metabolic enzyme activities and hepatocyte ultrastructure of common carp after gallium exposure', *Zoological Studies.,* **2003**, *42*, 455-461.
28. F. Atroshi, A. Rizzo, S. Sankari, I. Biese, P. Westermarck, and P. Veijalainen, "Liver enzyme activates of rats exposed to Ochratoxin A and T-2 toxin with antioxidants", *Bull. Environ. Contam. Toxicol.,* **2000**, *64*, 586-592.
29. R. V. Zikic, A. S. Stajn, B. I. Ognjanovic, S. Z. Pavlovic, and Z. S. Saicic, "Activities of superoxide dismutase and catalase in erythrocytes and transaminases in the plasma of Carps (*Cyprinus carpio, L.)* exposed to cadmium", *Physiol. Res.,* **1997,** *46*, 391-396.
30. E. H. Abou El-Naga, K. H. El-Moselhy, and M. A. Hamed, "Toxicity of cadmium and copper and their effect on some biochemical parameters of marine fish *Mugil seheli*", *Egyptian J. Aquatic Res.,* **2005,** *31*, 60-71.

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Full Paper

Spectrophotometric flow-injection analysis assay of tetracycline antibiotics using a dual light-emitting diode based detector

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Abstract: In this paper, a small dual light-emitting diode (LED)-based detector for FIA process analyser has been designed. The detector's optical parts comprise a flow-through cell, a dual-blue LED and a photodiode. Neither mirrors nor lenses are used. The optical path for the first LED detects the blank, while the other LED detects the sample. The detector's electronic components including a signal amplifier and an A/D converter are integrated on one small board connected to a PC for measuring the results. The designed spectrophotometric detector was used for the determination of tetracycline antibiotics. Uranyl acetate was used as a reagent forming orange-red complexes with the drugs in N,N–dimethylformamide. The complexes show absorption maxima at 410, 416 and 408 nm for tetracycline hydrochloride (TCH), chlortetracycline hydrochloride (CTCH), and doxycycline hydrochloride (DCH), respectively. The detection limit was found to be 0.38, 0.75, 1.44 μg mL^{-1} and the linear range was obtained at 1.0-3.0, 3.0-5.0, and 3.0-10.0 μg mL^{-1} for TCH, CTCH and DCH, respectively. The proposed method has been successfully applied to the determination of tetracycline antibiotic residues in milk samples. Moreover, this method is an environmentally friendly approach and suitable for routine analysis.

Keywords: tetracycline, chlortetracycline, doxycycline, flow injection, light-emitting diode, uranyl acetate

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Introduction

Tetracyclines are among the most important antibiotic families characterised by their wide ranges of antibacterial effects [1]. The structure of tetracycline and its derivatives are shown in Figure 1 and Table 1. This pharmacological family is used in human pathologies as well as in veterinary medicine, animal nutrition and feed additives for cattle breeding. Therefore, there is a continuing requirement for reliable, sensitive and selective procedures for their determination.

Spectrophotometric methods are the most widely used for the determination of tetracyclines in bulk and pharmaceutical preparations [2-4]. They usually involve the formation of a coloured derivative compound in a multi-step reaction, which is occasionally tedious and highly time-consuming. The major drawbacks of spectrophotometric methods are the low sensitivity [3,4] and sometimes the slow development of the colour [4] or its instability [2]. Methods based on flow injection (FI) analysis with spectrophotometric detector have also been reported for the assay of tetracyclines [5-6], some of them with a high sampling frequency, although these methods are not very sensitive.

The aim of this work is to develop a very simple and sensitive continuous-flow method for the determination of tetracycline, chlortetracycline, and doxycycline based on colorimetric reaction with uranyl acetate in N,N–dimethylformamide (DMF) using a dual light-emitting diode (LED)-based spectrophotometric detection. The use of LEDs in a flow-through cell is the key idea for miniature analytical devices. Moreover, the LED-based detector is less expensive and provides a performance which is as good as any commercial alternative.

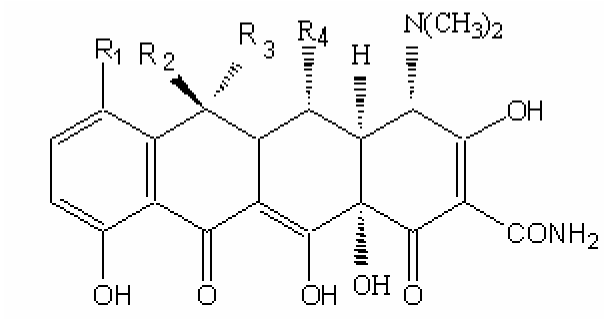

Figure 1. Structure of tetracycline

Table 1. Some tetracycline antibiotics according to Figure 1

Name	R_1	R_2	R_3	R_4
Tetracycline (TC)	H	OH	CH_3	H
Oxycycline (OTC)	H	OH	CH_3	OH
Chlortetracycline (CTC)	Cl	OH	CH_3	H
Doxycycline(DC)	H	H	CH_3	OH

Materials and Methods

Chemicals and reagents

The hydrochlorides of tetracycline (TCH), chlortetracycline (CTCH), and doxycycline (DCH) were of HPLC grade and purchased from Sigma (USA). Their stock solutions (100 μg mL^{-1}) were prepared by dissolving the appropriate amount of each hydrochloride salt in distilled deionised water. The solutions are stable for more than 1 month when kept at 4^0C and protected from sunlight. The standard solutions of the tetracyclines (TCs) were daily prepared from the stock solutions by careful dilution.

The carrier solution (0.01M DMF) was prepared by diluting 0.4 mL of DMF (AR grade, Merck, Germany) to 500 mL with distilled deionised water. The reagent solution (100 μg mL^{-1} uranyl acetate) was obtained by dissolving 0.0100 g of UO_2 [$(CH_3COO)_2.2H_2O$] (AR grade, Merck, Germany) in the carrier solution and diluting to 100 mL in a volumetric flask.

Na_2EDTA-Mcllvaine buffer solution (pH 4) was prepared by dissolving 15 g of disodium hydrogen phosphate dihydrate (Merck, Germany), 13 g of citric acid monohydrate (Merck, Germany) and 3.72 g of EDTA (Merck, Germany) in water and diluting to 1 L.

Florisil (0.150-0.250 mm) and oxalic acid were purchased from Merck (Germany). Acetonitrile (HPLC grade) was purchased from Carlo Erba (Italy).

Sample preparation procedure

Fifteen milliliter of cow's milk sample was diluted to 25 mL with Mcllvaine buffer-EDTA solution (pH 4) followed by centrifuging for 15 min, then only the supernatant was collected and passed through a Florisil syringe column. TCs were eluted from the column with 5 mL of 0.2 M oxalic acid : acetonitrile (4:1) then injected into the optimum FI-spectrophotometric system.

The designed LED-based absorbance detector and flow manifold

The design of the LED-based absorbance detector and flow manifold is shown in Figure 2. It consists of a peristaltic pump (Eyela MP3, Japan), and the sample or standard solution is injected via a Rheodyne 5041 rotary injection valve with a 135 μL sample loop. Tygon and teflon tubing (Elkay, Galway, Ireland) are used as a flow line for carrier (DMF) and reagent (uranyl acetate solution), and a Y-shaped connector is used for merging the streams. The sample containing a TC standard is injected then mixed with the carrier and the reagent solution forming an orange-red complex which passes through the laboratory-built flow-through cell. A dual super bright blue LED is used for producing monochromatic light for blank and sample solution. The signal generated is converted and integrated using the specially-made software program.

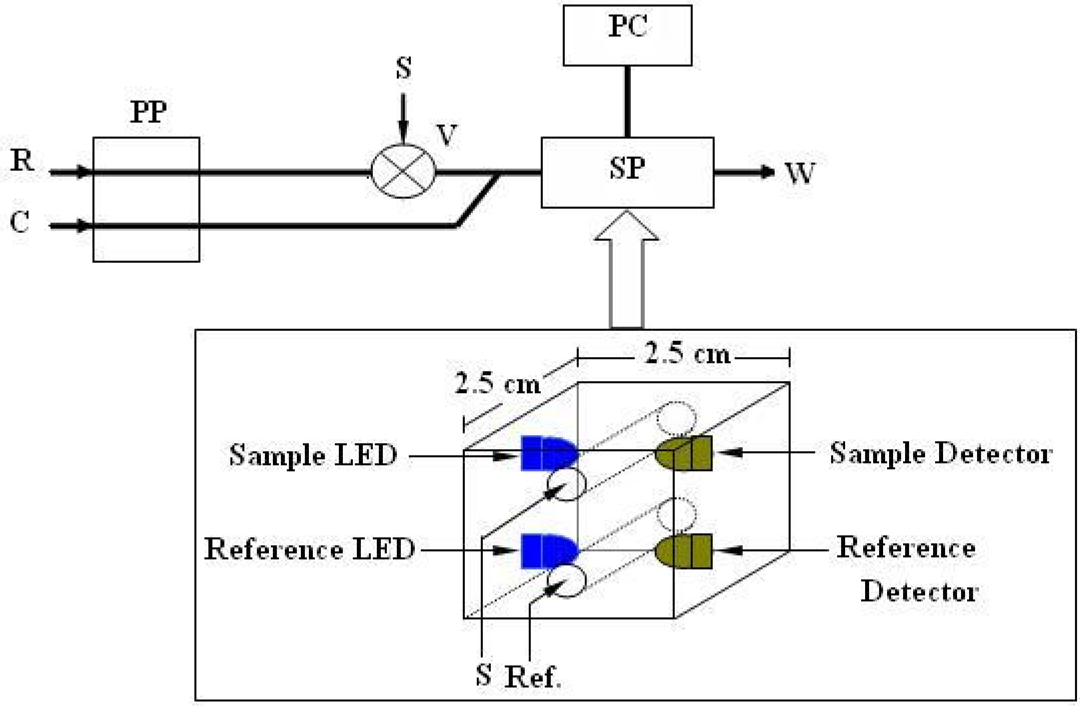

Figure 2. Schematic diagram of the FI-spectrophotometry manifold: PP = peristaltic pump, C = carrier (0.01 M DMF), R = reagent (100 µg mL^{-1} uranyl acetate), S = sample, V = injection valve with appropriate sample volume loop, SP = spectrophotometric detector, PC = personal computer, W = waste, Ref = reference or blank

Results and Discussion

Optimisation of the flow injection system

The orange-red complexes of the three TCs with uranyl acetate in DMF show absorption maxima at 410, 416, and 408 nm (for complex of tetracycline, chlortetracycline, and doxycycline, respectively) as exhibited in Figure 3. This is the reason for selecting the blue LED as the light source of the detector.

Optimisation experiments were carried out using the manifold in Figure 2 by injecting the tetracycline standard at various concentrations. The variables, ranges studied and the optimum values are shown in Table 2. Since TC, CTC and DC are in the same antibiotic family and their reactive sites have the same chromophore and show nearly the same absorption maxima with uranyl acetate in DMF, indicating the common site structure reactive to uranyl interaction, therefore it can be assumed that these TCs give the same optimum conditions and thus the optimised conditions obtained with TC can reasonably be used for the determination of CTC and DC.

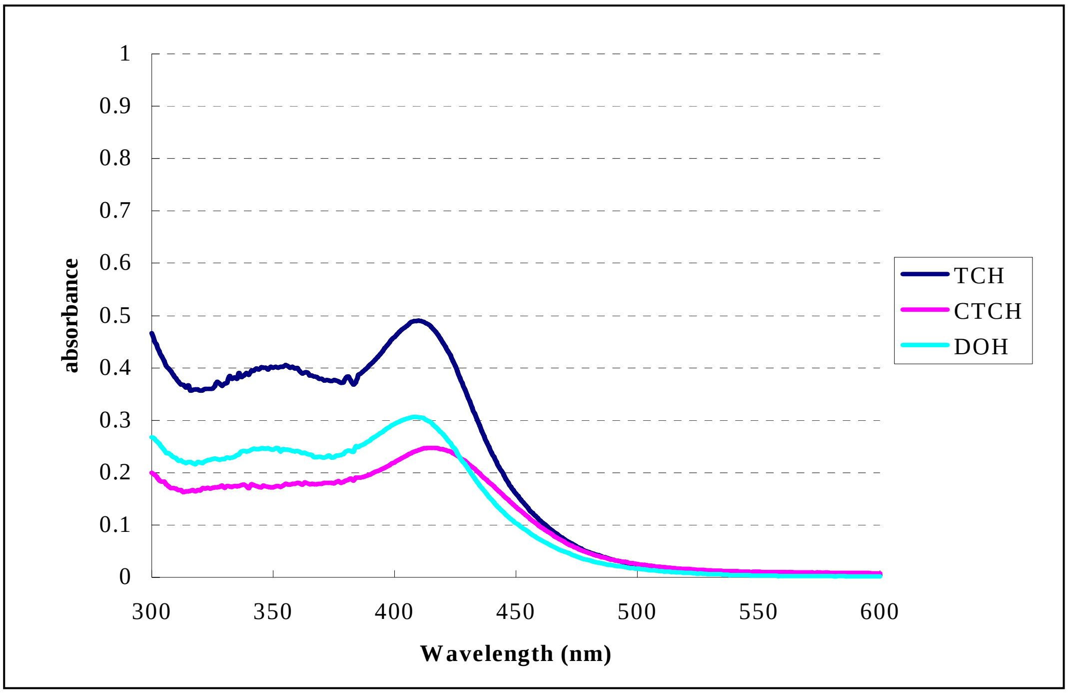

Figure 3. UV-VIS spectra of the complexes of tetracycline hydrochloride (TCH), chlortetracycline hydrochloride (CTCH), and doxycline hydrochloride (DCH) with uranyl acetate in DMF

Table 2. Optimum conditions for determination of tetracyclines using the manifold in Figure 2.

Parameter studied	Range studied	Optimum value
Uranyl acetate conc. (µg mL^{-1})	50-500	100
DMF conc. (M)	0.01-0.50	0.01
Flow rate (mL min^{-1})	0.5-4.0	1.0
Injection volume (µL)	67, 135, 271	135

Effect of uranyl acetate concentration

The influence of concentration of uranyl acetate between 50 and 500 µg mL^{-1} was examined. The highest analytical sensitivity was obtained when the concentration of uranyl acetate in 0.01 M DMF was 100 µg mL^{-1}, above which the sensitivity decreased suddenly as shown in Figure 4. Therefore, in order to achieve maximum sensitivity, 100 µg mL^{-1} uranyl acetate was chosen for further study.

Effect of DMF concentration

The effect of DMF concentration on the analytical sensitivity for tetracycline using the laboratory made detector was studied. The highest sensitivity was obtained with the DMF concentration of 0.01 M (Figure 5). Thus, this concentration was chosen.

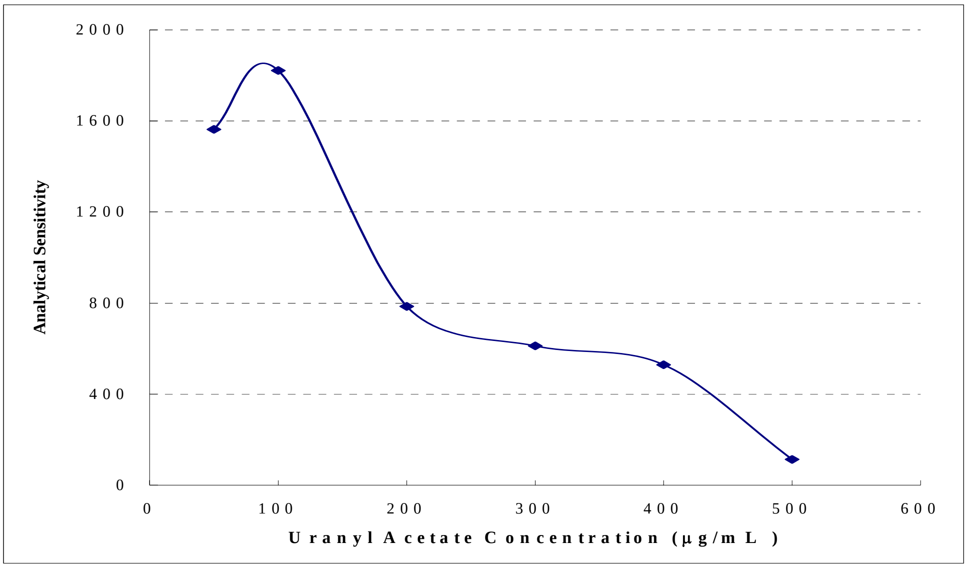

Figure 4. Relationship between uranyl acetate concentration and analytical sensitivity for tetracycline

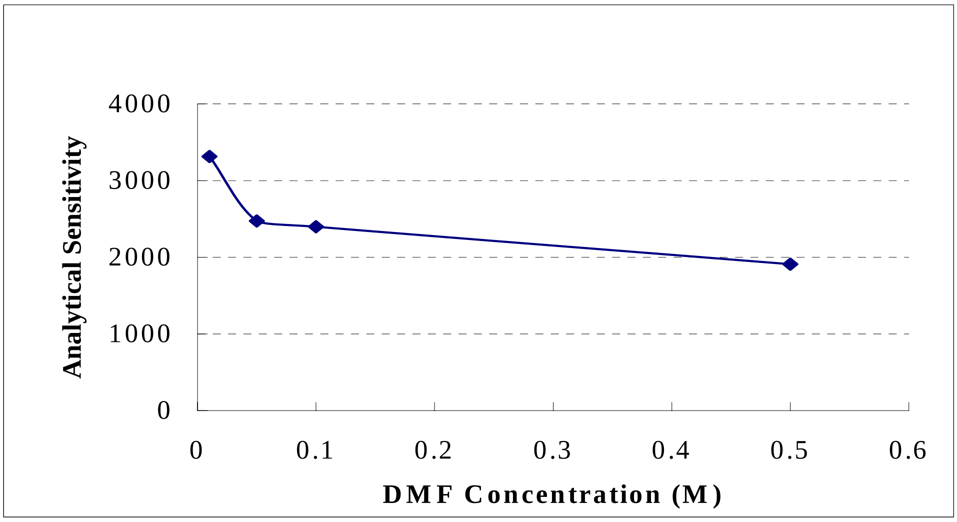

Figure 5. Relationship between DMF concentration and analytical sensitivity for tetracycline

Effect of reagent flow rate

The flow rate between 0.5-4.0 mL min^{-1} of the two lines, viz. reagent and carrier stream lines, was investigated simultaneously for tetracycline determination. As shown in Figure 6, the analytical sensitivity increases with an increasing flow rate of both streams. However when the flow rate is more than 1.0 mL min^{-1}, the sensitivity decreases suddenly. This is attributed to incomplete reaction of tetracycline and uranyl acetate in DMF. So the flow rate of 1.0 mL min^{-1} was chosen.

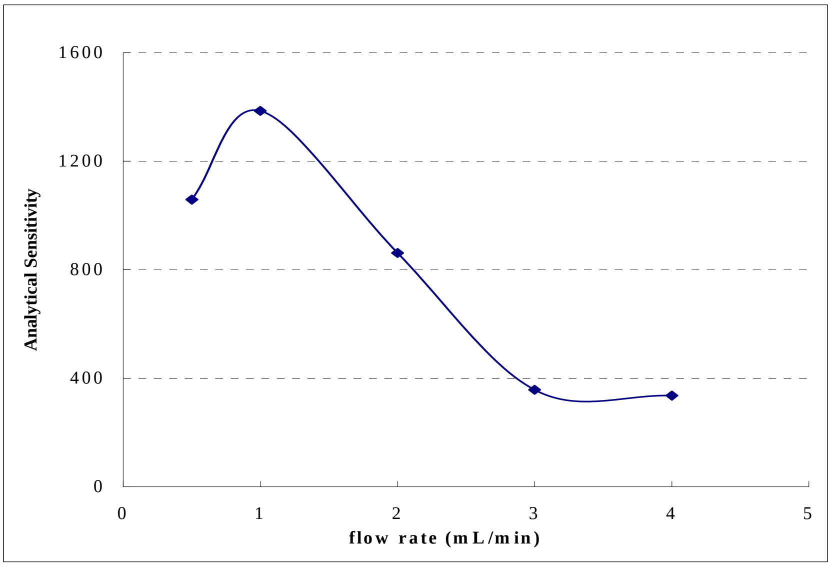

Figure 6. Relationship between flow rate of carrier and reagent, and analytical sensitivity for tetracycline

Effect of injection loop volume

This study was carried out at three injection loop volumes, viz. low (67 μL), medium (135 μL), and high (271 μL) volume on the analytical sensitivity for tetracycline. The representation of low, medium and high volume of injection has been established by varying a retain loop. Though many loops have been tested, the results could not be calculated because of the fluctuation of the signal. The lower bound loops gave dilution while the upper bound loops yielded fluctuations. These results could not be calculated because of high variant in deviation. Only three of them gave satisfactory results with good deviations. It was found that the highest sensitivity was obtained at 135 μL sample loop as exhibited in Figure 7, therefore it was chosen as optimum.

Under the optimum conditions (Table 2), calibration graphs were obtained for tetracycline, chlortetracycline, and doxycycline with the linear range at 1.0-3.0, 3.0-5.0, and 3.0-10.0 µg mL-1 for TCH, CTCH and DCH, respectively.

Analytical Application

The proposed laboratory-made LED-based spectrophotometric detector was evaluated by carrying out tetracycline, chlortetracycline, and doxycycline determination in milk samples before and after spiking with TCs standards at various concentration ranges. The calibration graphs obtained demonstrated that the analytical sensitivity was significantly enhanced and that the linear ranges at lower concentration and the limit of detection of these drugs were better than those obtained without passing through the Florisil syringe column (Table 3). Table 4 shows the precision and the recovery data obtained on cow’s milk samples. These data demonstrate that the proposed method has a good potential for the determination of TCs in real samples.

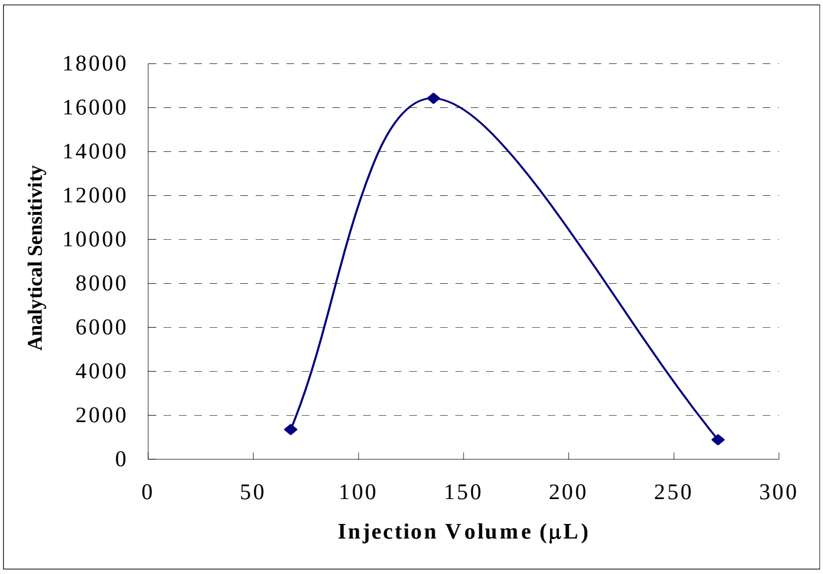

Figure 7. Relationship between injection volume and analytical sensitivity for tetracycline

Table 3. Linear ranges and detection limits for the determination of tetracycline antibiotic residues in milk samples with and without preparation by using Florisil syringe column followed by flow injection with a dual LED-based detector (n = 3)

Analyte	Without passing through Florisil column		With passing through Florisil column	
	Linear range ($\mu g\ mL^{-1}$)	Detection limit ($\mu g\ mL^{-1}$)	Linear range ($\mu g\ mL^{-1}$)	Detection limit ($\mu g\ mL^{-1}$)
TCH	1.0-3.0	0.38	1.0-3.0	0.19
CTCH	3.0-5.0	0.75	1.0-5.0	0.65
DCH	3.0-10.0	1.44	1.0-5.0	0.95

Table 4. Recoveries for TC-fortified milk

Analyte	Added ($\mu g\ mL^{-1}$)	Found ($\mu g\ mL^{-1}$)	%Recovery (%RSD, n=3)
TCH	1.0	0.97	97 (4.6)
	1.5	1.5	101 (6.9)
	2.0	2.1	103 (2.7)
CTCH	3.0	2.7	82 (5.2)
	4.0	3.7	92 (4.6)
	5.0	4.8	95 (6.2)
DCH	1.0	0.94	94 (3.9)
	2.0	2.1	106 (1.4)
	3.0	2.9	96 (5.2)

Conclusions

The proposed flow injection with a dual LED-based spectrophotometric method for the determination of tetracycline, chlortetracycline, and doxycycline was shown to be sensitive, selective, and reproducible. This method was successfully applied to the determination of these antibiotics in spiked cow's milk samples and should be suitable for routine analysis.

Acknowledgements

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References

1. S. Yang, J. Cha, and K. Carlson, "Simultaneous extraction and analysis of 11 tetracycline and sulfonamide antibiotics in influent and effluent domestic wastewater by solid-phase extraction and liquid chromatography-electrospray ionization tandem mass spectrometry", *J. Chromatogr. A*, **2005**, *1097*, 40-53.
2. U. Saha, A. K. Sen, T. K. Das, and S. K. Bhowal, "Spectrophotometric determination of tetracyclines in pharmaceutical preparations with uranyl acetate", *Talanta*, **1990**, *37*, 1193-1196.
3. K. M .Emara, H. F. Askal, and G. A. Saleh, "Spectrophotometric determination of tetracycline and oxytetracycline in pharmaceutical preparations", *Talanta*, **1991**, *38*, 1219-1222.
4. S. M. Sultan, I. Z. Alzamil, and N. A. Alarfaj, "Complexometric-spectrophotometric assay of tetracyclines in drug formulations", *Talanta*, **1988**, *35*, 375-378.
5. R. Karlíček and P. Solich, "Flow-injection spectrophotometric determination of tetracycline antibiotics", *Anal. Chim. Acta*, **1994**, *285*, 9-12.
6. A. Ruiz Medina, M. G. García Marín, M. L. Fernández de Córdova, and A. Molina Díaz, "UV spectrophotometric flow-injection assay of tetracycline antibiotics retained on Sephadex QAE A-25 in drug formulations", *Microchem. J.*, **2000**, *65*, 325-331.

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Full Paper

Quantitative characterisation of an engineering write-up using random walk analysis

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Abstract: This contribution reports on the investigation of correlation properties in an English scientific text (engineering write-up) by means of a random walk. Though the idea to use a random walk to characterise correlations is not new (it was used e.g. in the genome analysis and in the analysis of texts), a random walk approach to the analysis of an English scientific text is still far from being exploited in its full strength as demonstrated in this paper. A method of high-dimensional embedding is proposed. Case examples were drawn arbitrarily from four engineering write-ups (Ph.D. synopsis) of three engineering departments in the Faculty of Technology, University of Ibadan, Nigeria. Thirteen additional analyses of non-engineering English texts were made and the results compared to the engineering English texts. Thus, a total of seventeen write-ups of eight Faculties and sixteen Departments of the University of Ibadan were considered. The characterising exponents which relate the average distance of random walkers away from a known starting position to the elapsed time steps were estimated for the seventeen cases according to the power law and in three different dimensional spaces. The average characteristic exponent obtained for the seventeen cases and over three different dimensional spaces studied was 1.42 to 2-decimal with a minimum and a maximum coefficient of determination (R^2) of 0.9495 and 0.9994 respectively. This is found to be 284% of the average characterising exponent value (0.5), as supported by the literature for random walkers based on the pseudo-random number generator. The average characteristic exponent obtained for the four cases that were engineering-based and over the three different dimensional studied spaces was 1.41 to 2-decimal (closer by 99.3% to 1.42) with a minimum and a maximum coefficient of determination (R^2) of 0.9507 and 0.9974 respectively. This is found to be 282% of the average characterising exponent value (0.5), as supported by the literature for random walkers based on the pseudo-random number generator. In view of the range of the average characterising exponent across Faculties and the closeness of the average characterising exponent in the engineering-based cases in particular, it can be concluded that the engineering writing is strongly correlated. This study recommends that a very high characterising exponent value (e.g 1.42) is a mark of a very good engineering write-up.

Keywords: engineering write-up, random walker analysis, quantitative evaluation, power law

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Introduction

In the evaluation of scholarly publications, a major worldwide challenge has been the need to eliminate subjectivity in evaluating papers in terms of contribution to knowledge and the overall suitability for publication [1]. Manuscripts for publication are supposed to be objectively evaluated for presentation, scientific merit, quality of English, spellings and grammar, and the overall quality [2]. These measurement parameters also apply to the evaluation of projects, dissertations, and Ph.D. theses. Unfortunately, it is a common experience that some evaluations are biased, with judgements made unfairly in many instances. Evaluators are often accused of race discrimination, hatred, and inferiority complex. Their evaluation decisions and comments may have been motivated by the qualitative means of evaluation for most scientific writings, which depend on personal judgements.

Faced with this challenge, the scientific community has been making efforts at solving this important problem. An attractive approach is the development of a quantitative methodology with which all works may be evaluated. It is expected that the use of such a methodology should produce similar results from the assessments of two independent reviewers. Thus, engineering write-ups, which may include papers and Ph.D. theses, should be quantitatively evaluated. The aim of this study is to develop and apply a quantitative approach in evaluating engineering write-ups. Specifically, this contribution investigates the correlation properties in an English scientific text by means of a random walk. The framework of this approach is built on the principles supporting random walker movements in three different dimensional spaces (1-D, 2-D and 3-D) [3-5].

The idea of using a random walk to characterise correlations is not new. It was used e.g. in the genome analysis by Peng et al. [6] and Buldyrev et al. [7]. The former group analysed the fluctuations in the correlation exponents obtained for noncoding DNA sequences by generating correlated random sequences of comparable length and studied the fluctuations in this control system. They concluded that the DNA exponent fluctuations are consistent with those obtained from the control sequences having long-range power-law correlations. The latter researchers proposed a generalised Lévy walk (GLW) to model fractal landscapes observed in noncoding DNA sequences and provided an approximation of genomic DNA sequences, such as the distribution of strand-biased regions (those with an excess of one type of nucleotide) as well as local changes in the slope of the correlation exponent α. Random walk concept has also been applied in the analysis of texts [8-9]. For example, Schinner [9] analysed the Voynich manuscript using random walk mapping and token/syllable repetition statistics. The results significantly tighten the boundaries for possible interpretations by suggesting that the text has been generated by a stochastic process rather than by encoding or encryption of the language.

A major step in the approach of random walk is to analyse the empirical relationships between the average distance of random walkers from a known starting position (datum) and time steps [10-11]. In addition, a comparative analysis of the empirical relationship obtained with values cited in the literature for random walkers is made in the present work. This analysis is driven by the pseudo-random number generator in three different dimensional spaces. It is hoped that the findings of this study will stimulate further research and enable the research community to know whether or not an arbitrary engineering write-up is a form of random process, and that readers and researchers might be enlightened on how to have a measure of the relative quality of the write-up quantitatively.

Methodology

The methodology presented here is hinged on the random walker movement (RWM) principles, which are driven by the pseudo-random number generator in any space (1-D, 2-D or 3-D). RWM is governed empirically as [12]:

$$D_{av} \propto T^{\beta} \tag{1}$$

Expression (1) states that D_{av} varies directly as the β^{th} power of T. Here, β is referred to as the characteristic exponent. D_{av} is termed as the average distance of a number of random walk from a known starting position (datum after a known time step has elapsed), and T is the time step. It should be noted that for a particle undergoing pure random motion with reference to a fixed starting position in 1-D, 2-D or 3-D Euclidean space, the characterising exponent β is equal to 0.5. The explanation is that the particle moves away from the fixed starting position such that its average distance (D_{av}) is directly proportional to the square root of elapsed time (T). Now let us imagine the same particle being driven similarly ("randomly" so to say) by the organised string of the English language alphabets of equally organised thoughts called the "Engineering Write-ups", the average distance (D_{av}) measured is expected to be higher for the same elapsed time.

The intent of the author of the "Engineering Write-ups" is foremost to communicate the whole of his conception to the readers in the shortest possible time. This situation may be likened to a very fast moving particle aimed at a target. To establish the corresponding expression (1) for random walk movement being driven by an engineering write-up in any space, the method description is as follows:

> Let us assume a 10-letter word "Technology" in an engineering write-up which involves three random walks. In a 1-dimensional space there are only two possible random step movements (forward or backward). These are labelled 1 or 2 for digital identification purpose. In a 2-dimensional space there are only four possible random step

movements: two in each of the two mutually perpendicular directions. These are labelled 1, 2, 3 or 4 for digital identification purpose. In a 3-dimensional space there are only six random step movements: two in each of the three mutually perpendicular directions. These are labelled 1, 2, 3, 4, 5 or 6 for digital identification purpose.

Based on the description made above, a serial identification of the English alphabets without differentiation between small and capital letters is made. Each of the alphabets is then matched to a serial number. For example, "A" or "a" is matched to "1", "B" or "b" to "2", "C" or "c" to "3", … , and "Z" or "z" to "26" (Table 1). Thus, the interpretation of the word "Technology" is shown in Table 2.

Table 1. Serial identification of English alphabets without differentiation between small and capital letters

Alphabet	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Serial Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

In Table 2, the interpretation of Mod(SN,2) is that "SN" is divided by two (2) and the modulus of the remainder is obtained. This definition is similar for the 2-D and 3-D situations. It is assumed that the three random walks used have one consecutive time step delay interval before starting and ending respectively. Thus random walk 1 starts to be active on the instruction of the first letter (T) of the word "Technology" and stops to be active on the third letter (C) for an experiment involving three random steps. Random walk 2 becomes active on the instruction of the second letter (E) and stops to be active on the fourth letter (H) for an experiment involving three random steps. Random walk 3 becomes active on the instruction of the third letter (C) and stops to be active on the sixth letter (N) for an experiment involving three random steps. Referring to Table 2, the random direction followed by the walker depends on the dimensional space being investigated. The interpretation of Table 2 may be made from an understanding of expression (1). Simply explained, it means that the distance of each walker from the known starting position can be measured. Measurement is done at the end of the specified time steps and at the end of a constant step size. In the evaluation of the write-ups, it may be necessary to statistically determine the relationship among the sets of solutions. This is pursued in this work with the aid of the correlation coefficient (R) between two sets of data, and the coefficient of determination (R^2), as stated in the section on results.

Table 2. Digital random movement in three different dimensional spaces of the word "Technology"

Alphabets, Space /Instructions	10-Letters One Word "Technology"									
	T	E	C	H	N	O	L	O	G	Y
Alphabet Serial Number (SN)	20	5	3	8	14	15	12	15	7	25
1-D: Mod(SN,2)+1	1	2	2	1	1	2	1	2	2	2
2-D: Mod(SN,4)+1	1	2	4	1	3	4	1	4	4	2
3-D: Mod(SN,6)+1	3	6	4	3	3	4	1	4	2	2

Case Study

Four selected cases of engineering write-ups (synopses of abstracts) were made from the Postgraduate School, University of Ibadan, Ibadan, Nigeria. The synopses of abstracts (Ph.D. Theses 2000-2002) involved three Engineering Departments (Agriculture, Food Technology and Mechanical). These served as entry data to a FORTRAN-based algorithm for analysing the data for the purpose of establishing the corresponding expression (1) in each of the four cases studied. That is, each of these data was analysed like it was previously described for the 10-letter word "Technology". However, one hundred random walks (100), five hundred and fifty time steps (550) and constant step size (unity) were used to study each of the four cases. The numbers of alphabets used to compose the four write-ups were 628, 820, 884, and 682. Additional thirteen cases (13) involving different Departments were drawn arbitrarily for the same analysis above, using the same FORTRAN platform across another seven (7) Faculties. The findings of this study are presented in tabular as well as graphical forms in the results section.

Results

After extensive laboratory experiments, eight additional tables were generated. The first relates to the sample data for 100 random walks in 1-dimensional space (Table 3). In Table 4, the results of the sample logarithm of data for 100 random walks in 1-dimensional space are presented. Table 5 shows the sample data for 100 random walks in 2-dimensional space. An additional table, Table 6, was generated which contains the sample logarithm of data for 100 random walks in 2-dimensional space. The results presented in Table 7 relate to the sample data for 100 random walks in 3-dimensional space. Table 8 shows the sample logarithm of data for 100 random walks in 3-dimensional space. In Table 9, the characterising exponents of random walk movement in three different dimensional spaces are displayed. This employs four different engineering write-ups.

Table 10 shows R^2 of line of best fit for the four engineering write-up cases and three dimensional spaces. The graphs show the log of average distance against the log of time steps for the four cases in the three different dimensional spaces (Figures 1 to 12). In addition, Figure 13 shows the results of the first random walk (constant step size) trace for case 4 in 2-D. From Table 11, the Faculty of Public Health is the youngest of all studied Faculties of the University and this may explain why only one Department exists in the documentation by Olayinka et al. [4]. In Table 12, the average characterising exponent for cases in the Faculty of Technology is 1.4155 while that for all Faculties studied is 1.42 to 2-decimal.

Table 3. Sample data for 100 random walks in 1-dimensional space

Time step	Average distance from starting point (D_{av})			
	Case 1	Case 2	Case 3	Case 4
1	1.00	1.00	1.00	1.00
2	1.32	1.28	1.34	1.36
3	2.32	2.28	2.34	2.36
4	2.86	2.72	2.96	2.96
5	3.90	3.74	4.04	4.04
6	4.66	4.32	4.90	4.76
7	5.74	5.40	6.10	5.88
8	6.60	6.12	7.14	6.76
9	7.74	7.22	8.48	7.90
10	8.72	8.02	9.66	8.82
11	9.92	9.18	11.10	9.98
12	10.94	10.10	12.38	10.76
13	12.16	11.32	13.94	11.94
14	13.14	12.28	15.30	12.74
15	14.34	13.56	16.92	13.94
16	15.28	14.60	18.36	14.82
17	16.44	15.94	20.08	16.02
18	17.30	16.98	21.64	16.90
19	18.46	18.36	23.42	18.14
20	19.28	19.42	25.12	19.02

Table 4. Sample logarithm of data for 100 random walks in 1-dimensional space

Log of time step	Log of average distance from starting point {Log (D_{av})}			
	Case 1	Case 2	Case 3	Case 4
0.00000	0.00000	0.00000	0.00000	0.00000
0.69315	0.27763	0.24686	0.29267	0.30748
1.09861	0.84157	0.82418	0.85015	0.85866
1.38629	1.05082	1.00063	1.08519	1.08519
1.60944	1.36098	1.31909	1.39624	1.39624
1.79176	1.53902	1.46326	1.58924	1.56025
1.94591	1.74746	1.68640	1.80829	1.77156
2.07944	1.88707	1.81156	1.96571	1.91102
2.19722	2.04640	1.97685	2.13771	2.06686
2.30259	2.16562	2.08194	2.26799	2.17702
2.39790	2.29455	2.21703	2.40695	2.30058
2.48491	2.39243	2.31254	2.51608	2.37584
2.56495	2.49815	2.42657	2.63476	2.47989
2.63906	2.57566	2.50797	2.72785	2.54475
2.70805	2.66305	2.60712	2.82850	2.63476
2.77259	2.72654	2.68102	2.91017	2.69598
2.83321	2.79972	2.76883	2.99972	2.77384
2.89037	2.85071	2.83204	3.07454	2.82731
2.94444	2.91561	2.91017	3.15359	2.89812
2.99573	2.95907	2.96630	3.22366	2.94549

Table 5. Sample data for 100 random walks in 2-dimensional space

Time step	Average distance from starting point (D_{av})			
	Case 1	Case 2	Case 3	Case 4
1	1.00000	1.00000	1.0000	1.00000
2	1.86610	1.79196	1.82610	1.83439
3	2.97735	2.79196	2.83846	2.83439
4	3.84051	3.38794	3.61101	3.60693
5	5.12614	4.52391	4.84586	4.85415
6	6.33640	5.48172	6.02711	5.97540
7	7.67573	6.61297	7.30488	7.22845
8	9.06319	7.64927	8.63354	8.54204
9	10.58608	8.92885	10.17380	10.05175
10	12.01359	10.08524	11.69568	11.52777
11	13.55648	11.42482	13.32087	13.09810
12	15.12586	12.77247	15.01240	14.69195
13	16.80845	14.23856	16.77805	16.43040
14	18.38995	15.67711	18.54148	18.14368
15	20.12937	17.22049	20.42777	20.01306
16	21.84876	18.74635	22.32399	21.89820
17	23.65178	20.39897	24.29166	23.85775
18	25.39287	21.98258	26.28230	25.85255
19	27.28847	23.69270	28.36809	27.96545
20	29.15477	25.32019	30.44992	30.09641

Table 6. Sample logarithm of data for 100 random walks in 2-dimensional space

Log of time step	Log of average distance from starting point {Log (D_{av})}			
	Case 1	Case 2	Case 3	Case 4
0.00000	0.00000	0.00000	0.00000	0.00000
0.69315	0.62385	0.58331	0.60218	0.60671
1.09861	1.09103	1.02674	1.04326	1.04183
1.38629	1.34561	1.22022	1.28399	1.28286
1.60944	1.63435	1.50938	1.57813	1.57983
1.79176	1.84631	1.70142	1.79627	1.78765
1.94591	2.03806	1.88903	1.98854	1.97802
2.07944	2.20422	2.03461	2.15565	2.14500
2.19722	2.35954	2.18929	2.31982	2.30775
2.30259	2.48604	2.31107	2.45922	2.44476
2.39790	2.60686	2.43579	2.58933	2.57247
2.48491	2.71641	2.54729	2.70888	2.68730
2.56495	2.82188	2.65595	2.82007	2.79913
2.63906	2.91180	2.75220	2.92001	2.89832
2.70805	3.00218	2.84610	3.01690	2.99639
2.77259	3.08414	2.93100	3.10566	3.08640
2.83321	3.16344	3.01548	3.19013	3.17211
2.89037	3.23447	3.09025	3.26890	3.25241
2.94444	3.30646	3.16517	3.34526	3.33097
2.99573	3.37262	3.23160	3.41608	3.40441

Table 7. Sample data for 100 random walks in 3-dimensional space

Time step	Average distance from starting point (D_{av})			
	Case 1	Case 2	Case 3	Case 4
1	1.00000	1.00000	1.00000	1.00000
2	1.88267	1.83439	1.80610	1.86267
3	3.04144	2.97852	2.91591	3.02372
4	4.16210	4.04124	3.97414	4.13716
5	5.37859	5.21609	5.07255	5.30697
6	6.52545	6.31775	6.15279	6.41242
7	7.90703	7.74161	7.45029	7.76700
8	9.32355	9.16919	8.66822	9.06876
9	10.85630	10.74879	10.05908	10.45262
10	12.41551	12.34331	11.38322	11.84222
11	13.97233	14.04416	12.81896	13.27477
12	15.59779	15.86415	14.30008	14.71744
13	17.25155	17.80560	15.84431	16.24775
14	18.92464	19.82249	17.36775	17.74230
15	20.62928	21.90694	18.95914	19.30189
16	22.31717	24.07942	20.50274	20.76793
17	24.04298	26.38102	22.16668	22.38742
18	25.75615	28.76229	23.80007	23.92553
19	27.51095	31.25052	25.53355	25.56330
20	29.23524	33.78845	27.23595	27.18490

Table 8. Sample logarithm of data for 100 random walks in 3-dimensional space

Log of time step	Log of average distance from starting point {Log (D_{av})}			
	Case 1	Case 2	Case 3	Case 4
0.00000	0.00000	0.00000	0.00000	0.00000
0.69315	0.63269	0.60671	0.59117	0.62201
1.09861	1.11233	1.09143	1.07018	1.10649
1.38629	1.42602	1.39655	1.37981	1.42001
1.60944	1.68243	1.65175	1.62384	1.66902
1.79176	1.87571	1.84336	1.81691	1.85824
1.94591	2.06775	2.04661	2.00825	2.04988
2.07944	2.23254	2.21585	2.15966	2.20484
2.19722	2.38475	2.37479	2.30848	2.34685
2.30259	2.51895	2.51311	2.43214	2.47167
2.39790	2.63708	2.64221	2.55093	2.58587
2.48491	2.74713	2.76406	2.66027	2.68903
2.56495	2.84790	2.87951	2.76281	2.78795
2.63906	2.94046	2.98682	2.85461	2.87595
2.70805	3.02671	3.08680	2.94229	2.96020
2.77259	3.10536	3.18136	3.02056	3.03341
2.83321	3.17984	3.27264	3.09859	3.10850
2.89037	3.24867	3.35907	3.16969	3.17495
2.94444	3.31458	3.44204	3.23999	3.24116
2.99573	3.37537	3.52012	3.30454	3.30266

Table 9. Characterising exponents of random walk movement in three different dimensional spaces using 4 different engineering write-ups

Number of dimensional space	Characterising exponent			
	Case 1	Case 2	Case 3	Case 4
1	1.7157	1.2165	1.3139	1.1130
2	1.4577	1.2462	1.4753	1.2748
3	1.5040	1.6084	1.4723	1.5885

Table 10. R^2 of line of best fit for 4 engineering write-up cases in three different dimensional spaces

Number of Dimensional Space	R^2			
	Case 1	Case 2	Case 3	Case 4
1	0.9507	0.9962	0.9877	0.9974
2	0.9832	0.9887	0.9950	0.9899
3	0.9767	0.9959	0.9904	0.9866

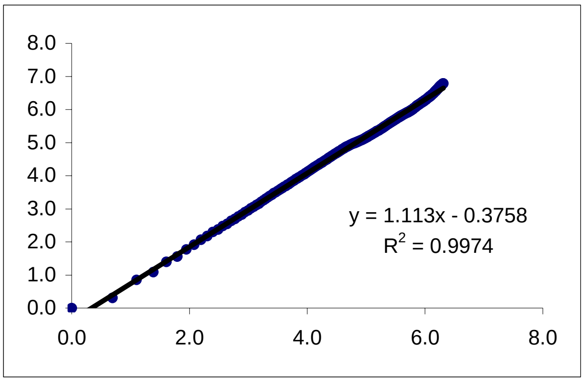

Figure 1. Log of average distance versus log of time step for case 1 in 1-D

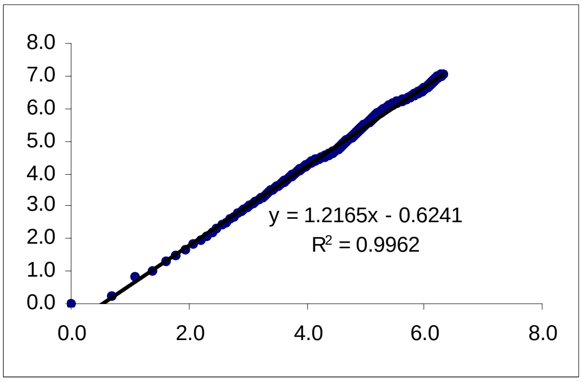

Figure 2. Log of average distance versus log of time step for case 2 in 1-D

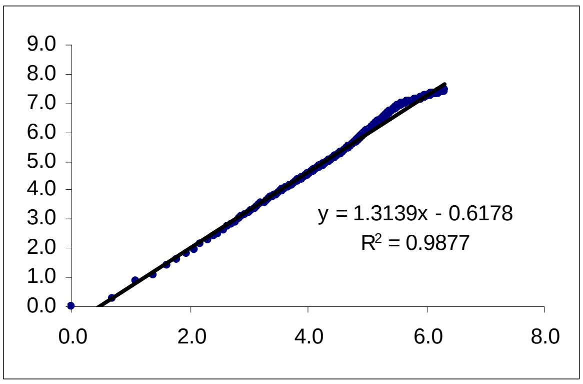

Figure 3. Log of average distance versus log of time step for case 3 in 1-D

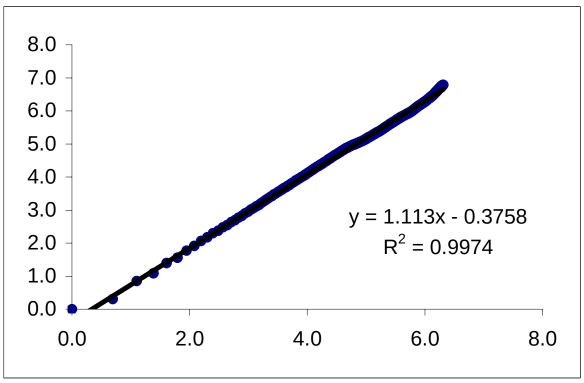

Figure 4. Log of average distance versus log of time step for case 4 in 1-D

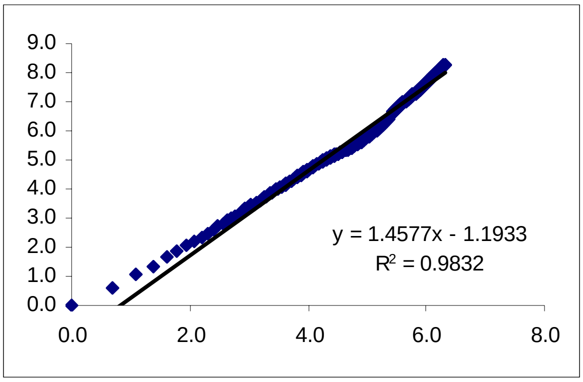

Figure 5. Log of average distance versus log of time step for case 1 in 2-D

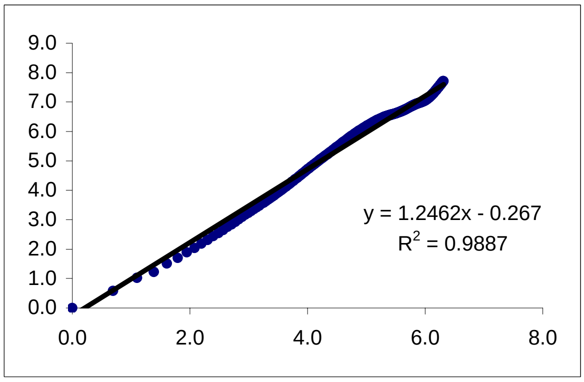

Figure 6. Log of average distance versus log of time step for case 2 in 2-D

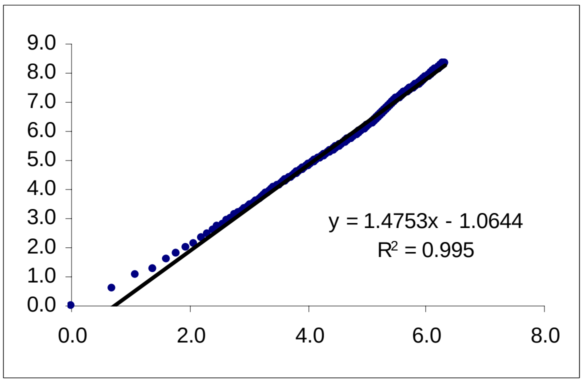

Figure 7. Log of average distance versus log of time step for case 3 in 2-D

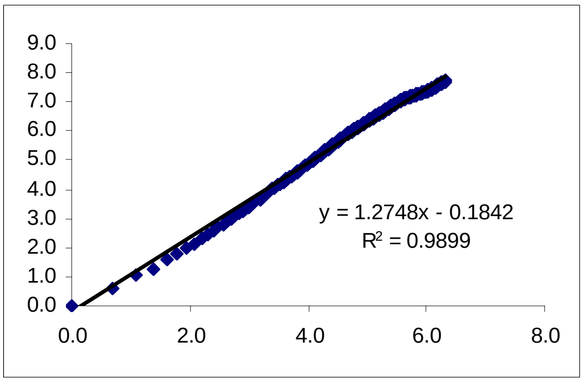

Figure 8. Log of average distance versus log of time step for case 4 in 2-D

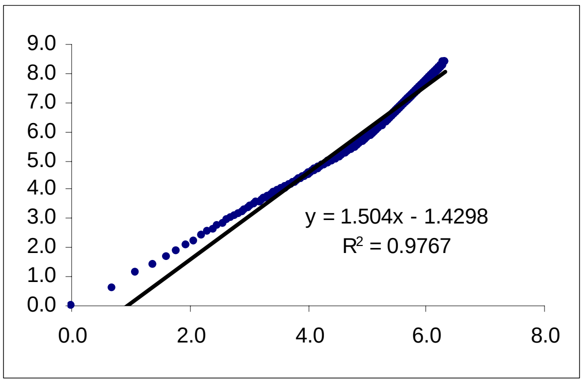

Figure 9. Log of average distance versus log of time step for case 1 in 3-D

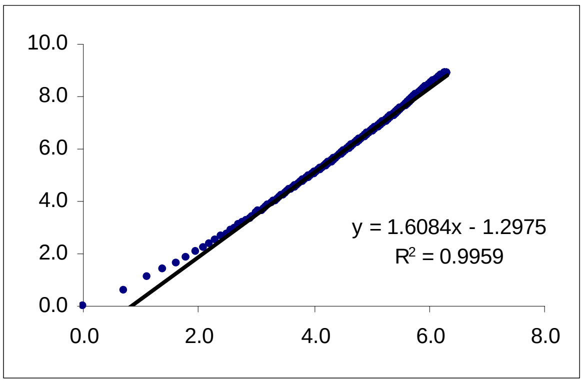

Figure 10. Log of average distance versus log of time step for case 2 in 3-D

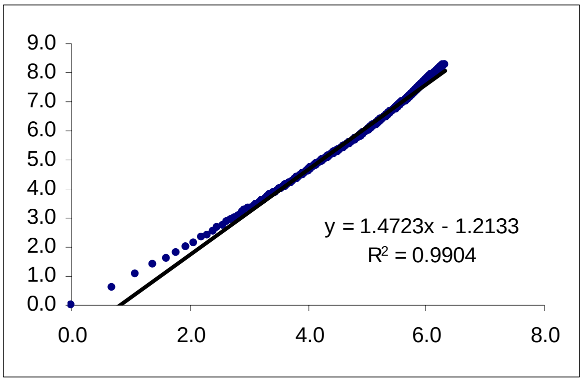

Figure 11. Log of average distance versus log of time step for case 3 in 3-D

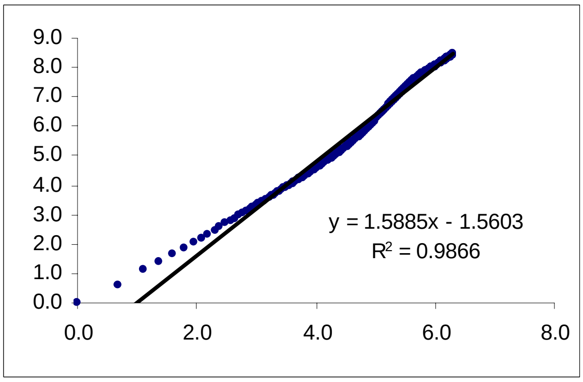

Figure 12. Log of average distance versus log of time step for case 4 in 3-D

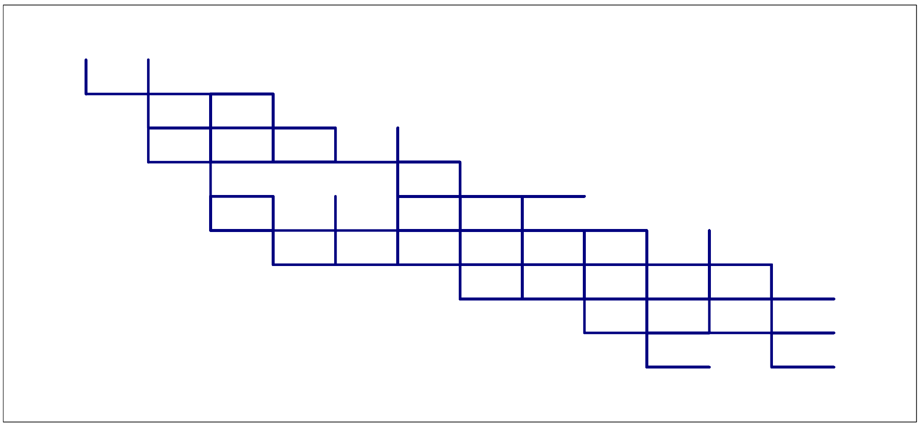

Figure 13. First random walk (constant step size) trace for case 4 in 2-D

Table 11. Characterising exponents of random walk movement and R^2 of line of fit for additional thirteen cases of write-ups

Faculty	Department	Number of alphabets used	1-Dimension space		2-Dimension space		3-Dimension space		Average slope (Faculty)	R^2 range (Faculty)
			Expo-nent	R^2	Expo-nent	R^2	Expo-nent	R^2		
Agriculture & Forestry	Agricultural Economics	891	1.3482	0.9949	1.7260	0.9794	1.4600	0.9962	1.4129	0.9794 to 0.9962
	Wildlife & Fisheries Management	834	1.2455	0.9941	1.2984	0.9931	1.3994	0.9838		
Basic Medical Sciences	Biochemistry	618	1.3980	0.9495	1.3323	0.9849	1.6797	0.9732	1.3796	0.9495 to 0.9953
	Virology	612	1.1560	0.9799	1.2606	0.9924	1.4512	0.9953		
Clinical Sciences & Dentistry	Epidemiology, Medical Statistics & Environmental Health	770	1.1724	0.9936	1.1827	0.9978	1.5425	0.9886	1.3447	0.9831 to 0.9981
	Physiotherapy	606	1.2241	0.9831	1.5546	0.9914	1.3920	0.9981		
Public Health	Epidemiology, Medical Statistics & Environmental Health	864	1.6986	0.9929	1.5508	0.9947	1.6361	0.9953	1.6285	0.9929 to 0.9953
Pharmacy	Pharmaceutical Chemistry	757	1.4429	0.9765	1.4457	0.9944	1.5726	0.9962	1.4846	0.9765 to 0.9962
	Pharmaceutical Microbiology & Clinical Pharmacy	723	1.4159	0.9905	1.4110	0.9861	1.6193	0.9958		
Science	Botany & Microbiology	707	1.2365	0.9900	1.2314	0.9942	1.5396	0.9863	1.3532	0.9863 to 0.9968
	Zoology	897	1.3377	0.9931	1.2544	0.9968	1.5196	0.9927		
Veterinary Medicine	Veterinary &Pharmacology	711	1.3833	0.9931	1.2817	0.9873	1.2756	0.9994	1.3424	0.9873 to 0.9994
	Veterinary Medicine	1097	1.2800	0.9962	1.2956	0.9961	1.5379	0.9922		

Table 12. Characterising exponents of random walk movement and R^2 of line of fit for Faculties

Faculty	Average characterising exponents (Faculty)	R^2 Range (Faculty)
Agriculture & Forestry	1.4129	0.9794 to 0.9962
Basic Medical Sciences	1.3796	0.9495 to 0.9953
Clinical Sciences & Dentistry	1.3447	0.9831 to 0.9981
Public Health	1.6285	0.9929 to 0.9953
Pharmacy	1.4846	0.9765 to 0.9962
Technology	1.4155	0.9507 to 0.9974
Science	1.3532	0.9863 to 0.9968
Veterinary Medicine	1.3424	0.9873 to 0.9994
Average characterising exponents across Faculties of study	1.42 to 2-decimal	

Discussion

Referring to the twelve graphs of log of average distance versus log of time step (four graphs to each corresponding dimensional space) and to Table 9 above, the range of the estimated exponent is found to be between 1.1130 and 1.7157 for all cases and numbers of the dimensional space considered while the average exponent is 1.4155 to four decimal places. The exponents estimated for case 3 in the three-dimensional spaces are fairly identical compared to other cases studied. It is very important to note here that the average exponent found in the literature for random walk movement in three different dimensional spaces with constant step size and using the random number generator as a driver is 0.5. Referring to Table 10 above, the range of the estimated R^2 is found to be between 0.9507 and 0.9974 for all cases and numbers of dimensional space considered, with case 1 observed in 1-dimensional space having a minimum R^2 value of 0.9507.

Results in Table 12 involving eight Faculties show that the average characterising exponent range is between 1.3424 and 1.6285. Experimentation with all seventeen cases over three different dimensional spaces shows that the average characteristic exponent is 1.42. The analysis of the data shows a very strong coefficient of determination of 0.9495 and 0.9994 for the minimum and maximum value, respectively. It thus implies that the exponent value of 1.42 is typical for any English text write-up. Since we are particularly interested in engineering write-ups, it seems that the exponent value of 1.42 may also be taken as a representative of this type of documents.

Conclusions

The objective of this paper is to report on the correlation properties in an English scientific text by means of a random walk. This has been achieved by showing how the proposed methodology can be used to judge the quality of engineering write-ups. In particular, the relationship between expression (1) and the quantitative level of the quality of the write-up as well as the results obtained in this work is explained. For example, how D and T affect the write-up quality and why the large exponent value of 1.4 can suggest a very good write-up are clearly stated. It is shown that for a random walk propelled in space using the pseudo-random number generator, the empirical relationship between the average distance and the time step is $D_{av} \propto T^{0.5}$, while for a random walk propelled in space using an engineering write-up this empirical relationship on the average becomes $D_{av} \propto T^{1.42}$. Therefore any engineering write-up may be likened to a form of random process characterised with an average exponent value of 1.42 to two decimal. It can be suggested that a very good engineering write-up will have an estimated exponent value very close to 1.42. This present study confirms that the average characterising exponent estimate of 1.4 is much greater than 0.5 (literature result) for a pure random motion. The exponent of 1.4 ensures a longer average distance covered in a very short time lapse compared to the exponent of 0.5.

Acknowledgements

The authors gratefully acknowledge the Postgraduate School, University of Ibadan, for providing information utilised in testing the theory proposed in the current work. In particular, thanks to Professor A.I. Olayinka and his research team. The words of encouragement of Professor P.O. Aiyedun on this research work are also acknowledged.

References

1. E. Petridou and K. Sarri, “Evaluation research in business schools: students’ rating myth”, *International Journal of Educational Management*, **2004**, *18*, 152-159.
2. A. I. Olayinka, L. Popoola, M. Fabunmi, and O. Fagbola (Ed.), “Synopses of Abstracts, Ph.D. Theses 2000-2002”, Postgraduate School, University of Ibadan, Ibadan, Nigeria, **2002**.
3. S. B. Lee and H. Nakanishi, “Markov matrix analysis of random walks in disordered continuous media”, *Physica A: Statistical Mechanics and Its Applications*, **1999**, *269*, 378-394.
4. Z. Jia, J. You, R. Rao, and M. Li, “Random walk search in unstructured P2P”, *Journal of Systems Engineering and Electronics*, **2006**, *17*, 648-653.
5. Y. X. Zhang, J. P. Sang, X. W. Zou, and Z. Z. Jin, “Random walk on psercolation under an external field”, *Physica A: Statistical Mechanics and Its Applications*, **2005**, *350*, 163-172.

6. C.-K. Peng, S. V. Buldyrev, A. L. Goldberger, S. Havlin, M. Simons, and H. E. Stanley, "Finite-size effects on long-range correlations: Implications for analyzing DNA sequences", *Physical Review E*, **1993**, *47*, 3730-3733.
7. S. V. Buldyrev, A. L. Goldberger, S. Havlin, C-K. Peng, M. Simons, and H. E. Stanley, "Generalized Lévy-walk model for DNA nucleotide sequences" *Physical Review E*, **1993**, *47*, 4514-4523.
8. P. Kokol, V. Podgorelec, M. Zorman, T. Kokol, and T. Njivar, "Computer and natural language texts - a comparison based on long-range correlations", *Journal of the American Society for Information Science*, **1999**, *50*, 1295-1301.
9. A. Schinner, "The Voynich manuscript: Evidence of the hoax hypothesis", *Cryptologia*, **2007**, *31*, 95-107.
10. W. den Hollander and P. W. Kasteleyn, "Random walks with 'spontaneous emission' on lattices with periodically distributed imperfect traps", *Physica A: Statistical and Theoretical Physics*, **1982**, *112*, 523-543.
11. G. H. Weiss, I. Dayan, S. Havlin, J. E. Kiefer, H. Larralde, H. E. Stanley, and P. Trunfio, "Some recent variations on the expected number of distinct sites visited by an n-step random walk", *Physica A: Statistical and Theoretical Physics*, **1992**, *191*, 479-490.
12. J. Feder, "*Fractals*", Plenum Press, New York, **1988**.

Appendix

52 Popular Alphabets found in the text message.
abcdefghijklmnopqrstuvwxyzABCDEFGHIJKLMNOPQRSTUVWXYZ
16 Agric. Engrg. Case4: Prof. Lucas "Design fabrication and evaluation of a beniseed (Sesamum indicum L.) oil expeller"
Some physical and mechanical properties of two benis
eed accessions were determined at five moisture leve
ls and used in the design of beniseed oil expeller.
A portable expeller for beniseed was fabricated base
d on the results of the determined properties. vario
us engineering values for the oil expeller has avera
ge capacity of 10kg beniseed per hour which, were st
ated. The efficiency of the expeller in terms of oil
recovery from the seeds as affected by wormshaft sp
eed and seed moisture content was reported for the t
wo accessions of the beniseed investigated. The maxi
mum filtered oil recovery for the two accessions was
observed at wormshaft speed of 45rpm and for seed m
oisture content of 5.3%. The estimated cost of the d
esigned oil expeller was stated with a clause that m
ass production would reduce the cost drastically.*
22 Mech. Engrg. Case3: Alabi Prof. "Fractal analysis and characterization of tread patterns of automobile tyres"
The author considered the fractal dimensions for the
tread patterns of selected 22 new and used tyres (1
2 brands). Preliminary studies on some familiar and
non-familiar objects having arbitrary shapes were de
veloped using fractal trees and the development of s
elf-similar fractal curves through the process of sc
aling and line segment substitution. Hence, the stud
y considered the two-dimensional (2-D) and three-dim
ensional (3-D) space fractal analyses of the tread p
atterns on new and used tyres. From the preliminary
studies carried out, the fractal dimensions obtained
in all cases considered were mostly identical with
the values quoted in the literature; lying between 1
.0 and 3.0. Similarly, 2-D space fractal dimensions
obtained in all cases for the printed tread patterns
were found to lie between 1.0 and 2.0. Moreover, 3-
D space fractal dimension of the tread patterns cons
idered, approached asymptotically the value of 3.0 w
ith increasing tread depth. Thus based on the values
of the fractal dimensions obtained, it is possible
to characterize the degrees of wear of the tyre' tre
ad pattern.*
20 Food Tech. Case2:Akingala Prof. "Functionality of flour in relation to physical and chemical properties of seeds of selected cowpea (Vigna unguiculata) varieties"
The functionality of flour in terms of Brdender visc

oamylograph pasting properties and thermal propertie
s, in relation to seed chemical composition and phys
ical properties, and product sensory quality was det
ermined for 28 cowpea varieties. Significant differe
nces were noticed in paste viscosities with hot past
e viscosity properties. Presoaking of seeds for 4 ho
urs before dehulling produced optimum particle size
distribution and highest HTPV in cowpea flour. Therm
al properties were significantly different with tran
sition enthalpy change (#H) explaining 80% while T-P
eak and T-onset explaining 14% and 5% of the variati
on in flour thermal properties respectively. Starch
and protein are the dominant macromolecular variable
s determining functionality of cowpea flour. The aut
hor suggested HTPV and #H as the important indices f
or flour production. There was a negative influence
of protein on HTPV an #H. This according to the auth
or might be due to reduction in starch concentration
.*
16 Agric. Engrg Case1: Igbeka Prof. Tillage systems, water management and their effects on soil properties and vegetable production.
Th author investigated the effect of no-tillage (NT)
, slashing (SH), ploughing (PHO), ploughing plus bed
ding(PHB) and two planting techniques; broadcasting
(BR) and drilling (DR) on soil physical and chemical
 properties using Randomized Complete Block design (
RCB). The saturated hydraulic conductivity in the 0
- 10cm layer was in the order PHO>PHA>PHB>NT>SH and
were significantly different at 5% probability. Soil
moisture potential at 10cm depth was least in NT(-48
cb) while PHA had the highest value (-32cb). At 0-10
cm, there were no significant differences in chemica
l properties while at 10-20cm depth, PHA was most ef
fective in enhancing soil nutrient status. Broadcast
ing had the best crop growth with PHB. watering was
recommended three times a week at 83.2% relative hum
idity and average rainfall 15.9mm*

Note that 16 on line three (3) indicates that the Abstract of the work supervised by Prof. Lucas was read from a document formatted into 16 lines, and the * on the last line (line 20) indicates the end of the Abstract. Thus 16 and * are format requirements to enable the computer to determine the beginning and end of each of the Abstract studied.

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Full Paper

Machinability study on discontinuously reinforced aluminium composites (DRACs) using response surface methodology and Taguchi's design of experiments under dry cutting condition

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Abstract: The development of metal matrix composites with discontinuous reinforcement represents a well-established method for improving the strength and stiffness of a material. This paper discusses the use of Taguchi's design of experiments and response surface methodology (RSM) for minimising the surface roughness in turning of discontinuously reinforced aluminium composites (DRACs) having aluminum alloy 6061 as the matrix and containing 15 vol. % of silicon carbide particles with a mean diameter of 25μm under dry cutting condition. The measured results are then collected and analysed with the help of a commercial software package MINITAB15. The experiments are conducted using Taguchi's experimental design technique. The matrices of test conditions include cutting speed, feed rates and depth of cut. The effect of cutting parameters on surface roughness is evaluated and the optimum cutting condition for minimising the surface roughness is determined. A second-order model is established between the cutting parameters and the surface roughness using RSM. The experimental results reveal that the most significant machining parameter for surface roughness is feed, followed by cutting speed. The predicted values and measured values are fairly close, which indicates that the developed model can be effectively used to predict the surface roughness in the machining of DRACs.

Keywords: discontinuously reinforced aluminium composites (DRACs), metal matrix composites (MMCs), surface roughness, Taguchi's design of experiments, response surface methodology

Abbreviations:

DRACs	:	discontinuously reinforced aluminium composites	DF	:	degrees of freedom
MMCs	:	metal matrix composites	Seq SS	:	sequential sum of squares
ANOVA	:	analysis of variance	Adj SS	:	adjusted sum of squares
BUE	:	built-up edges	Adj MS	:	adjusted mean of squares
BHN	:	Brinells hardness number	F	:	Fishers Test
SEM	:	scanning electron microscope	P	:	probability statistic
CBN	:	cubic boron nitride			
RSM	:	response surface methodology			

Introduction

Machining of discontinuously reinforced aluminium composites (DRACs) presents a significant challenge to the industry since a number of reinforcement materials are significantly harder than the commonly used high speed steel tools and carbide tools [1]. The reinforcement phase causes rapid abrasive tool wear; thus the widespread usage of DRACs is considerably impeded by their poor machinability and high machining costs. Based on the available literature on DRACs it is clear that the morphology, distribution and volume fraction of the reinforcement phase, as well as the matrix properties are all factors that affect the overall cutting process [1-2], but as yet relatively few published reports are related to the optimisation of the cutting process.

From some early conventional turning tests on Al/SiC metal matrix composites (MMCs) [3-4] it is found that the tool wear is excessive and surface finish is very poor when carbide tip tools are used for machining. The hard SiC particles of Al/SiC MMCs, which intermittently come into contact with the hard surface, act as small cutting edges like those of a grinding wheel on the cutting tool edge which in due course gets worn out by abrasion and resulting in the formation of poor surface finish during turning . When Al/SiC MMCs job slides over a hard cutting tool edge during turning, it always presents a newly formed surface to the same proportion as the cutting edge and consequently, due to friction, high temperature and pressure the particles of the Al/SiC MMCs adhere to the cutting tool edge, as shown in our case for a cubic boron nitride (CBN) tool (Figure 1). In this way more particles will join up with those already adhering and the so-called built-up edge (BUE) is formed and if this process is continued for some time, it appears to nibble away on the turned surface and produces a very poor surface finish during turning [5].

Due to the high cost of these tools, it is still desirable to optimise the cutting conditions. Moreover to get good surface quality and dimensional properties, it is necessary to employ optimisation techniques to find the optimal cutting parameters and also to employ theoretical models to do predictions. Taguchi's design of experiments (DOE) and response surface methodology (RSM) can be conveniently used for these purposes. Suresh et al. [6] used the response surface method and genetic algorithm for predicting the surface roughness and optimising the process parameters. Kwak [7] has applied Taguchi's DOE and RSM for optimising geometric errors in the surface grinding process. According to Sahin and Motoreu [8], RSM is more practical, economical and relatively easy to use. In the present study, the effect of cutting parameters on the surface roughness of DRACs upon machining under dry cutting is evaluated and a second-order model is developed for predicting the surface roughness.

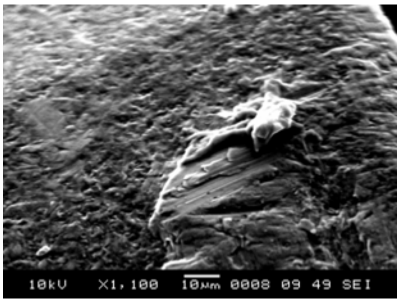

Figure 1. Typical wear pattern and material sediments observed on a CBN tool

Materials and Methods

General

The work piece specimens used were Al/SiC MMCs popularly known as DRACs. They consisted of aluminum alloy 6061 as the matrix and containing 15 vol. % of silicon carbide particles (mean diameter 25μm) in the form of cylindrical bars of length 120 mm and 40 mm in diameter manufactured in Vikram Sarabhai Space Centre (VSSC) Trivandrum. This was prepared by stir casting process (pouring temperature 700-710°C, stirring rate 195 rpm, extrusion at 457°C, extrusion ratio 30:1, direct extrusion speed 6.1m/min) to produce Ø40mm cylindrical bars. The specimens were solution-treated for 2h at a temperature of 540^{o}C in a muffle furnace (temperatures were accurate to within ±2^{o}C and quench delays in all cases were within 20 s). After solutionising, the samples were water-quenched to room temperature, and subsequently aged for six different times to obtain samples with different Brinell hardness numbers (BHN), out of which one sample was selected: one with 94 BHN obtained at peak condition, i.e. 2h at 220^{o}C. The sample selected was kept in a refrigerator right after the heat treatment. Figure 2 shows the SEM image of DRACs containing 6061 Al and 15 vol.% SiC particles of 25 μm. The chemical composition of the specimen is shown in Table 1.

The turning method as a machining process was selected. The experimental study was carried out using a PSG A141 lathe (2.2 KW) with variable cutting speed, feed and depth of cut. The selected cutting tool was cubic boron nitride insert KB-90 (ISO code) for machining of DRAC material. The ISO codes of the cutting tool insert and tool holders are shown in Table 2. The surface condition of the machined work-piece was observed using a JEOL JSM-6380LA analytical scanning electron microscope. Surface roughness was measured using a Taylor/Hobson surtronoic 3+ surface roughness measuring instrument (Figure 3).

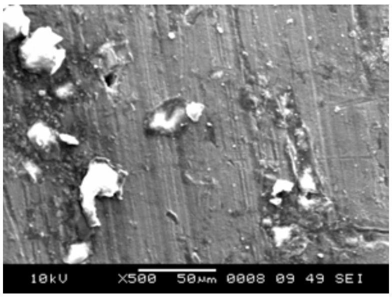

Figure 2. SEM image of DRACs (6061 Al/ 15% SiC, 25 µm)

Table 1. Nominal chemical composition of base metal (6061 Al alloy)

Element	Cu	Mg	Si	Cr	Al
Weight percentage	0.25	1.0	0.6	0.25	Balance

Table 2. Details of cutting tool and tooling system used for experimentation

Tool holder ISO code	STGCR 2020 K-16
Tool geometry specification	Approach angle:91^o Tool nose radius:0.4 mm Rake angle: 0^o Clearance angle: 7^o
Tool insert CBN (KB-90) ISO code	TPGN160304-LS

Figure 3. Layout of equipment for roughness measurement

Response surface methodology

The surface finish of machined DRACs is important in manufacturing engineering applications. It has a considerable effect on some properties such as wear resistance, light reflection, heat transmission, coating and resisting fatigue. While machining, the good quality of the parts can be achieved only through proper cutting conditions. In order to know the surface quality and dimensional properties in advance, it is necessary to employ theoretical models making it feasible to predict the function of operation conditions [9]. Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimise this response [10].

In many engineering fields, there is a relationship between an output variable of interest 'y' and a set of controllable variables $\{x_1, x_2 . . . .x_n\}$. In some systems, the nature of the relationship between 'y' and 'x' values might be known. Then, a model can be written in the form:

$$y = f(x_1, x_2, ..., x_n) + \varepsilon \qquad (1)$$

where 'ε' represents the noise or error observed in the response 'y'. If we denote the expected response as:

$$E(y) = f(x_1, x_2, ..., x_n) = \hat{y} \qquad (2)$$

then the surface is represented by:

$$\hat{y} = f(x_1, x_2, ..., x_n) \qquad (3)$$

This is called the response surface. In most of the RSM problems, the form of relationship between the response and the independent variable is unknown. Thus the first step in RSM is to find a suitable approximation for the true functional relationship between 'y' and the set of independent variables employed. Usually a second-order model is utilised in response surface methodology [10]:

$$\hat{y} = \beta_o + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i} \sum_{j} \beta_{ij} x_i x_j + \varepsilon \qquad (4)$$

The β coefficients used in the above model can be calculated by means of using the least square method. The second-order model is normally used when the response function is not known or nonlinear.

Taguchi's DOE method

Taguchi's DOE method has been used widely in engineering designs [11-12]. The main trust of the Taguchi's DOE technique is the use of parameter design, which is an engineering method for product or process design that focuses on determining the parameter (factor) settings producing the best level of a quality characteristic (performance measure) with minimum variation. Taguchi design provides a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. To determine the best design requires the use of a strategically designed experiment which exposes the process to various levels of design parameters.

Experimental design methods were developed in the early years of the 20th century and have been extensively studied by statisticians since then, but they were not easy to use by practitioners [12]. Taguchi's approach to the design of experiments is easy to adopt and apply for users with limited knowledge of statistics; hence it has gained a wide popularity in the engineering and scientific communities. There have been plenty of recent applications of Taguchi technique to material processing for process optimisation; some of the previous works are listed [13-16]. In particular, it is recommended for analysing metal cutting problems to find the optimal combination of parameters [16]. Further, depending on the number of factors, interactions and their levels, an orthogonal array is selected by the user. Taguchi's DOE uses signal–noise [S/N] ratio as the quality characteristic of choice. The S/N ratio is used as the measurable value instead of the standard deviation due to the fact that as the mean decreases, the standard deviation also decreases and vice versa. In other words, the standard deviation cannot be minimised first and the mean brought to the target. In practice, the target mean value may change during the process development. Two of the applications in which the concept of the S/N ratio is useful are the improvement of quality through variability reduction and improvement of measurement. The S/N ratio characteristics can be divided into three categories given by equations (5-7), when the characteristic is continuous:

Category 1, nominal is the best characteristic,

$$\frac{S}{N} = 10\log\frac{\bar{y}}{s_y^2} \tag{5}$$

Category 2, smaller is the best characteristic,

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum y^2\right) \tag{6}$$

Category 3, larger is the best characteristic,

$$\frac{S}{N} = -\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right) \tag{7}$$

where '$\bar{y}$' is the average of observed data, 's_y^2' the variation of 'y', 'n' the number of observations, and 'y' the observed data. For each type of characteristics, with the above S/N ratio transformation, the smaller the S/N ratio the better is the result.

Experimental details

The orthogonal array for two factors at three levels was used for the elaboration of the plan of experiments. The array L_{27} was selected, which has 27 rows corresponding to the number of tests (26 degrees of freedom) with 13 columns at three levels. The factors and the interactions were assigned to the columns. The first column (A) was assigned to the cutting speed (m/min), the second column (B) to feed (mm/rev), the fifth column (C) to the depth of cut (mm), and the remaining were assigned to interactions. The output to be studied was the surface roughness, for which an analysis of variance (ANOVA) was carried out. The steps of our study of optimisation are presented in Figure 4. The selected levels and factors in machining of DRACs are shown in Table 3.

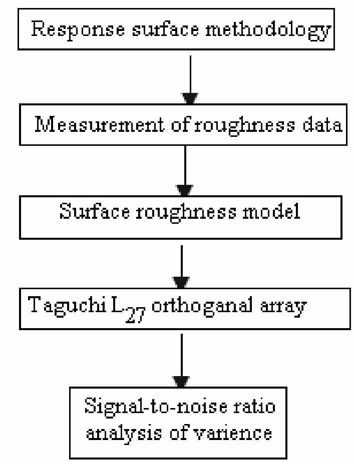

Figure 4. Steps of the optimisation process

Table 3. Levels and factors in machining of DRACs

Level	(A) Cutting speed (m/min)	(B) Feed (mm/rev)	(C) Depth of cut(mm)
1	45	0.11	0.25
2	73	0.18	0.50
3	101	0.25	0.75

Results and Discussion

Effect of control parameters on surface roughness

In Taguchi's DOE method, the term "signal" represents the desirable value and "noise" represents the undesirable value. The objective of using S/N ratio is to obtain a measure of performance to develop products and processes insensitive to noise factors. The S/N ratio indicates the degree of predictable performance of a product or process in the presence of noise factors. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The S/N ratio for each parameter level is calculated by averaging the S/N ratios obtained when the parameter is maintained at that level. Table 4 shows the S/N ratios obtained for different parameter levels.

Table 4. Response table for S/N ratios for the condition: smaller is better (surface roughness)

Level	(A) Cutting speed (m/min)	(B) Feed (mm/rev)	(C) Depth of cut (mm)
1	-10.629	-8.680	-10.386
2	-10.421	-9.967	-10.351
3	-10.162	-12.565	-10.476
Delta	0.466	3.885	0.124
Rank	2	1	3

The calculated S/N ratio for three factors on the surface roughness in machining of DRACs for each level is shown in Figure 5. As also shown in Table 4, feed is a dominant parameter on the surface roughness followed by cutting speed. The depth of cut had a much lower effect on the surface roughness. Lower surface roughness is always preferred. The quality characteristic considered in the investigation is “the smaller the better”. In the present investigation, when the feed is at 0.11mm/rev the surface roughness was minimum. Contrary to the feed, low cutting speed had the maximum effect. The reason is that the increase in feed increases the heat generation and hence, tool wear, which results in higher surface roughness. The increase in feed also increases shatters and produces incomplete machining of the work piece, which leads to higher surface roughness. Figure 6 shows the interaction plot for S/N ratios (dB) at different feeds.

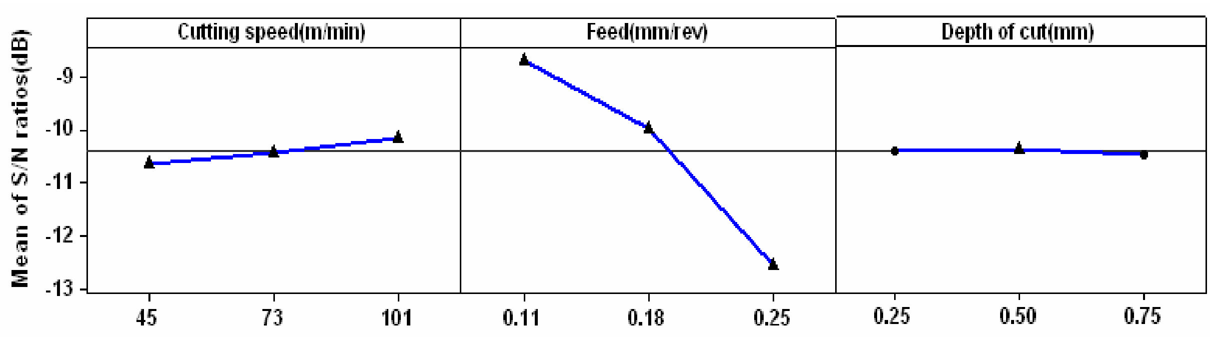

Figure 5. Mean S/N graphs for surface roughness under different parameters

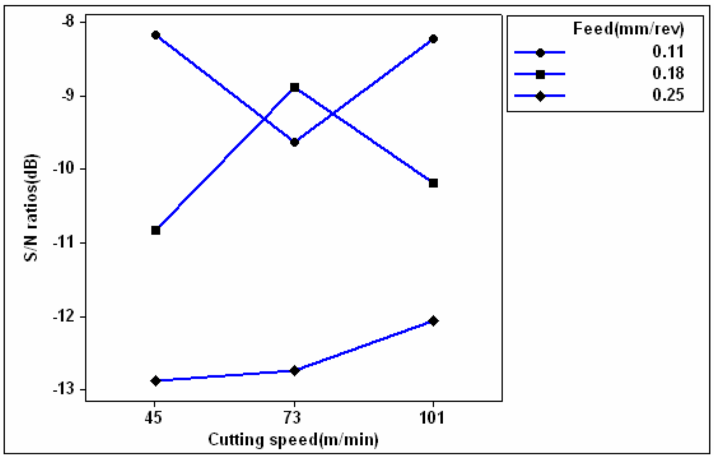

Figure 6. Interaction plot for S/N ratios (dB) at different feeds and cutting speeds

On the examination of the percentage of contribution (P %) of the different factors (Table 5) for surface roughness it can be seen that feed has the highest contribution of about 85.85%. Thus feed is an important factor to be taken into consideration while machining DRACs. Interactions (AxC), cutting speed (m/min), depth of cut (mm) does not present a statistical significance or a percentage of physical significance of contribution to the surface roughness.

Table 5. Analysis of variance for S/N ratios for surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percent P (%)
(A) Cutting speed (m/min)	2	0.9829	0.9829	0.4914	0.89	0.447	1.20
(B) Feed (mm/rev)	2	70.4764	70.4764	35.2382	63.92	0.000	85.85
(C)Depth of cut(mm)	2	0.0742	0.0742	0.0371	0.07	0.935	0.09
AxB	4	10.1851	10.1851	2.5463	4.62	0.032	6.20
AxC	4	0.9231	0.9231	0.2308	0.42	0.791	0.56
BxC	4	10.0143	10.0143	2.5036	4.54	0.033	6.10
Residual Error	8	4.4102	4.4102	0.5513			
Total	26	97.0662					100

Note: DF = degree of freedom; Seq SS = sequential sum of squares;
Adj MS = adjusted mean of squares; F = Fishers Test; P = probability statistic

Response surface analysis

The second-order response surface representing the surface roughness (Ra) can be expressed as a function of cutting parameters such as cutting speed (A), feed (B), and depth of cut (C). The relationship between the surface roughness and machining parameters has been expressed as follows:

$$R_a = \beta_0 + \beta_1(A) + \beta_2(B) + \beta_3(C) + \beta_4(A^2) + \beta_5(B^2) + \beta_6(C^2) + \beta_7(AB) + \beta_8(AC) + \beta_9(BC) \quad (8)$$

From the observed data for surface roughness, the response function has been determined in uncoded units as:

$$R_a = 8.17546 - 0.0596633A - 42.2636B - 0.863964C + 0.000394133A^2 + 118.878B^2 - 4.55200C^2 - 0.0331633AB + 0.0105357AC + 26.0714BC$$

The result of ANOVA for the response function of surface roughness is presented in Table 6. This analysis is carried out for a level of significance of 5%, i.e. for a level of confidence of 95%. From the analysis in Table 6, it is apparent that the F (calculated value) is greater than the F (table value) ($F_{0.05, 9, 10} = 3.02$) and hence the second-order response function developed is quite adequate.

Table 6. ANOVA table for response function of surface roughness

Source	DF	Seq SS	Adj MS	F	P
Regression	9	10.0318	10.0318	23.53	0.000
Residual Error	10	0.4737	0.47365		
Total	19	10.5055			

Note: DF = degree of freedom; Seq SS = sequential sum of squares;
Adj MS = adjusted mean of squares; F = Fishers Test; P = probability statistic

From equation (8) contours for each of the response surfaces at different feeds are plotted. Surface plots of surface roughness at cutting speed - feed planes are shown in Figure 7. These plots can help in the prediction of the surface roughness at any zone of the experimental domain. It is clear from these figures that the surface roughness increases with the increase of feed; Figure 8 shows the SEM images of the machined surface under different feeds. Contour plots of surface roughness at cutting speed - feed planes are shown in Figure 9.

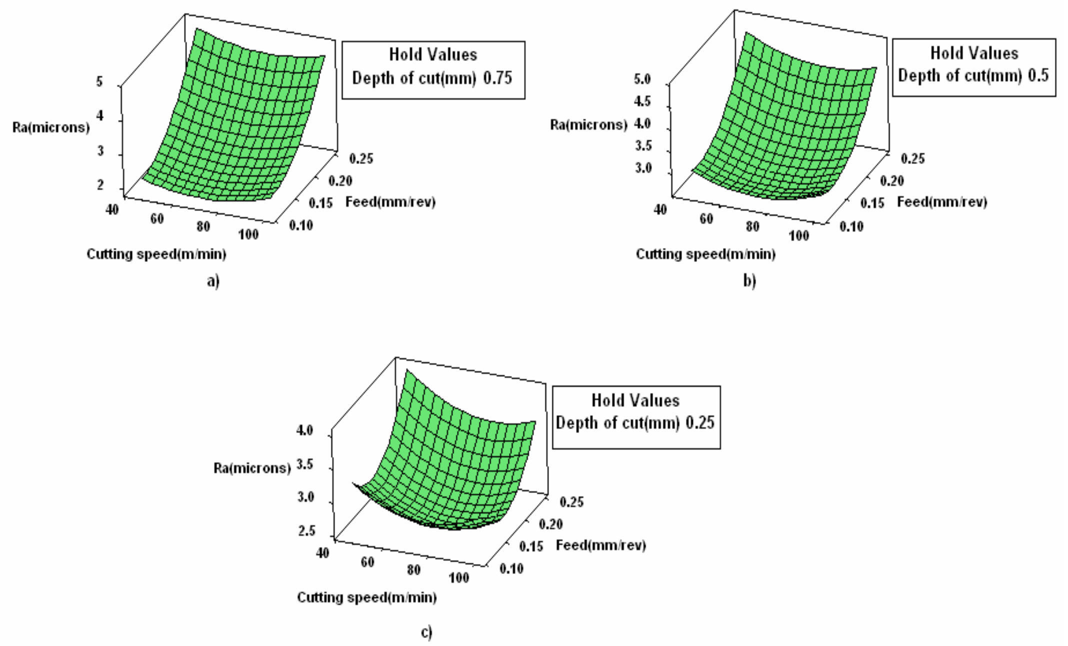

Figure 7. Surface plots of surface roughness at cutting speed - feed planes for different depths of cut: a) 0.75mm, b) 0.5mm, c) 0.25mm

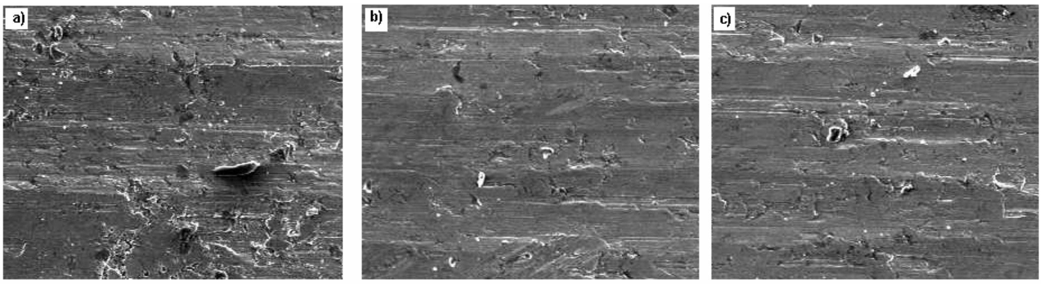

Figure 8. SEM images of machined surface at different feeds: (a) 0.25mm/rev, (b) 0.18mm/rev, (c) 0.11mm/rev

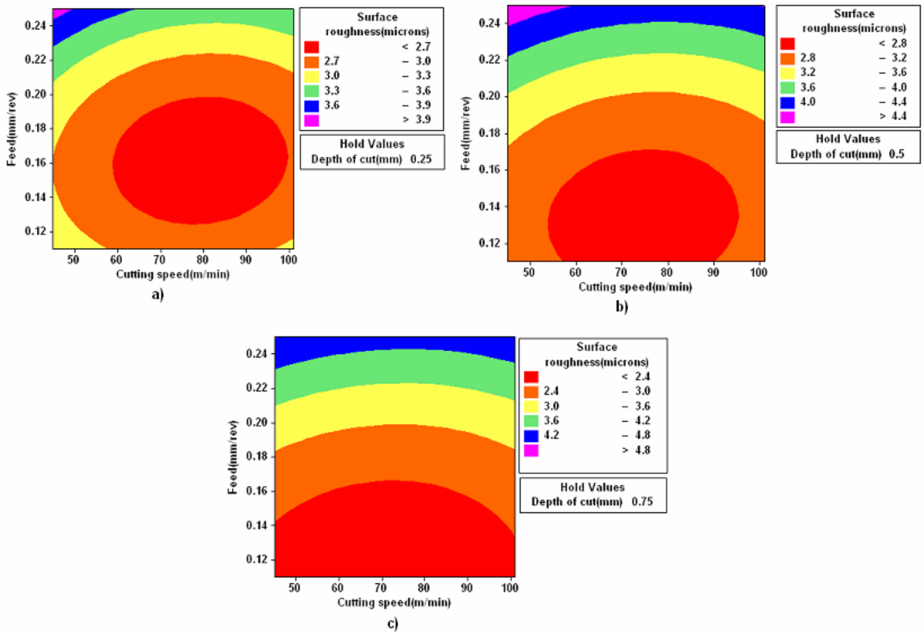

Figure 9. Contour plots of surface roughness at cutting speed - feed planes for different depths of cut: a) 0.25mm, b) 0.5mm, c) 0.75mm

Confirmation experiment

In this study, a confirmation experiment was conducted with the 3 levels of optimal process parameters (A, B, C– Table 3). Resulting from the optimisation process, three R_a values (3.249µm, 2.889 µm and 4.674 µm) were obtained from the response function derived from equation 8 for levels 1, 2 and 3, respectively. These R_a values were compared against the experimentally determined values (3.220µm, 2.720 µm and 4.600 µm). The predicted values and the measured ones are fairly close, which indicates that the developed model can be effectively used to predict the surface roughness in the machining of DRACs. A comparison between predicted and measured values is shown in Figure 10.

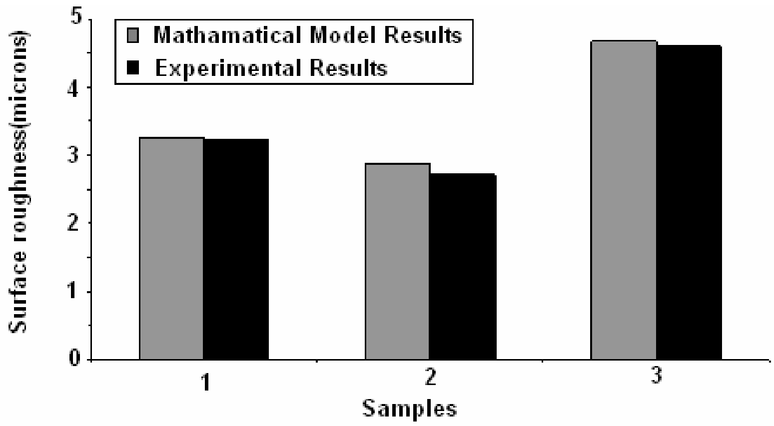

Figure 10. Comparison of surface roughness obtained by mathematical modeling and experiment for three different conditions: (1) cutting speed 45m/min, feed 0.11mm/rev, depth of cut 0.25mm; (2) cutting speed 73m/min, feed 0.18mm/rev, depth of cut 0.5mm; (3) cutting speed 101m/min, feed 0.25mm/rev, depth of cut 0.75mm

Conclusions

The effects of different cutting conditions under dry cutting on the surface roughness resulting from the turning process in machining of DRACs have been evaluated with the help of Taguchi's technique and response surface methodology, and optimal machining conditions to minimise the surface roughness have been determined. It was found that feed is the dominant parameter affecting surface roughness, followed by cutting speed while depth of cut shows minimal effect on surface roughness compared to other parameters. To achieve a good surface finish of the DRACs work piece a slower feed is preferred.

Response surface methodology provides a large amount of information with a small amount of experimentation. A second-order response surface model for surface roughness has been developed from the observed data. The predicted and measured values are fairly close, which indicates that the developed model can be effectively used to predict the surface roughness resulting from the machining of DRACs with 95% confidence intervals. Using such model, one can obtain a remarkable savings in time and cost.

References

1. S. Ramrattan, F. Sitkins, and M. Nallakatala, "Optimization of the casting and machining processes for metal matrix composites", *Proceedings of the Canadian Society for Mechanical Engineers Symposium*, McMaster University, **1996**.
2. J. M. Monaghan, "The use of quick stop test to study the chip formation of a SiC/Al metal matrix composite and its matrix alloy", *Journal of Processing of Advanced Materials*, **1994**, *4*, 170-179.
3. L. A. Loony, J. M. Monaghan, P. O'Reilly, and D. R. P. Toplin, "The turning of an Al/SiC metal matrix composite". *Journal of Material Processing Technology*, **1992**, *33*, 453-468.

4. K. Weinert and W. Konig, "A consideration of tool wear mechanism metal matrix composite (MMC)". *Annals of the CIRP*, **1993**, *42*, 95-98.
5. A. Manna and B. Bhattacharyya, "A study on different tooling systems during machining of Al/SiC-MMC", *Jounal of Material Processing Technology*, **2002**, *123*, 476-482.
6. P. V. S. Suresh, K. V. Rao, and S. G. Desmukh, "A genetic algorithmic approach for optimization of the surface roughness prediction model", *International Journal of Machine Tools and Manufacturing*, **2002**, *42*, 675-680.
7. J. S. Kwak, "Application of Taguchi and response surface methodologies for geometric error in surface grinding process", *International Journal of Machine Tools and Manufacturing*, **2005**, *45*, 327-334.
8. Y. Sahin and A. R. Motorcu, "Surface roughness model for machining mild steel", *Materials and Design*, article in press.
9. D. C. Montgomery, "Design and Analysis of Experiments", John Wiley and Sons, New York, **1984**.
10. P. J. Ross, "Taguchi Techniques for Quality Engineering: Loss Function, Orthogonal Experiments, Parameter and Tolerance Design", 2nd Edn., McGraw-Hill, New York, **1996**.
11. M. S. Phadke, "Quality Engineering Using Robust Design", Prentice-Hall, Englewood Cliffs (NJ), **1989**.
12. W. H. Yang and Y. S. Tarng, "Design optimization of cutting parameters for turning operations based on the Taguchi method", *Journal of Material Processing Technology*, **1998**, *84*, 122-129.
13. Y. L. Su, S. H. Yao, C. S. Wei, W. H. Kao, and C. T. Wu, "Design and performance analysis of TiCN-coated cemented carbide milling cutters", *Journal of Material Processing Technology*, **1999**, *87*, 82-89.
14. C. Y. Nian, W. H. Yang, and Y. S. Tarng, "Optimization of turning operations with multiple performance characteristics", *Journal of Material Processing Technology*, **1999**, *95*, 90-96.
15. J. P. Davim, "Design optimization of cutting parameters for turning metal matrix composites based on the orthogonal arrays", *Journal of Material Processing Technology*, **2003**, *132*, 340-344.
16. J. A. Ghani, I. A. Choudhury, and H. H. Hassan, "Application of Taguchi method in the optimization of end milling operations", *Journal of Material Processing Technology*, **2004**, *145*, 84-92.

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Full Paper

Computational analysis and visualisation of wind-driven naturally ventilated flows around a school building

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Abstract: Most Thai state schools are designed to use cross-flow natural ventilation as a passive cooling system. The aim of this study is to investigate the effects of geometry and orientation of a school building on the airflow distribution around it. Computational fluid dynamics (CFD) commercial software was used as a tool in this simulation. The 3-D flow simulation of the building domain was performed with prevailing wind to identify a proper strategy of flows around the building. It was found that the cross orientation of the building to wind direction might not necessarily result in good ventilation in classrooms. Flow visualisation with hydrogen bubble technique was set up to qualitatively validate the numerical results. A water flow was maintained at 3.7 cm/s, with corresponding to flow Reynolds number of 3,556. The numerical results were found to agree well with the experimental results.

Keywords: natural ventilation, CFD, school building, flow visualisation, hydrogen bubble technique

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Introduction

There are approximately 350,000 schoolchildren in about 500 schools in densely populated communities such as municipalities and urban areas in Thailand. The majority of these schools are state-owned wherein most classrooms are naturally ventilated through open doors and windows. Air movement is allowed to penetrate the school buildings. At least 11 buildings of the state schools under

Chiang Mai municipality are constructed in standard dimensions according to the Ministry of Education. These four-storey school buildings have three classrooms, an activity room and a toilet in each of the floors except the ground floor, which is open space with no wall. The indoor air distribution is of great importance to students in the classroom. Poor indoor air quality in the classroom due to insufficient ventilation affects the students directly.

Ventilation is of three types, i.e. natural ventilation, mechanical ventilation and hybrid ventilation. The first type is increasingly becoming an important target for the design strategy to reduce the energy consumed by the air conditioning system with consequent reduction in CO_2 emission. Natural ventilation has been used as a powerful passive cooling method, especially in tropical regions like Thailand. Its advantage is the reduction of initial construction cost and operating cost for residential buildings while maintaining a ventilation rate consistent with the requirement of acceptable indoor air quality [1]. It can also improve indoor air quality, supply a high level of thermal comfort, and encourage energy saving on the air conditioning system. Two major types of natural ventilation are single-sided and cross ventilation. The former takes place when the building communicates with the outdoor environment through openings which are on the same exterior wall while the latter is mainly for naturally ventilated buildings. Normally the ventilation rate of a building is dependent on the wind and the temperature acting simultaneously. The pressure difference across an opening is defined as a function of two major forces, namely inertia and buoyancy. This is because indoor airflow patterns do not only depend on wind speed but also on the position and orientation of the building as well as the type, size, and position of the opening. Thus, a careful design of wind flow around a building is very important to fully utilise the potential of cross ventilation [2]. Changing of architectural design elements such as the position and orientation of the building, the roof shape, the balcony configuration type and the location of windows can modify the interior airflow magnitude and pattern. These architectural design elements govern the indoor airflow pattern and improve the indoor comfort level [3, 4].

A number of studies have been performed with a computational tool. Computational fluid dynamics (CFD) technique is an art of replacing the governing partial differential equations of fluid flow with numbers. It has become popular due to the fact that it supports and complements both pure experiment and pure theory, as well as its revealing results and low cost of labour and equipment. Particularly in the last two decades, the CFD technique was extensively used to predict the air movement within the rooms and around the buildings. Tantasvasdi et al. [5] explored the potential of using natural ventilation as a passive cooling system for new house designs in Thailand. CFD was used to calculate airflow in the house. It was found that it is preferable to have a larger inlet aperture than a larger outlet one. Sreshthaputra et al. [6] coupled energy simulation softwares, i.e. DOE-2 and CFD simulations to analyse heat transfer and airflow performance of an unconditioned 100-year-old Buddhist temple. Mochida et al. [7] investigated methods for controlling airflow in and around a building in order to improve indoor thermal comfort by utilising cross ventilation. Evola and Popov [8] applied CFD with Reynolds averaged Navier-Stokes equation (RANS) approach to wind-driven natural ventilation in a cubic building. Flows inside and around the cross and single-sided naturally ventilated buildings were determined. Like the CFD, flow visualisation has greatly assisted the fundamental understanding of a wide variety of fluid dynamic phenomena. A number of studies have been performed with the flow visualisation technique. Smith and Paxson [9] studied the motion and deformation of a hydrogen bubble time-line in time and space gathering digitally interfacing dual-view video sequences of a bubble time-line with a computer-aided display system. Latterly, Smith and Lu [10] used hydrogen-bubble flow visualisation pictures to establish local instantaneous velocity profile information. Eiamsa-ard et al. [11] studied experiments of the flow going past two obstacles near a channel wall using the hydrogen bubble technique. Bao and Dallmann [12] studied on the local separated flows around a rounded backward facing step using hydrogen bubble technique. Guo et al. [13] studied visually with conducting on the excited laminar-turbulent transition within a flat plate boundary layer flow in a water tunnel using hydrogen bubble technique. Zhang et al. [14] examined the aerodynamic characteristics of a square cylinder with an upstream rod in a staggered arrangement. Flow visualisation with hydrogen bubble technique was carried out.

The present research investigates the effects of building geometry and orientation on airflow distribution around a school building and in a typical state school classroom, which is designed as a cross-flow naturally ventilated room. CFDRC® [15], a commercial software, was used as a tool in this simulation by means of the finite volume method. A range of wind speeds and different wind directions, according to local meteorological conditions were utilised as the boundary conditions. Finally, flow visualisation with hydrogen bubble technique was used to verify the numerical results.

Materials and Methods

Numerical simulation

Wind flow patterns around building may strongly affect indoor air flow, thus investigating air flow around inlet openings of a classroom is important. The airflow pattern is predicted using a fundamental airflow model involving turbulence. A 3-D finite-volume approach is adopted by the software CFDRC® because of its capability of conserving solution quantities. The program solves the conservation equations for continuity, momentum, and energy as well as the equations for turbulent kinetic energy and its dissipation rate. The two-equation k - ε turbulence closure [16] is used. The governing equation of an incompressible steady-state flow can be written as

$$\nabla \bullet \left(\rho V \phi \right) = \nabla \bullet \left(\Gamma \nabla \phi \right) + S_{\phi} \tag{1}$$

where ρ is the air density, ϕ represents the mean velocity component, pressure and turbulent parameters, V is the mean velocity, Γ is the diffusion coefficient, and S_{ϕ} is the source term but it was ignored in this study. This equation is also known as the generic conservation equation for a quantity ϕ. Integrating this equation over a control-volume cell, we have

$$\int_{\vartheta} \nabla \bullet (\rho V \phi) d\vartheta = \int_{\vartheta} \nabla \bullet (\Gamma \nabla \phi) d\vartheta \tag{2}$$

In the k - ε turbulent model, the notation of k is the kinetic energy and ε is the turbulence dissipation rate. The turbulent viscosity is expressed as

$$v_t = \frac{C_\mu k^2}{\varepsilon} \tag{3}$$

The transport equations for k and ε are

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho u_j k) = \rho P - \rho\varepsilon + \frac{\partial}{\partial x_j}\left[(\mu + \frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial x_j}\right] \tag{4}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_j}(\rho u_j \varepsilon) = C_{\varepsilon_1}\frac{\rho P\varepsilon}{k} - C_{\varepsilon_2}\frac{\rho\varepsilon^2}{k} + \frac{\partial}{\partial x_j}\left[(\mu + \frac{\mu_t}{\sigma_\varepsilon})\frac{\partial\varepsilon}{\partial x_j}\right] \tag{5}$$

with production term P defined as

$$P = v_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\frac{\partial u_m}{\partial x_m}\delta_{ij}\right)\frac{\partial u_i}{\partial x_j} - \frac{2}{3}k\frac{\partial u_m}{\partial x_m} \tag{6}$$

In the above equations, v_t is the turbulent viscosity, ρ is the fluid density, u_i and u_j are the mean velocity components in the x_i and x_j directions respectively, μ and μ_t are the laminar and turbulent dynamic viscosities respectively, and δ_{ij} is Kronecker delta. The turbulence model constants used in equations 3-6 are $C_\mu = 0.09$, $C_{\varepsilon_1} = 1.44$, $C_{\varepsilon_2} = 1.92$, $\sigma_k = 1.0$, and $\sigma_\varepsilon = 1.3$. To ensure the reliability of the simulation, model verification was performed by comparison of numerical results with Laser Doppler Anemometry (LDA) measurement of indoor air flows in a model room by Posner et al. [17]. The comparative results of the numerical simulations and experimental data were found to be in good agreement [18].

Model geometry

The school model is based on standard dimensions of the real school building. Figure 1 shows details of the building geometry at the façade. The dimensions are of 15.0 m × 36.3 m × 16.7 m (width × length × height). The dimensional detail of the computational domain is sufficiently large to avoid disturbance of the air flow around building. Each storey of the building (2^{nd}–4^{th} floor) has a similar room arrangement, i.e. three classrooms, a recreational room and a toilet. Figure 2 illustrates a horizontal section of 3^{rd} floor. A, B and C are classrooms, D is the toilet, and E is the recreational room. Each classroom has two doors with a space opening above each door. A corridor is a common path to every room on the floor. There are four sliding windows on the exterior wall. Overhang slabs at the façade and rear are designed for shading from excessive solar heat gain. For simplification, the building model is assumed to be located on a plane with no other buildings in the vicinity. To investigate effects of wind incidence angle (WIA) on the outdoor air flow, the building is rotated counterclockwise from the north in this square domain as detailed in Figure 3.

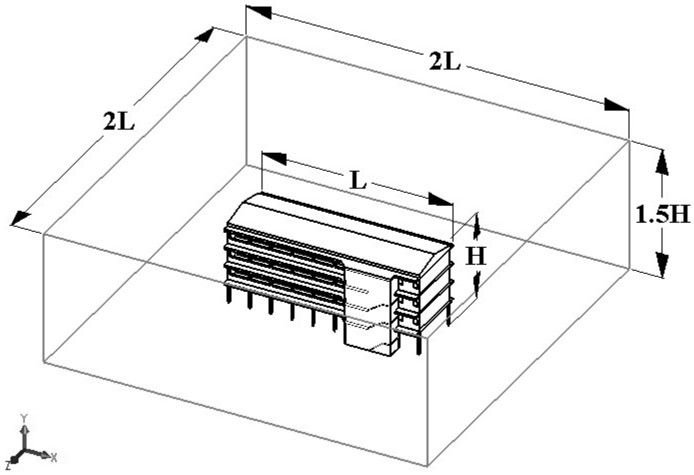


Figure 1. CFD model of school building

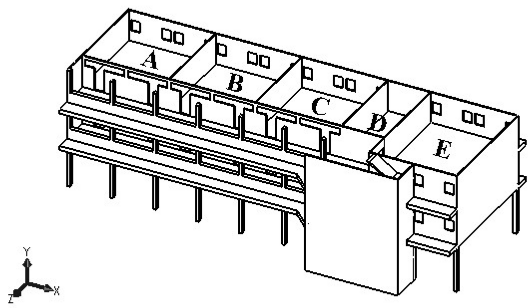


Figure 2. Typical sectional view of 3rd floor

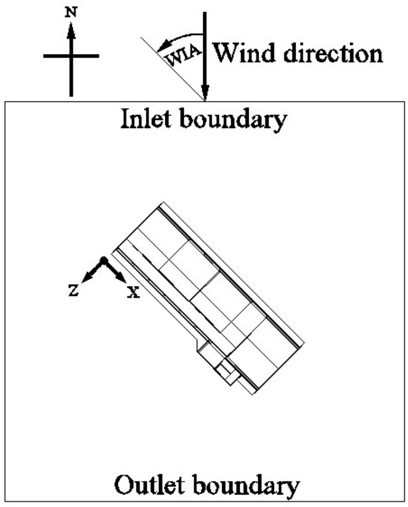


Figure 3. WIA with top view of building domain

Meshing

The computational domain has been changed by the building rotation within the domain. The tetrahedral cell has been chosen for meshing purpose. All computational domains of this study were undertaken for generating mesh by means of relative cell size. An actual mesh size was calculated by multiplying the length of the largest edge of the coordinate-aligned bounding box of the entity by a given parameter. The maximum relative cell size of 0.02 was used as a limit for generating local mesh of all domains. Meshing of this computational domain was carried out with 330,000 cells, covering the whole volume of the domain. A sensitivity analysis of the numerical scheme on the grid refinement was performed by using a finer grid, i.e. a relative cell size of 0.0175 (549,000 cells), but the change in the results was negligible. The simulations were carried out using the relative cell size of 0.02 because less time was required for solution convergence.

Model set-up and boundary conditions

The flow domain of the building was simulated with prevailing wind blowing along x-axis (Figure 1). Simulation of the real conditions is rather complicated due to the uncontrollable nature of the outdoor conditions. To reduce the complexity of the simulation, buoyancy effects are neglected. At a wind speed of 4 m/s, the buoyancy effect was diminished as a result of the wind-driven force [21]. All surfaces of the building domain are considered as isothermal walls and the no-slip condition is set at these walls. To simplify this computation, the flow is assumed to be a steady, incompressible and turbulent flow. The prevailing wind was set to blow through the inlet boundary from the north (Figure 3). At the outlet boundary of the domain, a constant pressure is assumed. The flow at the walls and ceiling of the domain box is simulated as the inlet boundary condition except for the ground being as the no-slip condition. To investigate the effect of WIA, the building is rotated 360^{o} counterclockwise around the center of the domain box with a 15° increment. The inlet boundary conditions of the building domain are presented as follows:

$$\frac{u}{u_o} = \left(\frac{z}{z_o}\right)^{\alpha} \tag{7}$$

where u is the local wind speed at elevation z, u_o is the meteorological wind speed at the reference elevation z_o, α is the parameter that varies with the ground roughness and is selected as 0.22 for the suburban area. The reference speed u_o is set at 4.0 m/s at the elevation z_o = 10 m.

Computational configuration

The calculations were carried out on an Intel Pentium®4-3.0 GHz with RAM of 1.0 GB. A converged solution was defined as either that the criterion of residual values of less than 0.0001 for all dependent variables was met or when the number of iterations arrived at 5000. Under-relaxation was applied to stabilise the convergence. Most cases were ended by convergence solutions.

Flow visualisation

A setup of flow visualisation arrangement is shown in Figure 4. The experiment was conducted in a low-speed multipurpose water tunnel. The walls of the test section were made of acrylic plate so that they were transparent to light sources. The suitable velocity of water was 3.7 cm/s. The working section area was 15 cm × 20 cm (width × length) and the depth of water was kept at 3 cm, corresponding to the open channel flow Reynolds number of 3,556. There were two water containers: a major tank which contained a water circulating pump, and a minor tank which received discharge water from the circulating pump.

The experimental setup consisted of: (a) a flow visualisation table, which contained all components on a steel frame, (b) two water tanks consisting of the major tank as the main reservoir and the minor tank which supplied water flow to the test section area, (c) the test section area which controlled water flow for a uniform flow and was equipped with a 0.25 mm-diameter stainless wire and electrodes to generate hydrogen bubbles, (d) a hydrogen bubble generating circuit consisting of an electronic equipment box, (e) two halogen lamps which were used as light sources at both sides of the wall of the test section area, (f) a circulating pump of submersible pump type, which was submerged in the major tank to supply water to the minor tank, (g) a flow meter which was used to adjust the water flow rate that was supplied to the minor tank, and (h) a still picture camera and a video camera which were used to view and record the motion of the hydrogen bubbles at the top of the test section area.

Figure 4. Experiment setup of flow visualisation by hydrogen bubble technique

Results and Discussion

Numerical results

To study the airflow around the school building and the natural ventilation for classrooms, a number of planes were used to determine the numerical results as displayed in Figure 5. A horizontal plane A and 3 vertical planes B-1, B-2, B-3 display the velocity fields. A vertical lane C is used to study air velocity magnitude around building before blowing through the windows of the three classrooms. Wind that enters through the door is not suitable to ventilate the room because it can blow directly from the floor to the occupants [20]. So the study of airflow around corridor is not considered in this study..

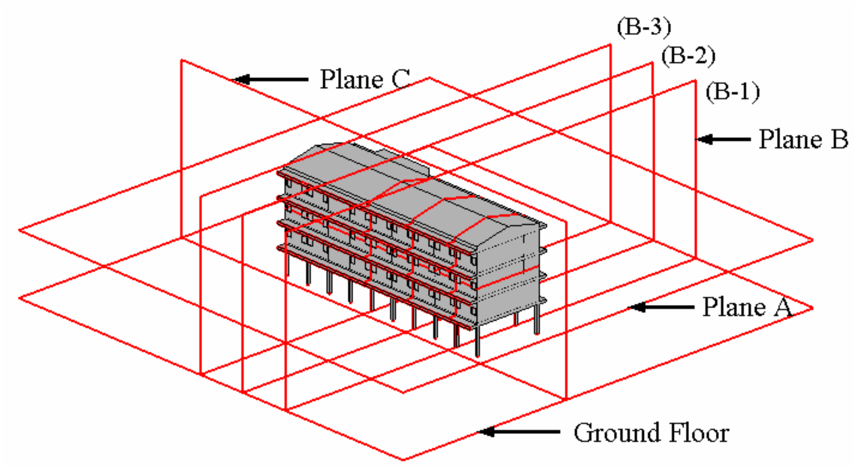
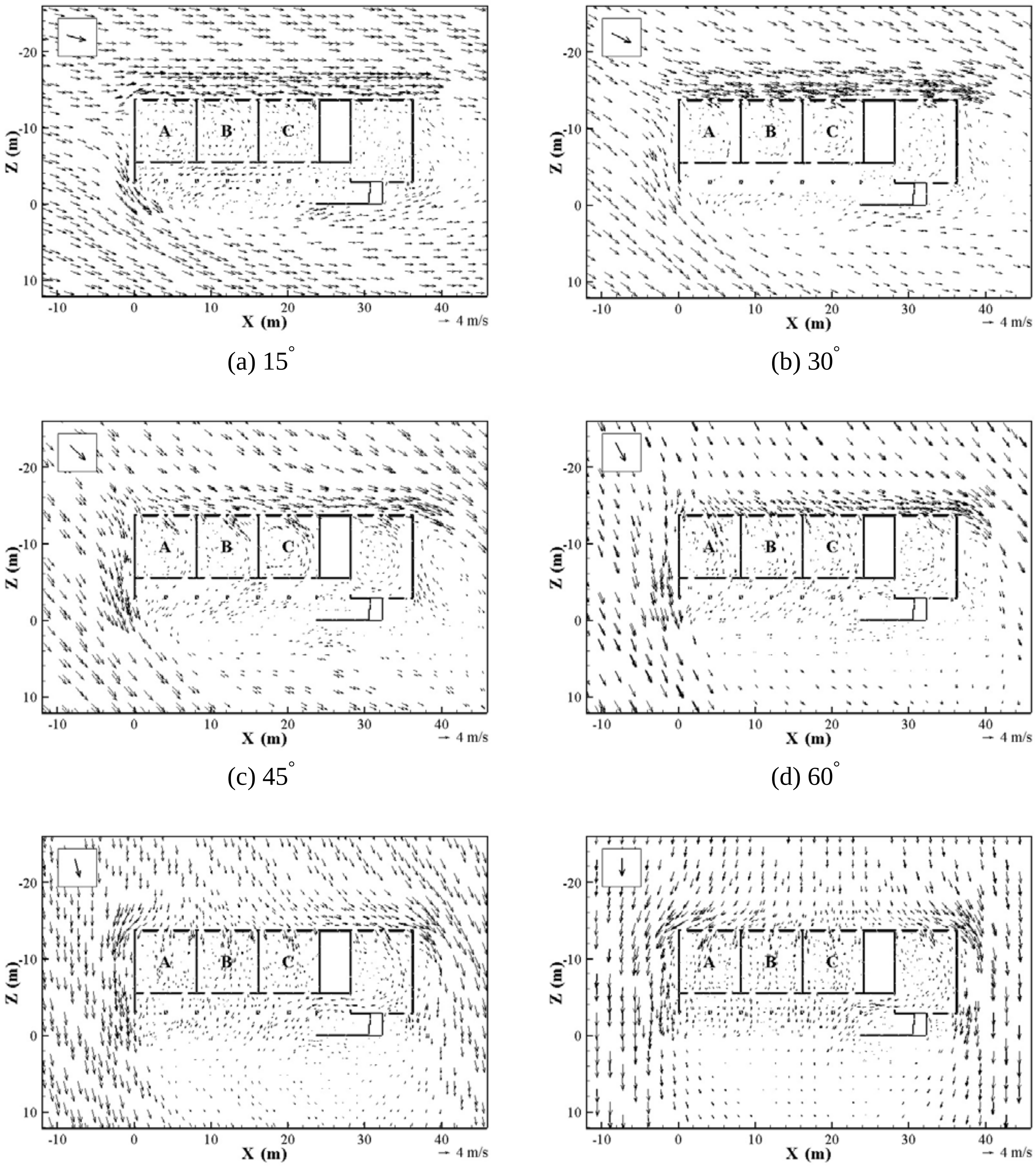


Figure 5. Sliced planes of numerical results. The planes B-1, B-2 and B-3 are sliced at x = 4.10, 12.15, and 20.15 m respectively

Figures 6(a-f) show the horizontal plane of the velocity components at middle height of the 3rd floor according to plane A. The wind that blew parallel to the building had no significant effect on the indoor air flow. Diagonal wind at 15°-60° created a swirl flow in the classrooms while straight wind attacked on the exterior wall, a stagnant flow region being generated around there. High strength wind of 30°-90° WIA tended to flow through the windows of classroom A. At 75° WIA, the wind that passed through the windows of classrooms A and B was straighter than that through classroom C. On the other hand, at 90° WIA classroom C obtained straight wind through the windows. This may have been caused by the location of classroom C which is at the middle of building. In the case of WIA > 90°, it was found that the mirror angle cases of z-axis, i.e. 0° & 180°, 15° & 165°, 30° & 150°, etc., gave no different results. A re-attachment flow, i.e. a separate flow found to the left sharp edge of the building and reattaching itself to the building, occurred at left end of the corridor. The flow next to the re-attachment tended to remain in the direction of the main upstream. Stagnant flow was found around the façade. A small area of stagnant zone was found at 15° WIA as shown in Figure 6(a). This zone expanded gradually and became largest at 90°. This type of zone of recirculation flow might form one of the contaminated regions [21].

Figures 7(a-f) show the vertical plane of the velocity components at the middle of the three classrooms (A, B and C) according to planes B-1, B-2, and B-3, respectively. At 90° WIA, it was found that the main flows tended to go up above the roof or down under the basement rather than fully going straight to the building wall at the 3rd floor. This is known as the downwash-upwash pattern on the upwind wall. A velocity field of higher speed wind curves upward over the roof and decelerates as it curves downward over the wake on the downwind side of the façade. The downwind wall of the building exhibits a region of low average velocity and high turbulence [21]. The upward flow was found to exist over most of the façade. The rooms on the 4th floor received a diagonal wind in an upward direction through the windows. On the other hand, the rooms on the 2nd floor received a downward wind. A stagnant flow was found around the exterior wall of the 3rd floor. A similar behaviour of wind blow was also found with the WIA at 270°. Numerical results of 90° and 270° WIA were similar. A zone of recirculating flow was found behind the leeward wall. These numerical results are consistent with those recommended by Tantasavasdi et al. [5], that the elevated floor allows more wind to flow to the building. On the other hand, an on-slab design essentially creates a reverse flow at the façade, reducing the natural ventilation rate.



(a) 15° (b) 30°

(c) 45° (d) 60°

(e) 75° (f) 90°

Figure 6. Horizontal velocity fields on the 3rd floor: Figures (a-f) correspond to WIA = 15°, 30°, 45°, 60°, 75°, and 90° respectively.

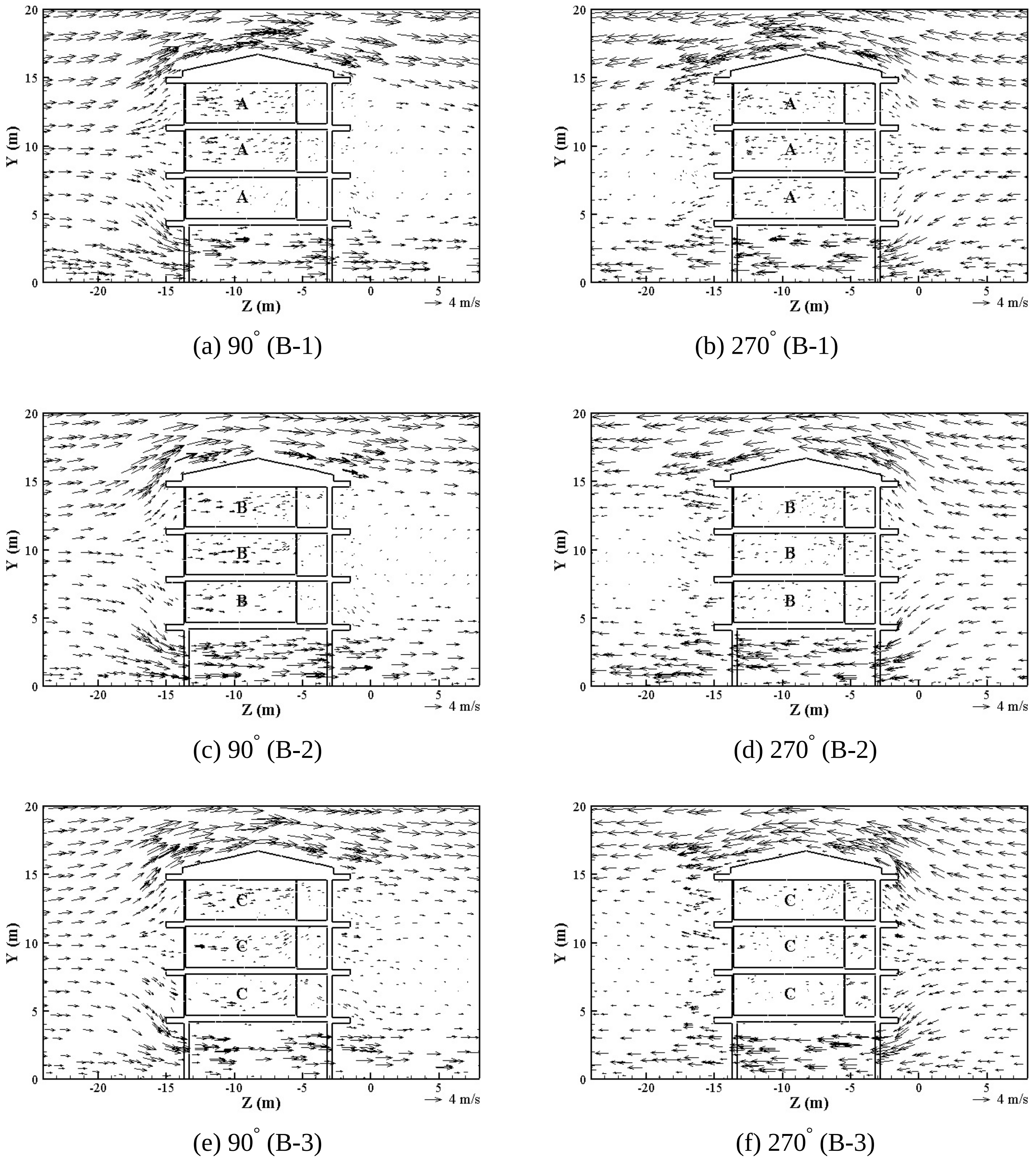


Figure 7. Vertical velocity fields at the middle of the classrooms: The planes B-1, B-2, and B-3 are sliced at x = 4.10, 12.15, and 20.15 m respectively.

From Figures 8(a-f), according to plane C in Figure 5, which is sliced at z = -15 m, it was found that the wind velocity around the window openings of classroom B was same as the classroom C but different from classroom A, especially when WIA increased to 90°. This may be attributed to the corner position of building. Therefore classroom A was not included in this study. The 90° WIA case showed that the wind velocity magnitude around the window openings was less than at other WIAs, i.e. a stagnant zone was found around the window side wall. The wind that blew down to the basement floor had a greater magnitude than that to the upper floors. Wind speeds and directions before passing through the windows of all classrooms (B and C) were averaged and shown in Table 1. From the arithmetic mean value of wind velocity, it was found that the mirror angle cases of z-axis were similar (0° & 180°, 15° & 165° and 30° & 150°). Wind speed was reduced before reaching the boundary of the building, and its direction changed while it approached the building. Hence the horizontal angle was found to differ from WIA significantly, a direct impingement case. The incoming wind speeds and directions will be used as the inlet boundary conditions for the classroom computational domain in future work. It would be useful to develop and plan a natural ventilation strategy in the building orientation for classrooms. This may improve thermal comfort of the students. Local meteorological data, e.g. wind speed, wind direction and ambient temperature may be collected and utilised with the findings from this study to identify an appropriate window opening. Appropriate location, type and size of the window may be investigated to obtain better ventilation.

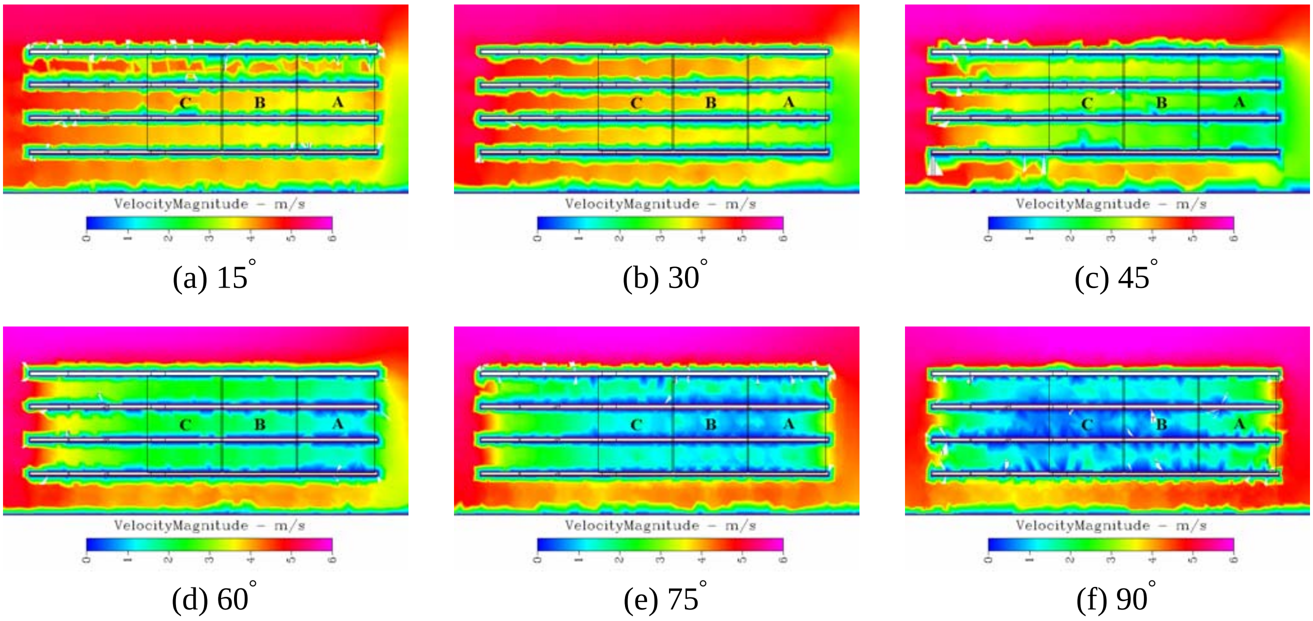


Figure 8. Wind velocity magnitudes adjacent to exterior wall: Figures (a-f) correspond to WIA = 15°, 30°, 45°, 60°, 75°, and 90° respectively.

Table 1. Average wind speed and direction in classrooms B and C

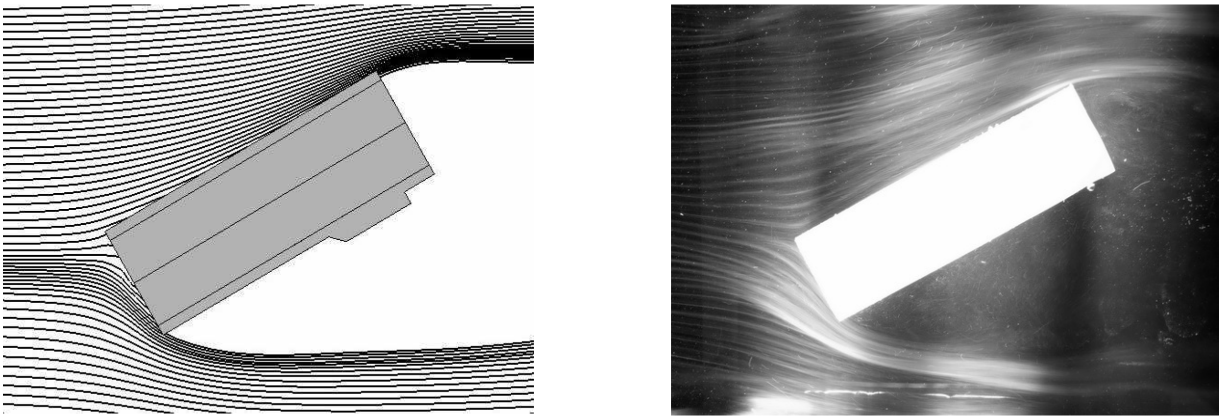
WIA (degree)	Velocity magnitude (m/s)[a]	Horizontal angle (degree)[b]
0	1.43/0.37 (1.14-2.01)	2.14
15	2.83/0.14 (2.64-2.96)	3.92
30	2.96/0.27 (2.69-3.35)	6.39
45	2.10/0.19 (1.73-2.25)	11.29
60	1.72/0.18 (1.46-1.98)	20.33
75	0.97/0.13 (0.75-1.10)	48.94
90	0.76/0.21 (0.42-1.01)	109.98 (-70.02)

[a] Arithmetic mean/Standard deviation (range)

[b] Relative to x-axis according to Fig. 3; minus sign denotes mirror direction.

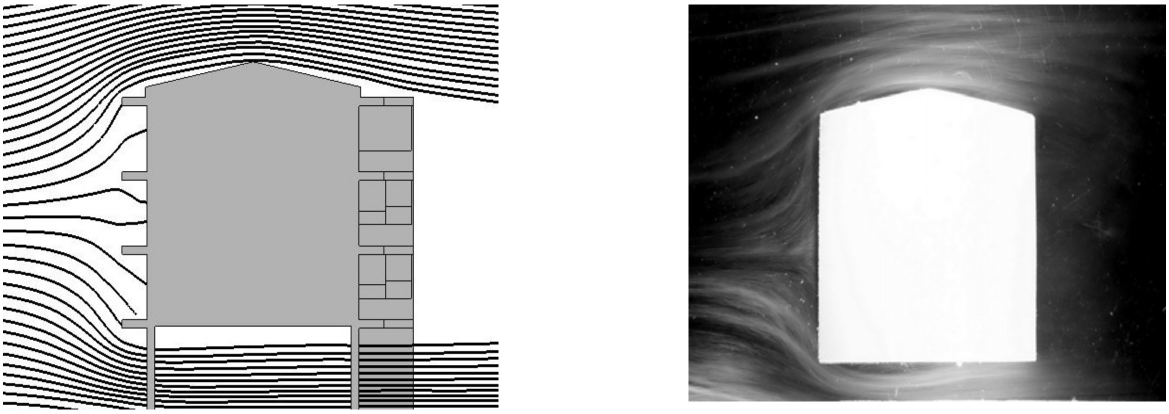
Experimental results

A flow visualisation by hydrogen bubble technique was conducted to support the numerical results visually. A building model (made of plywood) with a scale of 1:500 was placed in the test section area of the water channel. A dimensional analysis was undertaken to determine the water flow in the channel. A similarity between the external flow for the school building and that for the building model was calculated based on the Reynolds number. In this experiment it was assumed that the hydrogen bubbles was moved at the same velocity as water [11]. It was difficult to generate hydrogen bubbles by varying the water flow rate because hydrogen bubbles can dissolve in the water rapidly. Therefore an appropriate flow rate of generating hydrogen bubbles had to be maintained. It was easier to vary the flow rate in the simulation. In the first case, a similarity in water flow was determined to simulate a new computational 30° WIA case that was taken to compare with the horizontal cross section. The new computation with wind speed of 3.0 m/s and 30° WIA was modeled for the same Reynolds number. Figure 9 shows a picture from the post-processing of the computational result and a photograph of the experiment in comparison. Similar to the first case, the computational result of a new run with wind speed of 3.0 m/s and 90° WIA was also compared with the vertical cross section. Figure 10 exhibits a side view of the school building in the 90° WIA case. The computed and the experimental results were found to be qualitatively in good agreement.



(a) Computational (b) Experimental

Figure 9. Top views of school building models at 30° WIA



(a) Computational (b) Experimental

Figure 10. Side views of school building models at 90° WIA

Conclusions

An investigation of the airflow around the building of a typical state school which was designed for natural cross-flow ventilation for classrooms was carried out. A three-dimensional CFD program was used as the tool for simulation experiments. The flow around the school building was simulated to obtain the speeds and directions of the circulating wind. Based on the findings, the following conclusions can be drawn:

- The cross orientation of the building to the wind direction may not necessarily result in good ventilation in the classrooms.
- The geometry and orientation of the building has a strong effect to the airflow around it. The rooms in the middle zone of the building seem to get more uniform ventilation than those at the end.
- The flow visualisation by hydrogen bubble technique can give rise to the flow field. This proves to be a useful tool for verifying the numerical results qualitatively.

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References

1. L. Yang, G. Zhang, Y. Li, and Y. Chen, "Investigating potential of natural driving forces for ventilation in four major cities in China", *Energy and Buildings*, **2005**, *40*, 738-746.
2. A. Mochida, H. Yoshino, T. Takeda, T. Kakegawa, and S. Miyauchi, "Methods for controlling airflow in and around a building under cross-ventilation to improve indoor thermal comfort", *Journal of Wind Engineering and Industrial Aerodynamics*, **2005**, *93*, 437-449.
3. E. Prianto and P. Depecker, "Optimization of architectural design elements in tropical humid region with thermal comfort approach", *Energy and Buildings*, **2003**, *35*, 273-280.
4. E. Prianto and P. Depecker, "Characteristic of airflow as the effect of balcony, opening design and internal division on indoor velocity", *Energy and Buildings*, **2002**, *34*, 401-409.
5. C. Tantasvasdi, J. Srebric, and Q. Chen, "Natural ventilation design for houses in Thailand", *Energy and Buildings*, **2001**, *33*, 815-824.
6. A. Sreshthaputra, J. Haberl, and M. J. Andrews, "Improving building design and operation of a Thai Buddhist temple", *Energy and Buildings*, **2004**, *36*, 481-494.
7. A. Mochida, H. Yoshino, T. Takeda, T. Kakegawa, and S. Miyauchi, "Methods for controlling airflow in and around a building under cross-ventilation to improve indoor thermal comfort", *Journal of Wind Engineering and Industrial Aerodynamics*, **2005**, *93*, 437-449.
8. G. Evola and V. Popov, "Computational analysis of wind driven natural ventilation in buildings", *Energy and Buildings*, **2006**, *38*, 491-501.
9. C. R. Smith and R. D. Paxson, "A Technique for evaluation of three-dimensional behavior in turbulent boundary layers using computer augmented hydrogen bubble-wire flow visualization", *Experiments in Fluids*, **1983**, *1*, 43-49.
10. C. R. Smith and L. J. Lu, "Image processing of hydrogen bubble flow visualization for determination of turbulence statistics and bursting characteristics", *Experiments in Fluids*, **1985**, *3*, 349-356.
11. S. Eiamsa-ard, C. Leksongneon, S. Sripattanapipat, V. Kongkaitpaiboon, and P. Promvonge, "Visualization study of flow pattern around two obstacles near a channel wall with hydrogen bubble technique", *Proceedings of the 17th Conference of Mechanical Engineering Network of Thailand*, **2003**, TF 026.
12. F. Bao and U. Dallmann, "Some physical aspects of separation bubble on a rounded backward-facing step", *Aerospace Science and Technology*, **2004**, *8*, 83-91.
13. H. Guo, Q. X. Lian, Y. Li, and H. W. Wang, "A visual study on complex flow structures and flow breakdown in a boundary layer transition", *Experiments in Fluids*, **2004**, *37*, 311-322.
14. P. F. Zhang, J. J. Wang, S. F. Lu, and J. Mi, "Aerodynamic characteristics of a square cylinder with a rod in a staggered arrangement", *Experiments in Fluids*, **2005**, *38*, 494-502.
15. CFD Research Corporation, "Engineering Simulations Software", Huntsville, Alabama, **2003**.

16. B. E. Launder and D. B. Spaulding, "The numerical computation of turbulent flows", *Computational Methods for Applied Mechanical Engineering*, **1974**, *3*, 269-289.
17. J. D. Posner, C. R. Buchanan, and D. Dunn-Rankin, "Measurement and prediction of indoor air flow in a model room", *Energy and Buildings*, **2003**, *35*, 515-526.
18. C. Nitatwichit, Y. Khunatorn, and N. Tippayawong, "Investigation and characterization of cross ventilation flows through openings in a school classroom", *Journal of the Chinese Institute of Engineers*, **2008** (in press).
19. G. Gan, "Numerical method for a full assessment of indoor thermal comfort", *Indoor Air*, **1994**, *4*, 154-168.
20. C. Nitatwichit, Y. Khunatorn, C. Tantakitti, and N. Tippayawong, "Effects of wind speed and incoming direction on indoor airflow pattern in a classroom", *International Conference on Technology and Innovation for Sustainable Development*, 25-26 January **2006**, Khon Kaen, Thailand.
21. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Fundamentals Handbook, "Airflow around Buildings", Atlanta, **2001**, Ch. 16.

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