Microstructure changing and moisture removing of lychee during microwave vacuum drying

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Abstract: Micrographs of lychee pericarp and pulp during microwave vacuum drying were tested and analyzed in order to illuminate the microstructure change of lychee and effect of the change on moisture removing in lychee. The results showed that the pericarp consisted of three parts: outer layer with cuticle, inter layer and inner layer. Outer layer and inter layer cells are easily destroyed than inner layer because of small and intact inner layer cells. Furthermore, micrographs showed that the moisture content of pulp keep constant with the temperature increasing at first 40 min due to the inner layer cells prevent the moisture removing from pulp. The long tubular structure of pulp cell would become break and lost over time, because the intercellular spaces reduced and the moisture removing was slow down in pulp. Meanwhile, the microstructure of lychee dried with temperature control was better than that without temperature control.

Keywords: Lychee, microstructure, microwave vacuum drying, moisture removal, temperature profile

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1 Introduction

Lychee (*Litchi chinensis* Sonn.) is one of the major seasonal fruits in South China, whose commercial value loss increases rapidly after harvest 72 h at room temperature[1]. Therefore, the processing and preservation of lychee are very imperative. At present, drying is an extensive processing method for lychee, including hot-air drying[2-4] and vacuum freeze drying[5]. Air dried lychees bear little resemblance to the fresh fruit with deep brown pulp and soft taste. Freeze dried lychees have high quality white pulp, high nutrient and crispy taste. However, high energy consumption and high cost cause limited application of freeze dried lychees. Therefore, a novel drying method should be applied to dry lychees.

Microwave vacuum drying (MVD) was already used to dry many foods, like green tea[6], papaya[7] and mangosteen[8] due to the lower energy consumption and the higher quality retention. In previous studies, authors studied the MVD process for lychees and obtained the optimal technical condition and drying characteristics of whole lychee[9]. Generally, drying time, energy consumption and quality of materials are used to describe the drying process[10-12], and good quality is judged by freshness, expected appearance, flavor and texture[13]. Drying causes many changes in the structure of plant material, including shrinkage, increased porosity, decreased ability to imbibe water, and damage to microscopic structure[14]. At present, microstructure of samples was tested in many researches because microstructure of food could reflect the macroscopic quality of food. Therefore, it is the most needed method for food processing to formulate new food products and to preserve original nutrient[15]. In general, it has been

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recognized that the microstructure plays an important role in determining the quality of food[16-18], and it has been found that many problems in food research are rooted in events that occur at the microstructure level[10,15,19].

Many of previous researches only analyzed and compared micrographs of materials at the end of processing for microstructure of plant materials[20-23]. The lack of study in dynamic microstructural changes of food material during drying process hinds a better development of this area. Wang et al.[24] determined the microphotographs of potato slices at different stages during microwave freeze drying (MFD), which clearly showed that the dynamic change in microstructure from freeze stage to desorption stage. It was concluded that dynamic micrographs could better reveal the drying characteristics change of materials during drying process. In this research, whole lychee fruits were used as materials, which not only tested microstructure change of pulp, but also determined the microstructure of pericarp.

The objectives of this work were to test the dynamic micrographs of lychee pericarp and pulp with or without temperature control during MVD, to clearly show the microstructure change and moisture removing characteristics of lychee by combination temperature profile of pulp and moisture content curves of lychee pericarp and pulp during whole MVD.

2 Materials and methods

2.1 Materials

Fresh lychee fruits (*Litchi chinensis* Sonn.) cv. Huaizhi at commercially mature stage was picked from Xili orchard, Shenzhen, China (East longitude: 113°56'01.16", North latitude: 22°36'15.26"). The weight of each lychee fruit was about 25 g. Lychees were washed and redundant water was wiped with absorbent paper, then put them in a dryer for microwave vacuum drying tests.

2.2 Equipment

The lab-scale dryer was developed by authors. An independent drying cavity was set up in a rectangle resonant cavity, which could effectively avoid the corona discharge at the vacuum condition. The MVD process was operated at 5 kPa (absolute pressure). Three magnetrons were equipped at different angle. The power of microwave could be adjusted continually. The core temperature of materials was detected by the optic fiber which could work well in microwave field. The surface temperature of materials was detected by infrared thermometer[9]. A schematic diagram of the vacuum microwave dryer is presented in Figure 1.

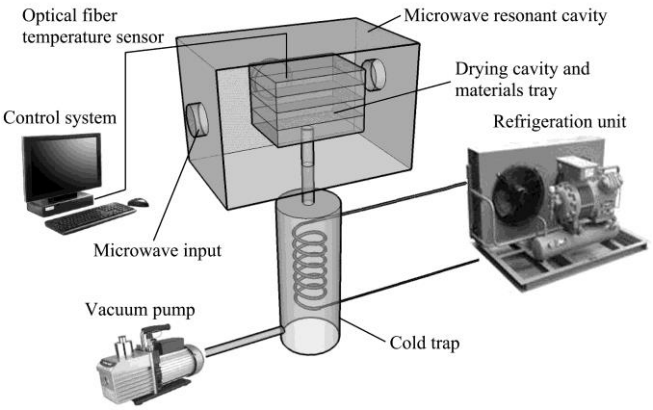


Figure 1 Schematic diagram of the microwave vacuum dryer

2.3 Drying experiment

Lychees were dried by MVD at 5 kPa (absolute pressure) until the final moisture content was less than 30% (wet basis). During MVD, pulp core temperature changes were recorded. According to the previous experiments, the optimal microwave power density and temperature were 0.6 W/g and 60-65℃, respectively. The microwave was turned on when the core temperature under low limitation, and which was turned off when core temperature exceeds upper limitation.

During MVD with microwave power density of 0.6 W/g with or without temperature control, and the effect of different drying time (0, 30, 60, 100, 140 and 200 min) was studied. The microstructure analysis of pulp and pericarp was conducted after cooling.

2.4 Moisture content

Moisture content was determined by the oven method[25]. At regular time intervals during the drying processes, samples were taken out and dried in the oven for 2-3 h at 105℃ until a constant weight (±0.02 g) was achieved. Weighing was performed using a digital balance, and then moisture content (wet basis or dry basis) was calculated. All the tests were performed in triplicate.

2.5 Sugar content

Sugar determination was carried out using high

performance liquid chromatography (HPLC, HP1200, Agilent) according to the method suggested by Huang et al.[26] About 2-5 g of sample was frozen by liquid nitrogen and milled and then transferred to 100 mL flask, added distilled water until reached to 100 mL. After mixing, the solution was filtered through a 0.45 μm filter for sugar content analysis. HPLC analysis was carried out using SugarPAK1 chromatographic column (6.5 mmid×300 mm) and refractive index (RI) detector. Water was used for elution with a flow rate of 0.4 mL/min and sample injection volume was 10 μL. The total run time was 20 min. The sum of glucose, fructose, and sucrose was considered as a measure of total sugars (TS).

2.6 Microstructure

Structural changes of lychees during VMD were studied by light microscopy (LM) with the paraffin section method[24]. The paraffin section experiment was described in detail as follows. Small cubes (pulp: about 4 mm^3, pericarp: about 2 mm^2) were removed from the internal zone of samples for microscopic examination. The sample cubes were fixed in formol-aceto-alcohol (FAA, formaldehyde 5%, glacial acetic acid 5% and 70% ethanol 90%) fixative solution for 24 hours. The ratio of fixative solution to samples was about 30:1. Dehydration was performed with 70%, 85% and 95% ethanol for 2 h respectively and with 100% ethanol for 50 min. Then samples were cleared in mixed solution (ethanol:xylene = 1:1) and pure xylene solution for 2 h respectively. Samples with xylene solution were put in china cups and melt paraffin was added in the cups (1:1). The cups were put in incubator at 40℃ for 24 h. After that, the cups were put in incubator at 60℃ and paraffin was dumped after melting at this temperature. And then new melting paraffin was added again in cups for 1 h and then dumped, which was operated triplicate. Last, samples were embedded in melting paraffin (melting point 55 to 57℃) using paraffin embedding box.

Paraffin section obtained obvious was done with a rotary microtome (RM 2126, Shanghai Leica Instruments Ltd., China) at 10 μm thickness. The sections were stuck on microslides with gelatin adhesive by tweezers. After deparaffinage with xylene for 10 min, the sections were rehydrated with a series of decreasing ethanol concentrations (100%, 95%, 85% and 70%) for 10 min respectively, the Heidenhain's iron-alum hematoxyling method was employed for staining. Finally, the samples were examined under a light microscope (Eclipse 50i, Shanghai Nikon Instruments Inc, China) equipped with a digital camera (DS-Fi1, Shanghai Nikon Instruments Inc, China). The histological procedures were performed in duplicate.

2.7 Data analysis

The experimental data were analyzed using the statistical software SPSS 18 and analyses of variance were conducted by ANOVA procedure. All the measurements were carried out in triplicates. Mean values were considered significantly different when $p \leq 0.05$.

3 Results and discussion

3.1 Moisture content of Lychee pericarp and pulp

Drying curves of lychee pericarp and whole lychee during MVD are shown in Figure 2. The effect of MVD on moisture content of lychee pulp within primary 60 min is shown in Figure 3. Drying curves shown in Figure 2 indicate that moisture content of lychee pericarp decreased constantly within primary 50 min and then remained 21%-22% moisture content for a while and decreased again. From Figure 3, it can be seen that there were no significant differences ($p>0.05$) in moisture content among the samples dried with 0, 10, 20, 30 and 40 min, which means no significant water evaporation at this stage. The total removing moisture of whole lychee at first 40 min only came from pericarp. Pericarp and pulp both lost moisture between 40-50 min. Compared the moisture curves of whole lychee to pericarp in Figure 2, moisture content of pericarp was similarly constant at 50-140 min, due to the moisture content of lychee pulp decreased constantly. Then, the removing moisture of whole lychees came from pericarp to pulp after 140 min. Temperature curve in Figure 2 shows that the temperature of lychee pulp reached a peak at 40 min, because no moisture of pulp removed at first 40 min during drying. Microwave energy absorbed by lychee pulp was used for temperature increasing of pulp. The temperature of pulp decreased constantly because the moisture evaporation in pulp consumed a part of energy at 40-80 min.

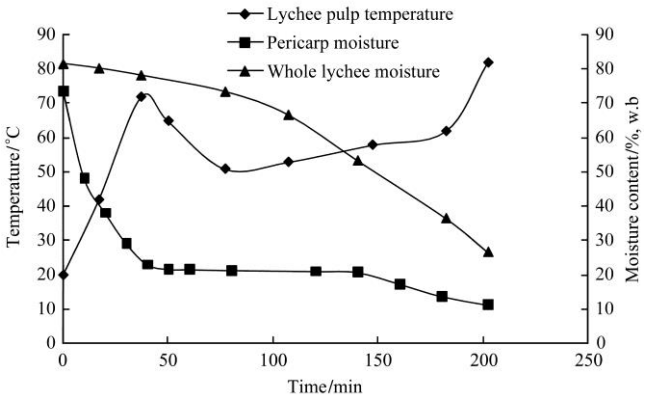


Figure 2 Lychee pericarp moisture content and lychee pulp temperature during whole drying process

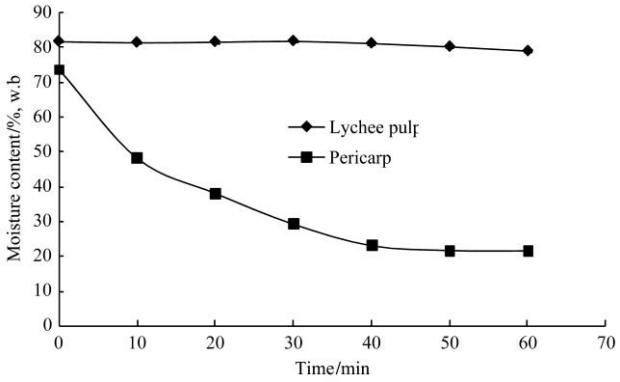


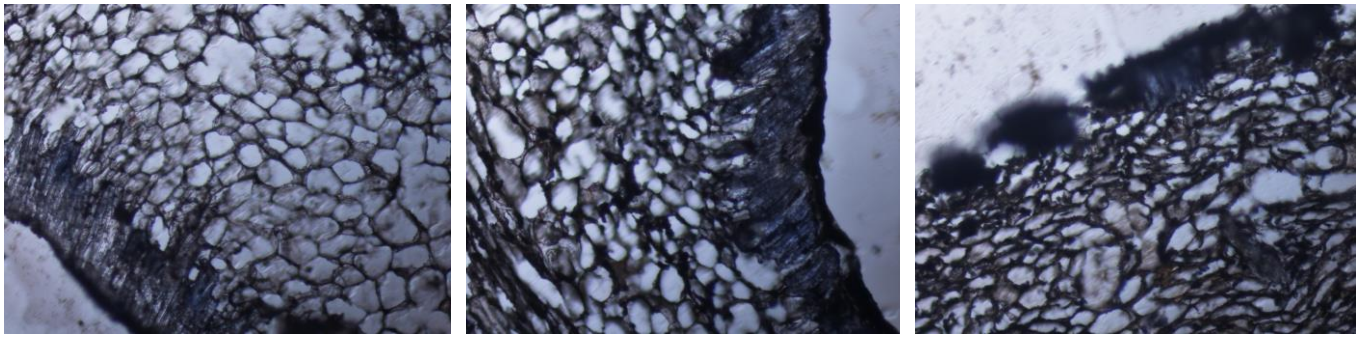
Figure 3 Moisture contents of lychee pulp and pericarp during primary 60 min drying

3.2 Change in microstructure of pericarp

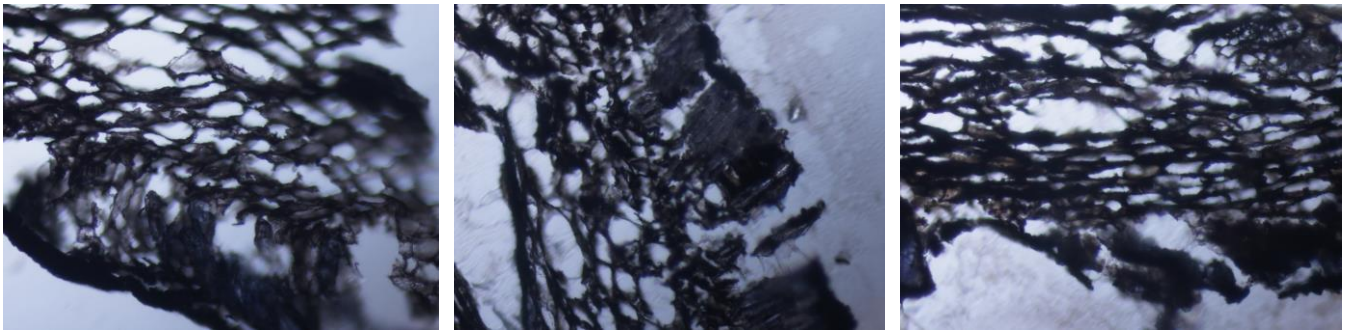
Figures 4 and 5 showed the results on cross-sectional microstructure change of lychee pericarp during MVD. It can be observed that the structure of lychee pericarp consisted of three parts: outer layer, inter layer and inner layer. The change in microstructure of outer layer and inter layer are shown in Figure 4 and inner layer is shown in Figure 5. Figure 4 showed that the cells of pericarp outer layer are intact with long irregular tubular in fresh samples, which covered by a thin layer (cuticle) for protection. Some breaking of cuticle layer appeared after drying 30 min, but the outer layer cells were still intact. As drying continues, more and more breaking of cuticle layer appeared and outer layer cells were wrinkled, folded and protruding into the empty spaces after drying 60 min. As discussed above (Figure 2), the moisture content of pericarp decreased constantly in first 50 min. It means that the lost moisture of pericarp was removed by long pore of outer layer cells and cuticle breaking in first 30 min. After that, wrinkled and folded outer layer cells resulted in pore deforming, which hindered the moisture removing of pericarp. However, more breaking of cuticle and more empty spaces in outer layer led to moisture removing easily.

Figure 4 also showed the microstructure change of inter layer during MVD. It can be observed that pericarp inter layer in fresh samples had polygon structure and the cells were intact with perfect contact. In first 40 min, the structure of inter layer changed a little, then more and more rupture of cellular walls and deformation of inter layer cells appeared between 40-140 min due to the constant microwave energy and moisture removing of pulp. After drying for 140 min, polygon structure of inter layer cells disappeared due to the deformation and broken cell walls protrude into empty spaces. At this stage, more moisture loss of pericarp causes more serious structure change of inter layer cell. In fact, simultaneous heating and moisture removal during drying often leads to severe structural change[16].

Microphotographs of inner layer cells during MVD were shown in Figure 5. It can be seen that the size of inner layer cells are significantly smaller than inter layer cells. Inner layer is characterized in fresh samples by irregular round and the cells are very intact. After drying for 30 min, broken cell wall was not seen in microphotograph (Figure 5b) while some broken were seen in microphotograph of inter layer cell walls (Figure 4b). Some broken of inner layer cell walls and cavities were seen until drying for 60 min, which explain why there was no significant difference in moisture content between fresh pulp and samples dried for 30 min. At early drying stage, intact inner layer cells prevented the moisture removing from lychee pulp. As drying continues, temperature of pulp increasing constantly broke the inner layer cell walls and empty spaces appeared. Then, the pericarp did not prevent the moisture removing of pulp any more. The external pore structure for moisture removing of pulp was formed and the moisture content decreased constantly after drying for 40 min. Cell walls damage occurred more and fragments of cell walls increased continually because of prolonged drying time (Figures 5d-f). Therefore, the profile of inner layer cells was lost gradually due to many stained fragments.

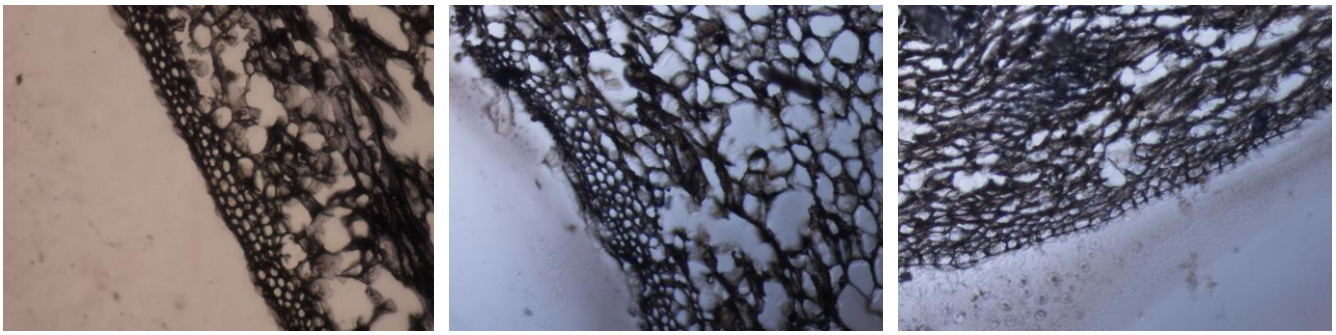


a. Fresh b. MVD, 30 min c. MVD, 60 min

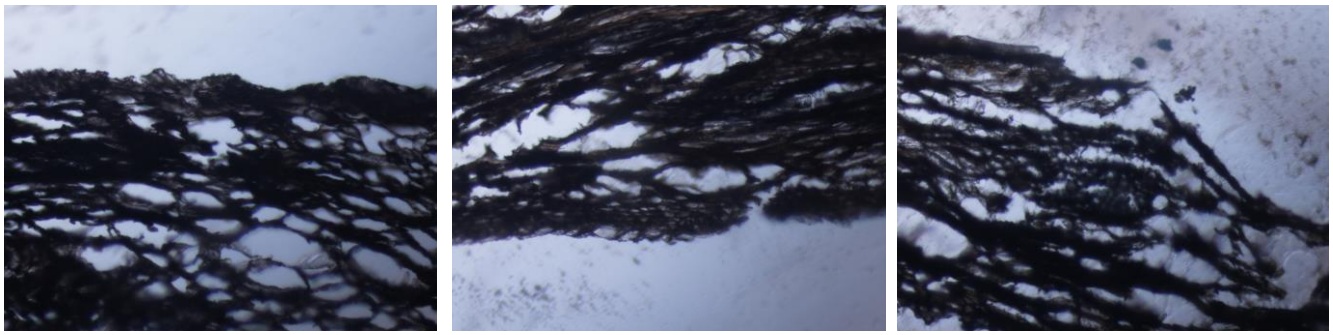


d. MVD, 90 min e. MVD, 140 min f. MVD, 200 min

Figure 4 The light micrographs for lychee pericarp outer layer and inter layer tissues in MVD process (200×)



a. Fresh b. MVD, 30 min c. MVD, 60 min



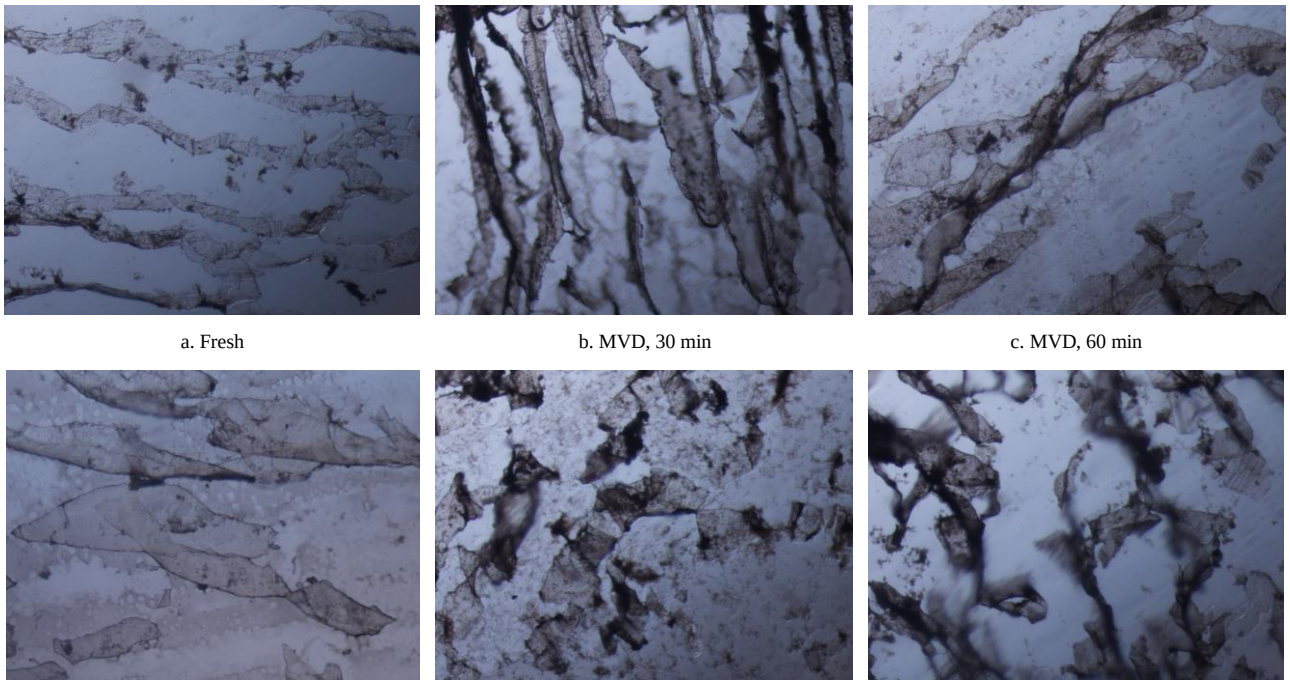
d. MVD, 90 min e. MVD, 140 min f. MVD, 200 min

Figure 5 The light micrographs for lychee pericarp inner layer tissues in MVD process (200×)

3.3 Change in microstructure of lychee pulp

Microphotographs of lychee pulp cells during MVD were shown in Figure 6. It can be observed that the pulp is characterized in fresh samples by long tubular cells and large intercellular spaces. At early drying stage, no water evaporated from pulp because of the prevention of pericarp inner layer, which resulted in the temperature of pulp increase to near 70℃. When comparing the structure of dried pulp (Figure 6b) with the tissue of raw lychee pulp (Figure 6a), a clear cell breakage was observed, indicating loss of turgor due to the high temperature of pulp[21]. More and more breaking of pulp cells appeared and the cells were wrinkled and folded because of prolonged drying time (Figures 6c and 6d).

Meanwhile, the primary long tubular cell structure was lost gradually. At later drying stage, more and more fragments from cell walls breaking scattered in intercellular spaces (Figures 6e and 6f), which damage the pore structure of pulp cells and result in slow moisture removing. In fact, the dehydrated lychee pulp underwent a significant volume reduction as a result of microstructural change[23].



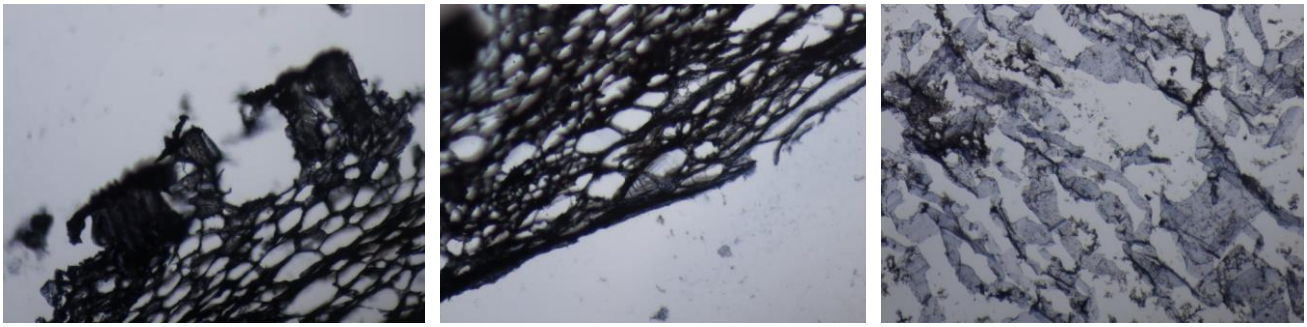
a. Fresh b. MVD, 30 min c. MVD, 60 min

d. MVD, 90 min e. MVD, 140 min f. MVD, 200 min

Figure 6 The light micrographs for lychee pulp tissues in MVD process (200×)

3.4 Comparison of microphotographs of lychee with or without temperature control

Figure 7 showed the microphotographs of pericarp and pulp in lychees dehydrated by MVD with temperature control. Compared outer layer microphotograph of pericarp dried with (Figure 7a) and without (Figure 3f) temperature control, long irregular tubular cells were both broken badly and large intercellular spaces appeared. Wrinkled and a little broken inter layer cells were observed in Figure 7a. The cell structure of inter layer was maintained better than that dried by MVD without temperature control. In addition, inner layer cells were both wrinkled and broken, which resulted that irregular round cell structure lost thoroughly and inner layer was also broken (Figures 7b and 4f). Although broken and folded pulp cell walls can be seen in Figure 7c, the primary long tubular cell structure of pulp was maintained better than that dried by MVD without temperature control (Figure 5f). In general, the microstructure of lychee can be improved due to temperature control during MVD, which explains that the quality of lychee dried with temperature control is better than that dried without temperature control.



a. Pericarp, outlayer and inter layer b. Pericarp, inner layer c. Pulp

Figure 7 The light micrographs for pericarp and pulp tissues of MVD terminal lychee with temperature control (200×)

4 Conclusions

The lychee pericarp consists of three parts: outer layer with cuticle, inter layer and inner layer. Long irregular tubular cells of outer layer and polygon cells of inter layer are broken easily, which result in more large intercellular spaces. Therefore, the moisture in lychee pericarp removes easily to surroundings. However, only small part inner layer cells were broken and the integrity of this layer was maintained well at first 40 min. The evaporation water from lychee all came from lychee pericarp at first 40 min during MVD. In fact, inner layer in pericarp prevented the moisture removing from pulp, which resulted in increasing temperature profile of pulp at first 40 min. Three layer cells in pericarp were all broken and more and more breaking appeared because of prolonged drying time.

At early drying stage, long tubular pulp cells and large intercellular spaces were in favor of moisture transfer. However, breaking, wrinkle and fold appeared as temperature increasing and drying time prolonging, especially at the later drying stage (after 140 min). Therefore, fragments scattered in intercellular spaces, which resulted in slow moisture removing. Moisture in pulp suffered bigger and bigger binding force, which also retarded the moisture transfer from pulp to surroundings at the later drying stage. In addition, temperature control can help to form the better cell pore structure for moisture removing in lychee pulp.

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