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EFFECT OF VISCOELASTICITY OF PLANT-BASED FOOD MATERIALS ON TRANSPORT PHENOMENA DURING DRYING

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Abstract: *Water removal rate during drying mainly depends on the microstructural pathways of water migration inside the food materials and the mechanical properties of plant tissue. Currently there is no study that invstigated the interrelationship between viscoelastic property and transport phenomena during drying. In this study, the influence of viscoelastic property of plant-based food material on transport phenomena during drying has been experimentally investigated. Granny Smith apple and beet root have been taken as the samples in this study. A 2kN Instron universal testing machine and ImageJ software were used in order to measure and analyse the viscoelasticity of the samples. Three different fruits investigated show different viscoelastic properties along with different energy loss due to hysteresis. A positive relationship was found between energy loss due to viscoelastic nature of materials and drying kinetics. This correlation can be explained by the nature of the cell wall stiffness that facilitates or hinders the water migration in mechanical and thermal energy applications.*

Keywords: Visoelasticity, hysteresis, Drying kinetics, Initial porosity

1 INTRODUCTION

Most of the plant-based foods can be treated as hygroscopic-porous-amorphous materials [1-2]. The amount of moisture content in the plant based food materials is typically more than 80%, because of which they are considered as perishable commodities [3]. Inappropriate post-harvest processing causes substantial damage and wastage of seasonal fruits in many countries, which is projected to be almost 30–40% of seasonal fruits in developing countries [4]. This wastage can be mitigated by utilizing food drying technology. However, the basic understanding of food drying has not been completely established yet due to the diverse and complex nature of food materials.

Drying of foods is an ancient technique of post-harvest food processing. Enhancing the shelf life of the food materials by removing the water is the main purpose of drying. Throughout the drying process, numerous physical and chemical changes occur in foodstuffs which can be treated as the determinant of food quality. There are various factors including the processing treatment, preparing method, charecteristics of raw materials and drying conditions that significantly influence food quality [5–8]. In order to find out ideal conditions of drying, comprehensive understanding of underlying physics associated of foods drying is crucial. Moreover, simultaneous heat and mass transfer over the course of drying dependent on key physical properties of foodstuffs including moisture content, initial posrosity and microstructure of the food materials [9]. Collapse and shrinkage take place during drying due to simultaneous heat and mass transfer. Essentially, these structural modification substantially affect both transport phenomena and qulity.

Plant cell membranes and walls are semi-permeable and are regarded as the components that affect the transfer of water to and from parenchyma cells [10-11]. Generally, the cell wall of plants comprises approximately 60% water, 2-8% pectin substances, 5-15% hemicellulose, 10-15% cellulose, 1-2% protein, and 0.5-3% lipids [12]. These proportions vary due to a variety of factors, such as environmental conditions, stage of maturity, processing after harvest, and botanical origin of the plant [13]. In addition to this, the mechanical properties of the tissue depends on the cell wall properties [14]. Intact cell walls and cell membranes are the main hindrance for water migration from the cell [15].

On the other hand, change of physical propertices depends on both process conditions and sample properties. Mechanical, structural and viscoelastic properties including hysteresis, creep and stress relaxation are the determinant of deformation food materials during drying [16]**.** Therefore, proper understanding of interrelationship between food properties and transport phenomena is essential.

Since plant based food materials contain a significant amount of moisture, they do not follow Hooks law as a solid body nor do they follow Newton's law of viscosity as a fluid. However, all the plant-based food materials show viscoelastic features. Force deformation curves for plant based food materials show some residual deformation remaining because none of the biological materials shows perfect elasticity. This means some energy is obtained by taking the difference between the loading work and the unloading work. This energy loss is referred to as specific damping capacity or hysteresis of plant based food materials [17]**.**

Although extensive research has been carried out on the establishement of material properties and transport phenomena relationship, no study exists that investigated the effect of mechanical hysteresis phenomena on drying kinetics. In this study, hysteresis phenomena of Granny Smith apple and beet root has been investigated . Finally, the influence of hysteresis phenomena on the drying kinetics were investigated.

2 MATERIALS AND METHOD:

2.1 Sample Preparation:

Granny Smith apple and beet roots were purchased from the local supermarket. The fresh fruits were kept in refrigerator until the time of experiment execution. First, the samples were sliced into 11 mm diameter and 12 mm height cylinders for compression tests as shown in Figure 1. For investigating the viscoelastic properties namely hysteresis, apple samples were subjected to 1mm deformation; whereas, beet root samples were encountered 3 mm extensions.

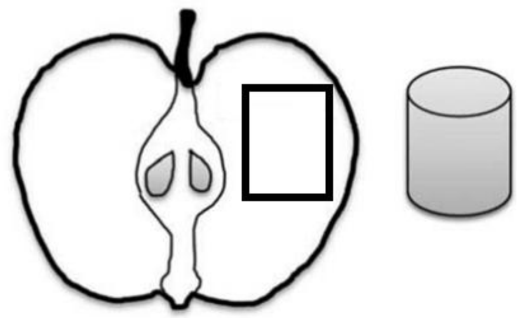

Figure 1: Preparation of sample(Granny Smith) for mechanical properties

2.2 Drying

Drying tests were performed based on the American Society of Agricultural and Biological Engineers (ASABE S448.1) standard [18]. The procedures for ASABE standard are as follows:

- Tests should be conducted after drying equipment has reached steady-state conditions. Steady state is achieved when the approaching air stream temperature variation about the set point is less than or equal to 1^0C.
- The sample should be clean and representative in particle size. It should be free from broken, cracked, weathered, and immature particles and other materials that are not inherently part of the product. The sample should be a fresh one having its natural moisture content.
- The particles in the thin layer should be exposed fully to the airstream.
- Air velocity approaching the product should be 0.3 m/s or more.
- Nearly continuous recording of the sample mass loss during drying is required. The corresponding recording of material temperature (surface or internal) is optional but preferred.
- The experiment should continue until the moisture ratio, MR, equals 0.05. M_e should be determined experimentally or numerically from established equations.

For convection drying, the samples were placed in household convection dryer and the temperature was set to 70^0C. The moisture loss was recorded at regular intervals of 10 mins with the digital balance (specification: 0.001g accuracy).

2.3 Measurement of Viscoelastic Properties

In order to investigate the viscoelastic properties, termed as hysteresis, Apple and pears slices were subjected to 1mm deformation; whereas, beet root slices experienced 3 mm deformation .The compression speed was maintained at 5 mm/min, as suggested in ASAE standard 368.1 [19]. Compression were carried out using the 2kN Instron universal testing machine. Both loadding and unloading experiments were conducted in order to investigate hysteresis phenomena of the samples. Force and deformation data from the compression test were recorded on a connected computer.

Hysteresis calculation can be done from the force-deformation curves obtained from loading and unloading using universal testing machines [20-21]. Hysteresis losses in loading-unloading test correlate well with the change of volume of foodstuffs during drying [22]. The difference between the areas is referred to as the Energy loss or hysteresis. Figure 2 shows the typical hysteresis curve for a viscoelastic plant based food materials [23].

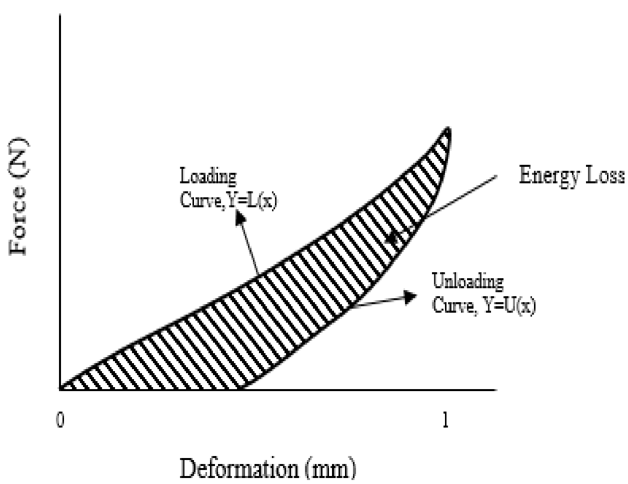

Figure 2: Schematic diagram of hysteresis parameters in the force-deformation curve

The energy loss due to hysteresis can be found by the following integrating equation [24]

Area, $A=\int_0^1 [L(x) - U(x)]dx$ (1)

Where, L(x)= trends of loading

U(x)= trends of Unloading

3 RESULT & DISCUSSION

3.1 Drying kinetics:

Drying kinetics of the selected samples have been presented in Figure 3. All of the samples shows similar trends of deceasing moisture content with drying time.

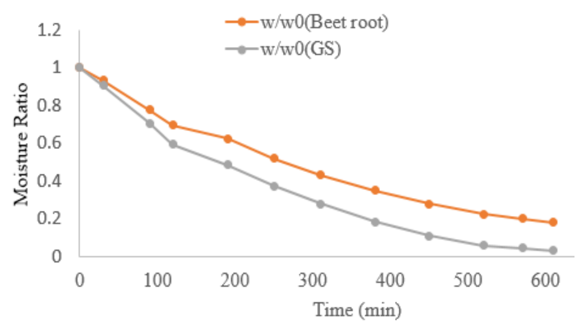

Figure 3: Weight loss of different plant based food materials slice in convective drying at 70°C

The result, as shown in Figure 3, indicates that the moisture migration rate is higher for apple than beet root. This result also demonstrates that in order to remove the same amount of water, beet root took the more heat energy than apple samples. The total energy required for removing water from plant- based food material significantly depends on water holding capacity, microstructure and visco-elastic properties of food materials. It can be hypothesisied that there may be an association between drying kinetics and viscoelastic properties of plant based food materials.

3.2 Hysteresis

Figure 4(a) and 4(b) illustrates the deformation nature of the selected plant based food materials during both loading and unloading. Since none of the biological materials shows perfect elasticity, apple and beet root show some remaining residual deformation which indicates their viscoelastics nature.

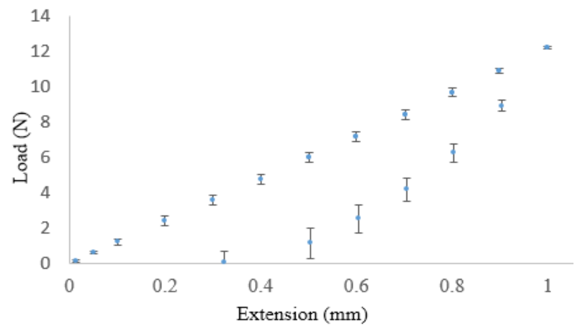

Figure 4(a): Load vs Extension Curve of Granny Smith apple

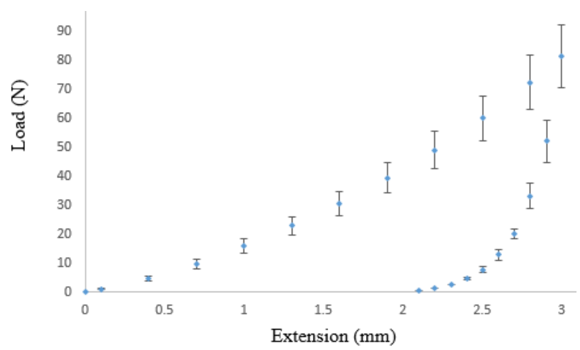

Figure 4(b): Load vs Extension Curve of beet root

After calculating the energy required for compression and stored energy obtained after unloading, loss enegy for the hysteresis phenomaena has been determined. From Figure 7 it is clearly apparent that all of the selected samples were compressed within its elstic limit. However, the unloading curves of the samples varies with the hysteresis properties of the sample. Beet root recovers least energy in comparison with appleTable 1 summarizes all the the energy related information for the selected samples.

Table 1: Energy Ratio of various viscoelastic plant based food materials

	Apple (Granny Smith)	**Beet root**
Energy Absorbed	6.02±0.23	95.76±12.88
Energy release	2.66±0.43	17.85±3.33
Energy loss	3.35±0.53	77.91±9.54

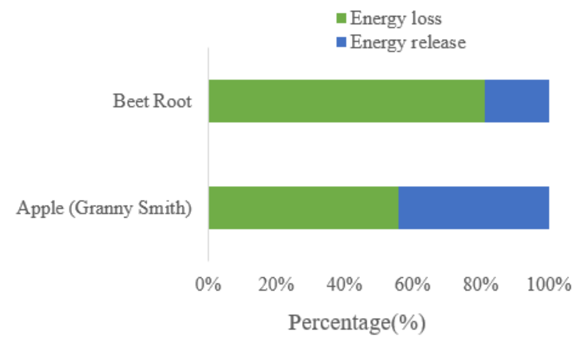

Figure 5: Energy ratio for different plant based food materials

Figure 5 presents the energy ratio for different plant based food materials where the energy loss accounts for the energy required to remove water from the tissue during compression. From the figure, it is found that apple has the lower amount of Energy ratio compared to beet root.

Taken these findings into consideration, a positive relationship between water migration by mechanical and thermal energy can be established. It can be concluded that moisture removal rate by the thermal process is directly proportional to the energy ratio. This finding suggests that drying kinetics noticeably depends on the viscoelastic characteristics of plant based food materials. The current findings substantially enrich our understanding of the association of drying kinetics and viscoelstic properties of plant based food materials.

4 CONCLUSION

Drying kinetics and dried food quality are subject to drying conditions and fresh food properties. In this study, viscoelastic properties specifically hysteresis were investigated and a relationship was established between the drying kinetics and hysteresis. A positive relationship was found between water migration by mechanical and thermal energy when the hysteresis was taken into account. The present study confirms previous findings and provides additional evidence that suggests viscoelastic charecteristics of plant-based food materials remakebly affect drying kinetics. The findings of this study will bring new understanding of the relationship of the viscoelastic properties of plant tissue with drying kinetics and thereby will help to optimise the energy requirement for drying.

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