Mj. Int. J. Sci. Tech. **2008**, *2*(02), 320-330

Maejo International Journal of Science and Technology

ISSN 1905-7873
Available online at www.mijst.mju.ac.th

Full Paper

Changes in viscoelastic properties of longan during hot-air drying in relation to its indentation

Jatuphong Varith*, Chanisara Noochuay, Tipaporn Khamdang, and Adisorn Ponpai
Department of Agricultural and Food Engineering, Maejo University, Chiang Mai, 50290, Thailand
* Author to whom correspondence should be addressed, e-mail: jatuphon@mju.ac.th

Received: 3 October 2007 / Accepted: 30 April 2008 / Published: 1 May 2008

Abstract: Changes in viscoelastic properties are related to the indentation of whole longan (*Dimocarpus longan* Lour.) in the drying process. The objective of this research is to determine parameters from a creep test to characterise the viscoelastic properties of on-progress dried longan. During 65°C hot-air drying, the whole longan was sampled every 2 hours to perform the creep test with a constant stress of 44 kPa using a texture analyser. Viscoelastic properties, viz. retardation time (λ_{ret}), instantaneous compliance (J_0), retarded compliance (J_1), creep compliance (J), Newtonian viscosity (η_0), and modulus of elasticity (E) were analysed using the four-element Burger's model. The λ_{ret} and E decreased linearly as the moisture content decreased from approximately 70% to 64-57%, then they linearly increased as the moisture content further decreased to 11%. The J and J_1 increased linearly and then decreased linearly as the moisture content decreased, showing the transition moisture content of 64%. The J_0 decreased as the moisture content decreased. There was no marked change in η, thus it was not involved in the indentation of dried longan. The moisture content of 64-57% was found to be the critical range leading to the indentation of longan during the drying process.

Keywords: longan, drying, creep test, viscoelastic properties, indentation

---

Introduction

Longan (*Dimocarpus longan* Lour.) is one of the most important crops of Thailand with an export value of 2.4 billion Baht in 2006 [1]. Concentrated production of longan in a short season causes the depreciation of the fresh produce selling price. The most popular method to prolong the longan shelf life is to dry the longan with a hot-air stream. Drying the longan with peel, referred to as ‘whole longan’, is generally more popular than drying the longan flesh because the drying process can be operated in large scale. However, the problem associated with whole longan large-scale drying is the incident of indentation of the finished product. Indented longan is considered as a low-grade product and lowers the selling price as much as 50%. Therefore, a study to characterise the viscoelastic properties of whole longan is necessary for the basic understanding of how indentation takes place during the hot-air drying.

Generally, drying of whole longan is accomplished with hot-air at 60-75°C for 60-72 hr. As drying progresses, the moisture content decreases slowly, resulting in shrinkage of the internal tissue. At the initial stage, the longan peel is softened, but toward the final stage, the peel becomes hardened. Indentation often occurs between these two drying stages but has never been defined in terms of a critical drying period or moisture content. It is comprehensible that the indentation of longan occurs due to the loading compression of longan in the drying cabinet. The nearly constant loading can be simulated using a creep test. Previously, the creep test was effectively used as a tool to characterise the viscoelastic properties of biological materials. Ru et al. [2] studied the nonlinear behaviour of apple flesh under uniaxial creep loading condition and found that the power law equation was adequate to predict the creep behaviour of apple flesh. The non-linear creep formulation predicted the creep behaviour of apple flesh to within 2.7% at 67.2 kPa loading level. Ru and Puri [3] further studied the nonlinear behaviour of apple and potato flesh under uniaxial and triaxial creep tests using the four material property functions in a nonlinear three-dimensional constitutive equation based on the Green-Rivlin theory. The nonlinear constitutive equation predicted the results which were comparable to the experimental data. The nonlinearity of both apple and potato flesh increased with loading time and became significant after an initial loading period of 90 sec. Datta and Morrow [4] studied the creep behaviour of biological materials with graphical and computational method. Both methods were based upon the assumption of linear viscoelasticity, and the four element Burger’s model was applied to the biological materials. The computational method was effective for determining the accurate magnitude of material constant and well described the experimental creep behaviour of apple, potato and cheese. On the other hand, the graphical method provided approximate values for the material constants used as initial values for available curve fitting.

Previous work about creep test applied on biological materials was reported on some products addressed above. However, the report on creep test being applied on longan has not been found. The objective of this study is to evaluate changes in viscoelastic properties of longan during hot-air drying in relation to the indentation of whole longan. Information obtained from this work should provide the drying strategy to minimise the indentation problem and improve the quality of dried longan.

Materials and Methods

Critical spot susceptible to indentation

This preliminary experiment aims to explore a critical spot on fresh longan where indentation often occurs. Grade AA, off-season longan cv. Dor, with an average diameter of 25 mm freshly harvested from orchard in Lumphun province, Thailand, was used in this work. The flat surface probe with a diameter of 60 mm was applied in compression mode by a texture analyser model TA-XT *Plus* (Texture Technologies, Inc., UK) with a cross-head speed of 1 mm/s on the longan fruit at 3 specific locations (Figure 1), providing the quasi-static load while the data acquisition sensitivity following ASAE Standards S368.4 [5] was ensured. Compression test was ended at the target strain of 20% of initial fruit height or equivalent to 5.2 mm to ensure an occurrence of longan indentation. The force-distance profile from the compression test was obtained and analysed. The test was accomplished with 6 replications. The location on the fruit which exhibited the lowest force at 20% strain was identified as the critical spot of indentation.

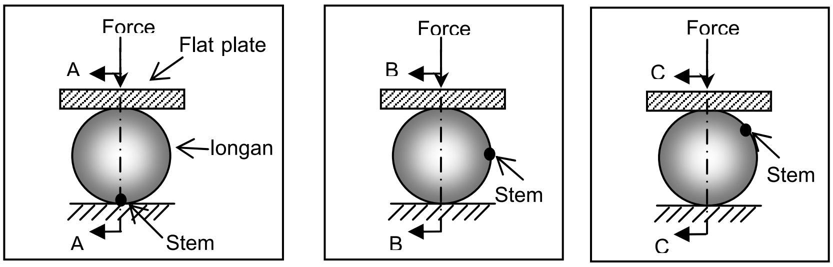

Figure 1. Test of critical spot of indentation on longan fruit: Plane A-A – at stem, Plane B-B – at 90° from stem, Plane C-C – at 45° from stem

Drying apparatus setup

A laboratory-scale hot-air dryer without air recirculation was used for the experiment (Figure 2). The dryer consisted of an axial fan, an electric heater and a drying basket with a capacity of 3 kg (20x25x10 cm: height x length x width) connected to an electric balance, model CP3202S (Satorius AG, Goettingen, Germany), for data acquisition (DAQ). The RS232 port of the electric balance was connected to a personal computer providing DAQ every 5 min. Two additional baskets (size 20x25x25 cm) without DAQ were placed in the front and back of the basket with DAQ to provide the creep test for the longan sample during drying. Overall length of the three baskets was 60 cm, equivalent to the thickness of the longan bed in industrial hot-air drying. A hot-air stream at 65°C with a velocity of 0.7 m/s, an optimum drying velocity reported by Achariyaviriya et al. [6], was employed to dry the longan. For each batch, the fruits were dried for 60 hr to the final moisture content of about 11%. The initial and intermediate moisture content of fresh longan was determined using the hot-air oven method at 103±1°C for 72 hr following ASAE Standards S325.2 [7].

Creep test analysis

The creep test was performed on the on-progress dried longan with a texture analyser model TA-XT *Plus* (Texture Technologies, Inc., UK). During drying with the hot-air apparatus, three longans from the front and back baskets without DAQ (Figure 2) were sampled every 2 hr to perform the creep test. Each longan was quickly placed on the texture analyser platform inside the temperature-controlled cabinet which provided a testing temperature of 65°C, similar to that in the hot-air dryer. A cross-head

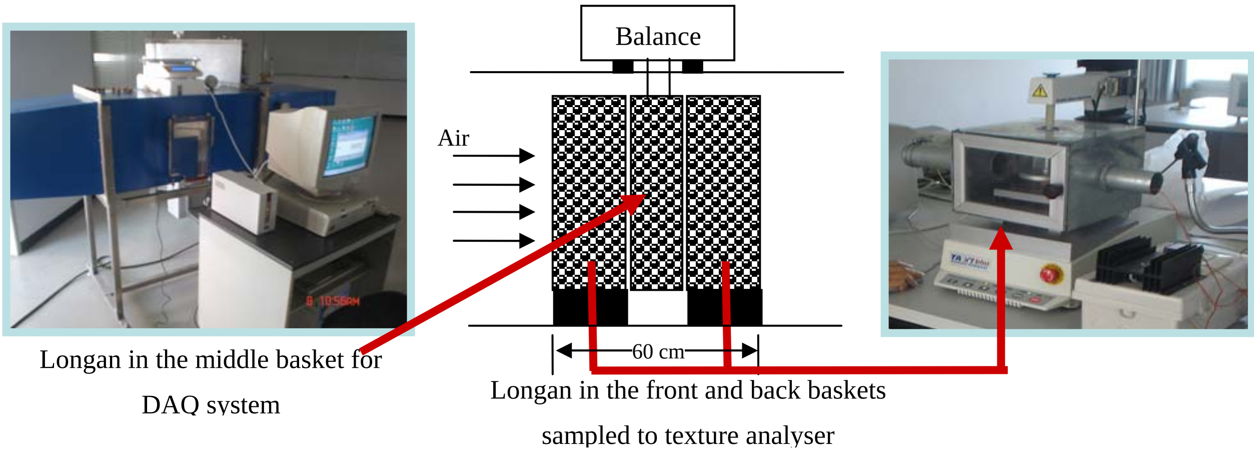

Figure 2. Laboratory-scaled tray dryer with DAQ system (left); Schematic diagram of longan basket setup inside drying chamber (middle); Texture analyser used for creep test (right)

speed of the 60-mm diameter flat-plate probe was set at 1 mm/s. For the creep test, the longan fruit was compressed and held with a constant stress of 44 kPa for 3 min (details of stress estimation are discussed later). Compression was performed on the fruit at the critical spot determined in the previous section. To analyse the data, assumptions of creep test were applied as follows:

a. A constant stress of 44 kPa was estimated from the stress on a single longan derived from the vertical load onto the bottom plane of longan in a commercial longan drying bed with a height of 60 cm, according to Figure 3.

b. The cross-sectional area used for stress calculation was assumed fixed at 0.639 cm^2 (Figure 3). Using a fixed area for stress calculation provided the approximate rather than the accurate magnitude of stress since the compressing area could change during constant loading. However, this approximate stress provided sufficient information to characterise the viscoelastic properties of longan in this work.

c. The stress applied on longan was assumed as a nominal stress [8], meaning that an internal integrity of longan was uniform and the effect of internal hole on stress was included in the assumption.

d. The strain applied on longan in this work, defined as a change in height compared to the original height of longan fruit, was assumed as an axial strain. The transverse strain on longan during compression was negligible.

After each test, the strain versus time profile of the creep test was analysed with four element Burger's model (Figure 4) following Eq (1):

$$J = J_0 + J_1\left(1 - exp\left(\frac{-t}{\lambda_{ret}}\right)\right) + \frac{t}{\eta_0} \qquad (1)$$

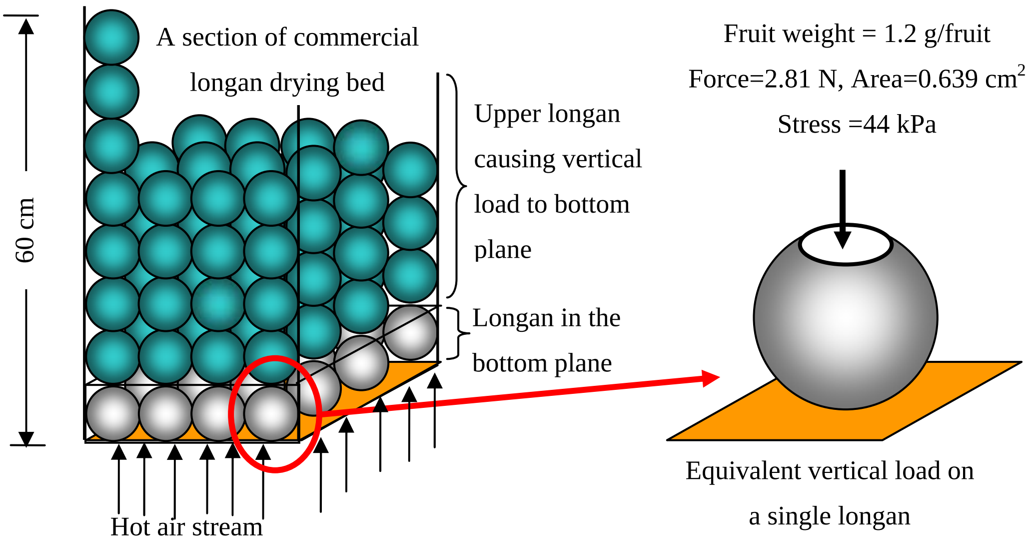

Figure 3. Schematic diagram of estimation of stress on longan for creep test analysis

where J is creep compliance which is a function of time (t), expressed by $\gamma/\sigma_{constant}$ or $1/E$ (E is elastic modulus, γ is strain, and $\sigma_{constant}$ is constant stress); J_0 is instantaneous compliance defined as $1/E_0$ (E_0 is elastic modulus of free spring); J_1 is retarded compliance defined as $1/E_1$ (E_1 is elastic modulus of compound spring); λ_{ret} is retardation time defined as a ratio of η_1/E_1 (η_1 is Newtonian viscosity of compound dashpot); and η_0 is Newtonian viscosity of free dashpot. The complete derivation of Burger's model was described by Steffe [9].

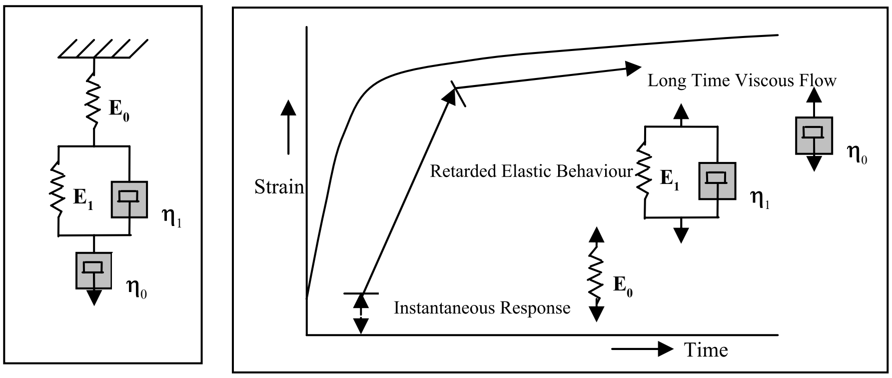

Figure 4. Mechanical analogy of four element Burger's model for the creep test of longan

The creep parameters, e.g. J_0, J_1, λ_{ret} and η_0 from Eq (1) were determined using generalised reduced gradient nonlinear optimisation embedded in Microsoft Excel™ (Frontline Systems, Inc. NV) with a prediction tolerance of 10^{-4} and 95% confident interval. Once J_0, J_1, λ_{ret} and η_0 were obtained from the optimisation, J was calculated using Eq (1) for each drying time (t). Plots of J_0, J_1, λ_{ret}, η_0, J, and E (a reciprocal of J) versus moisture content were obtained to characterise the changes in viscoelastic properties as well as the critical moisture content of longan susceptible to indentation during drying with hot air.

Results and Discussion

Critical indentation spot evaluation

Figure 5 shows that fresh longan compressed on plane A-A (at the stem) requires greater force to reach 20% of the original fruit height than that for plane B-B (90° from stem) and plane C-C (45° from stem). Greater compression force implies more resistance of the longan to external force. At a deformation of 5.2 mm (20% of initial height), compressing the longan at the stem requires a force of approximately 60 N while compressing the longan at 90° and 45° from the stem requires about 10 and 30 N respectively. It can be implied that the spot at 90° from the stem is the critical spot susceptible to indentation of longan due to the lowest compression force used. This result agrees with the observation that most dried longan fruits sampled from two industrial drying sites exhibited indentation, more than 80% of which were on the spot 90° from the stem. Therefore, for further creep test all samples were tested at the spot 90° from the stem.

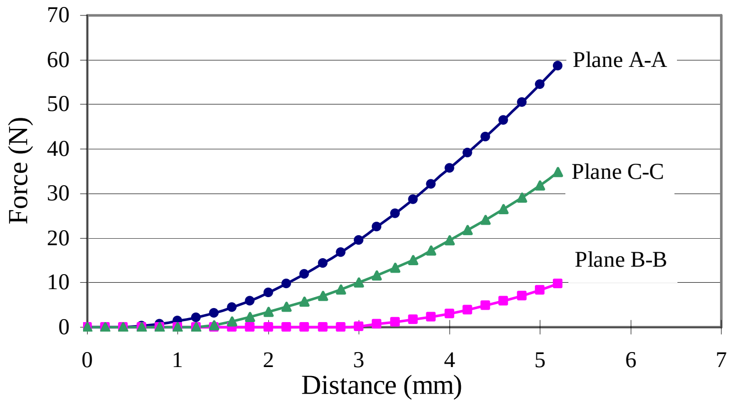

Figure 5. Average force-distance profiles to evaluate the critical indentation spot of fresh longan

Drying characteristics of whole longan

The drying curves of whole longan are different for the three locations of drying (Figure 6). The front basket, located near the heater, was subjected to direct 65°C hot air exposure, therefore it exhibited the fastest moisture decrease. The drying curve of the longan in the front basket fits well with an exponential model (r^2 of 0.99). On the other hand, the fruits in the middle (DAQ) and the back basket were subjected to indirect hot air after passing through the front basket. Thus the drying curves of longan in the middle (DAQ) and the back basket exhibited a slower moisture decrease. Both curves fit well with the 3rd degree polynomial models rather than the exponential model. The reason for these differences is the thickness of the basket. As hot air passes through the front basket, there is a pressure drop of air stream across the middle and back baskets. Heat is transferred to the longan in the front basket to remove moisture. Thus, the hot air is moistened and the enthalpy of the hot air stream is reduced resulting in a lower capacity to remove moisture from longan. So the drying rate decreases drastically as apparent in the drying curves of longan in the middle (DAQ) and back baskets. Since

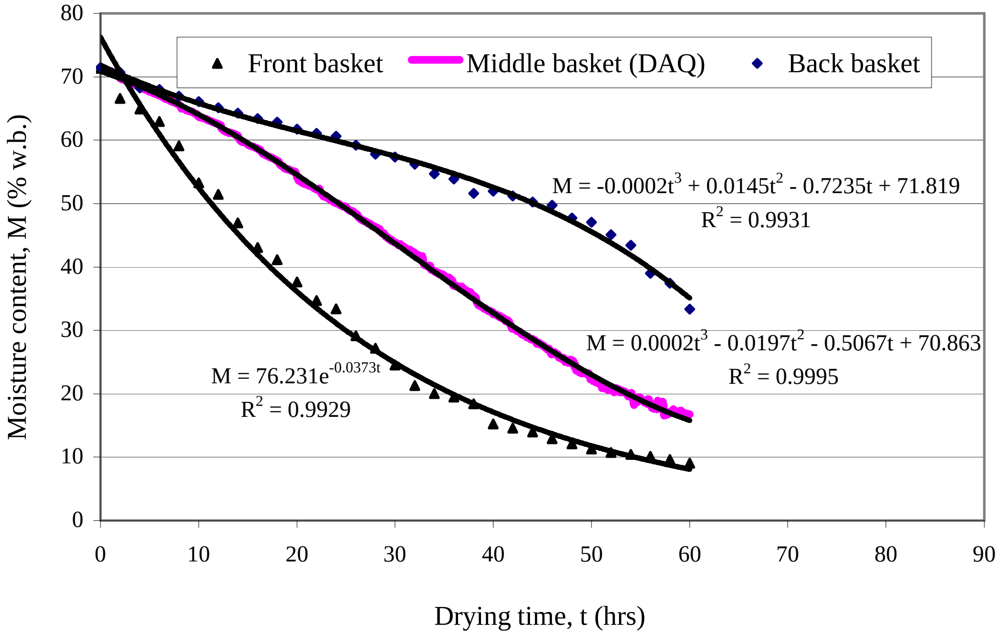

Figure 6. Drying curves of whole longan using hot-air (65°C) at velocity of 0.7 m/s

further experiments on the viscoelastic characteristics of longan during the drying process were done on the longan sampled from the front and back baskets, it is more appropriate to characterise the viscoelastic properties in relation to the moisture content rather than drying time.

Changes in viscoelastic properties

Figure 7 shows that the instantaneous compliance (J_0), representing the elastic part of longan, decreases with a decrease in moisture content. A decrease in J_0 suggests that longan loses its elastic behaviour, resulting in a slower response in resisting external loading. At the beginning of drying, the whole internal space of fresh longan is filled with longan flesh, therefore its elastic behaviour is evident. As the drying progresses, the flesh of longan shrinks markedly, thus air void becomes larger inside the dried longan. Consequently, it loses its capacity to react to the sudden external loading resulting in a decrease of its elastic behaviour.

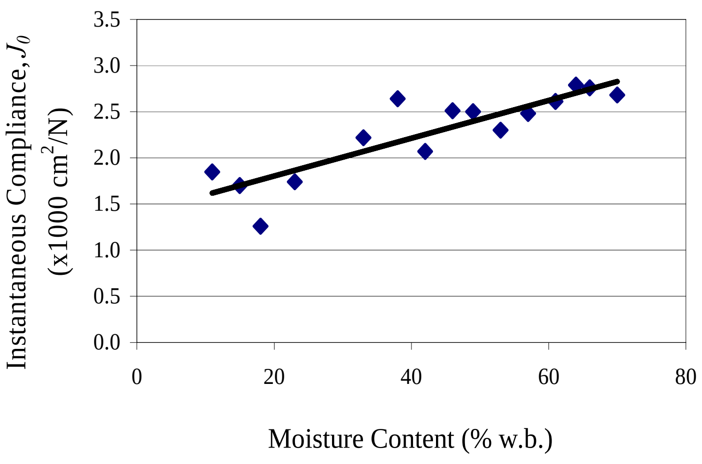

Figure 7. Relationship between instantaneous compliance (J_0) and moisture content of longan

Figures 8 and 9 indicate that the retarded compliance (J_1) and retardation time (λ_{ret}) of longan during drying are divided into two periods. The first period is identified by moisture content reduction from 71% to 64-57% (w.b.) while the second period is from 64-57% to 11% (w.b.) reduction of moisture content. The J_1 value represents the retarded elastic behaviour during constant loading. In relation to moisture content, J_1 during moisture reduction from 71 to 64% increases and then gradually decreases as longan continues to dry at moisture content below 64%. The λ_{ret} value, representing the time under constant loading until the strain reaches asymptotic plateau, exhibits the response to constant loading in a similar manner to J_1, with the transition moisture content of about 57%. Therefore the moisture content in the range of 57-64% is the critical range of viscoelastic changes during the drying of longan. However, the Newtonian viscosity (η_0) does not change during drying (Figure 10), implying that the changes in viscoelastic properties of longan during drying are not influenced by η_0. The creep compliance (J) in Figure 11 exhibits a similar trend of change to that of J_1, while the elastic modulus (E) in Figure 12 which is in inverse relationship to J_1 exhibits an opposite trend.

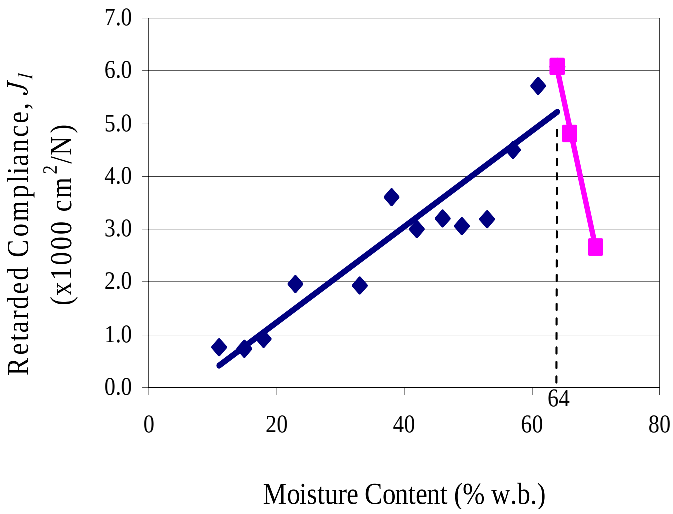

Figure 8. Relationship between retarded compliance (J_1) and moisture content of longan

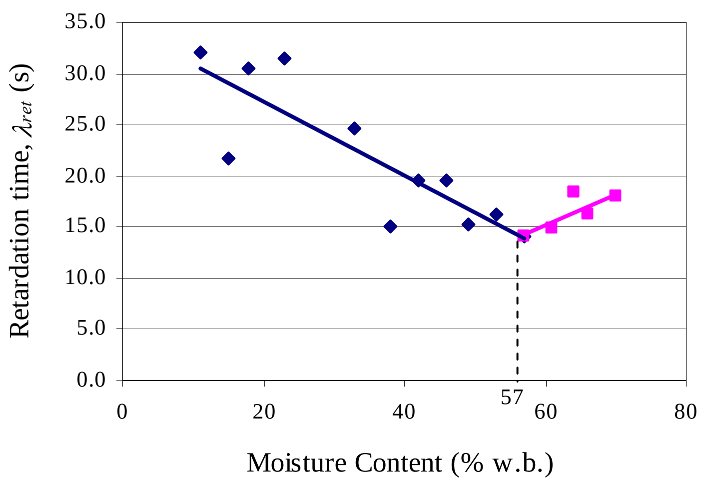

Figure 9. Relationship between retardation time (λ_{ret}) and moisture content of longan

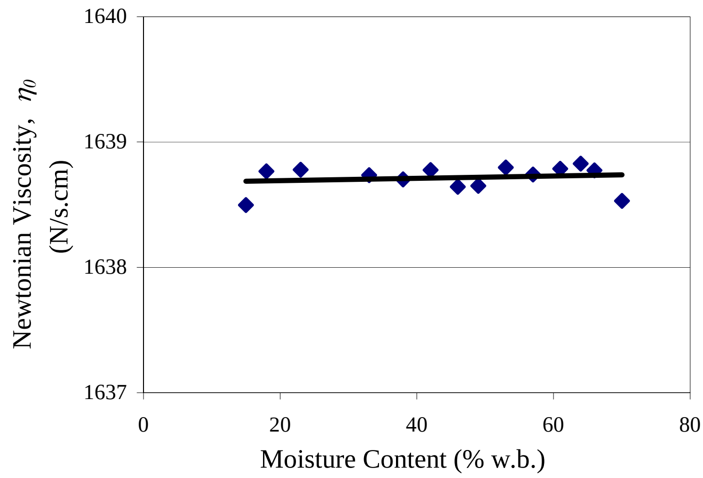

Figure 10. Relationship between Newtonian viscosity (η_0) and moisture content of longan

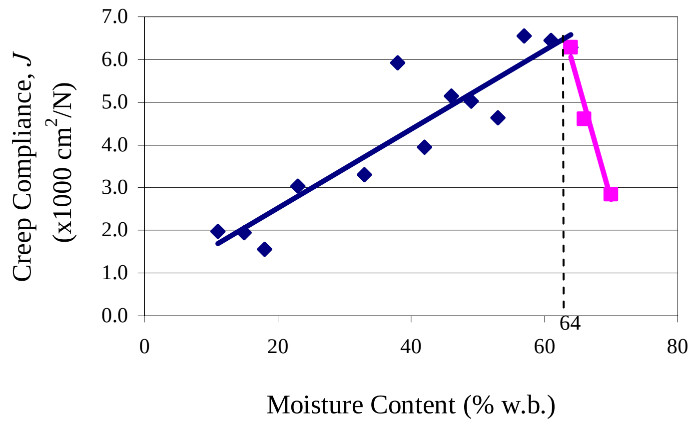

Figure 11. Relationship between creep compliance (*J*) and moisture content of longan

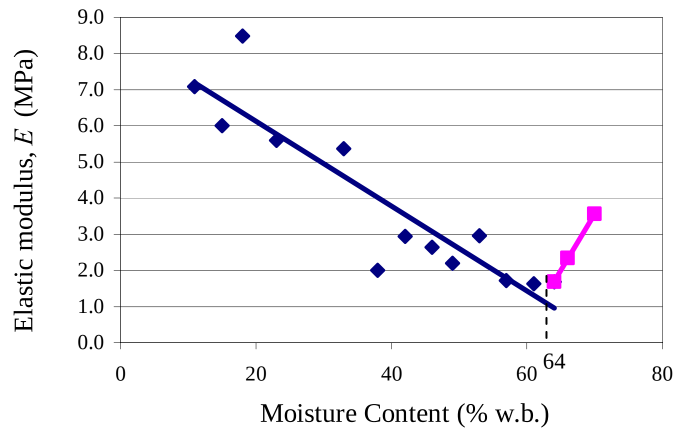

Figure 12. Relationship between elastic modulus (*E*) and moisture content of longan

The moisture content in the range of 57-64% is a critical range susceptible to indentation of longan because *E* and λ_{ret} are minimal while *J*, and J_1 are maximal. The minimum *E* at the critical moisture content also means minimal resistance of longan to the external force. In implementing the findings to the industrial drying process, care should then be taken during the critical moisture content range of 57-64% when the on-progress dried longan will be weakest and easily indented. If the constant load due to the weight of the drying bed is too high, longan at the bottom layer of the drying bed may be indented, especially at the critical moisture content. Once the drying progresses toward the final moisture content of 11% (w.b.), the peel will harden, in agreement with increasing E. However, the longan loses its ability to regain the original spherical shape, which is explained by the increasing of λ_{ret}. This results in a permanently indented longan, which drastically lowers the market value of the final product. Our findings also agree with the observation of the longan drying processors that special care must be taken during the 15-20 hours of drying (corresponding to the moisture content of about 60% w.b. in Figure 6) when the softening of longan in the drying cabinet tends to occur. Therefore our analyses are compatible with the practical guidelines from the longan drying processor, and also provide an in-depth explanation on how the viscoelastic properties influence the indentation of longan.

Conclusions

In this work, changes in viscoelastic properties of longan during hot air drying have been determined. Some important parameters derived from the creep test, including J, , E and λ_{ret}, indicate that longan indentation is related to its moisture content. At the beginning of the drying process, the fruit is softened (less firm) until moisture content is lowered to about 57-64%, when it starts to harden. Changes in the creep compliance (J), the retarded compliance (J_1), the elastic modulus (E) and the retardation time (λ_{ret}) correspond well with changes in viscoelastic properties during the drying process. Critical moisture content has been determined to be in the range of 57-64% (w.b.), at which J and J_1 are maximal and E and λ_{ret} are minimal. These findings could be a useful guide that helps to minimise permanent indentation of longan.

References

1. Office of Agricultural Economic, Thailand, online from http://www.oae.go.th/statistic/export/1301LOD.xls (in Thai), **2007**.
2. R. Ru, V. M. Puri., and C. T. Morrow, "Nonlinear Viscoelastic Properties of Apple Flesh Under Creep", ASAE Paper No. 88-6504. St. Joseph, MI, USA, **1988**.
3. R. Ru and V. M. Puri, "Characterization of Nonlinear Behavior of Apple and Potato Flesh Under Creep", ASAE Paper No. 91-6023. St. Joseph, MI, USA, **1991**.
4. A. K. Datta and C. T. Morrow, "Graphical and computational analysis of creep curves", *Transac. ASAE,* **1983**, *26*, 1870-1874.
5. ASABE Standards, "Compression Test of Food Materials of Convex Shape" St. Joseph, MI, USA, **2006a**, pp. 608-616.
6. A. Achariyaviriya, S. Soponronnarit, and J. Tiansuwan, "Study of longan flesh drying", *Drying Technology*, **2001**, *19*, 2315-2329.
7. ASABE Standards, "Moisture Measurement—Unground Grain and Seeds", St. Joseph, MI, USA, **2006b**, pp. 605-606.

8. N. N. Mohsenin, “Physical Properties of Plant and Animal Materials”, 2nd Edn., Gordon and Breach Publishers, New York, **1996**.
9. J. F. Steffe, “Rheological Methods in Food Process Engineering”, 2nd Edn., Freeman Press, East Lansing, **1996**.