Research Article

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Characteristics and oil absorption in deep-fat fried batter prepared from ball-milled wheat flour

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Abstract

BACKGROUND: The porous structure generated during frying influences oil absorption and textural qualities. The alteration in physical properties of wheat flour is suspected to affect the structure formation. The present study investigated the effect of physicochemical changes in wheat flour by the ball-milling process on structure formation and consequently oil absorption of a fried wheat flour batter model.

RESULTS: Batter models containing 600 g kg^{-1} moisture were made of 0–10 h ball-milled wheat flour and then fried in frying oil at 150 °C for 1–7 min. The samples made of milled flour possess larger pores and exhibit lower oil absorption than sample made of 0 h milled flour. The fracture force of a fried sample prepared from 5 and 10 h milled flour is lower than that of a sample prepared from 0 h milled flour.

CONCLUSION: The decrease in glass transition temperature (T_g) and melting temperature (T_m) of milled flour affect the microstructure formation in the fried wheat flour batter. The microstructure is responsible for oil absorption and fracturability in fried food. The samples made of flour of longer ball-milling time have lower oil absorption and higher crispness. Ball-milling may be a tool to produce mechanically modified wheat flour which can reduce oil absorption for fried batter.

Keywords: ball-milled wheat flour; glass transition; deep-fat fried batter; crispiness; oil absorption

INTRODUCTION

Attempts to reduce oil absorption in fried food have been extensively investigated, because the high level of oil content, especially saturated fat, from fried food has been recognised as a health problem in such diseases as coronary heart disease, cancer, diabetes and hypertension.[1] Many studies have reported that there are many factors affecting oil absorption in the frying process, including oil quality, surface area, frying temperature, and porosity. Saguy *et al.*[2] proposed that microstructure formation during frying is one of the predominant factors of oil absorption. The morphology of developed porosity (e.g. pore distribution and pore size) due to water evaporation allows oil to penetrate into the voids. In addition, the microstructure also influences the textural quality in fried food. The glass transition of polymer foods, a temperature-, time- and composition-dependent, material specific change in physical states from a glassy mechanical solid to a rubbery viscous liquid, is believed to be a factor in the formation of cellular structure in extruded foods, baked products and fried foods.[3–5]

Currently, the ball-milling process is applied to modify starch mechanically. Published studies report that ball-milling starch at room temperature changes the semi-crystalline structure in starch granules to the amorphous state.[6–10] Few reports related to using milling flour have been published on food applications. Among the few reports, Schlesinger[11] reported that the chemical alteration of wheat flour by ball-milling has an effect on bread loaf volume. Donelson and Gaines[12] used the completely damaged starch that had been separated from ball-milled wheat flour and then mixed with the native wheat-flour in a sugar-snap cookie formulation. They found that a high amount of ball-milled starch reduced the diameter of the cookie. In addition, the T_g depression in ball-milled wheat flour influenced the microstructural formation of fried wheat flour dough.[13]

For fried batter products, biopolymers such as starch and proteins from various sources, including chemically modified starch and cellulose derivatives have been substituted in the batter formulations in order to improve the quality of fried food and reduce oil absorption.[14–19] However, no report has been published on the use of mechanically modified wheat flour to reduce oil absorption or improve the quality of fried batter. The alteration of physical properties of wheat flour by the ball-milling process is suspected to affect cellular structure formation in fried batter. Therefore, in this study, ball-milled wheat flour was used in a wheat flour–water mixture as the batter model to study the influence of alteration in physical properties of wheat

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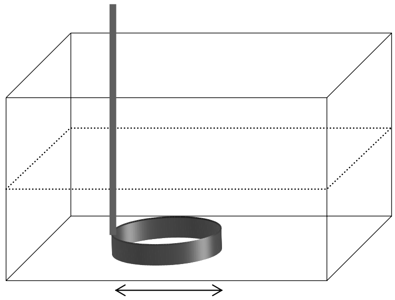

Figure 1. Teflon-coated circular mould used for the frying batter model.

flour on the characteristics of fried batter. First, the alteration in physicochemical properties of ball-milled wheat flour was studied. In addition, we investigated the effects of these alterations on the characteristic of the fried batter model, including oil absorption and textural properties.

MATERIALS AND METHODS

Wheat flour preparation and thermal properties

Ball-milling was carried out by using a rolling-type ball-mill (Irie Shokai V-I, Kanagawa, Japan) as reported by Thanatuksorn *et al.*[13] Twenty grams of wheat flour (75 g kg^{-1} gluten, 120 g kg^{-1} moisture content (Pioneer, Kanagawa, Japan) was placed in a stainless cylindrical container with a diameter of 9 cm and a height of 9 cm. Each sample was milled with 50 stainless balls of 1 cm diameter. The cylindrical mill was tumbled at room temperature for 0, 5 or 10 h at 90 rpm.

A differential scanning calorimeter (DSC) (Shimadzu DSC-50, Kyoto, Japan) was used to determine the melting temperature (T_m) and glass transition temperature (T_g) of wheat flour, as reported by Thanatuksorn *et al.*[5] The wheat flour was defatted by 750 g kg^{-1} *n*-propanol (Wako Chemical, Osaka, Japan), and moisture content was adjusted by exposure to saturated salts. Samples of higher moisture contents were prepared by mixing with distilled water. The 20 mg samples were weighed into an aluminium pan. Scanning temperature range was 0–200 °C with a heating rate of 5 °C min^{-1}. Average values of two replicate samples were taken as T_g and T_m. Moisture contents of samples were determined by difference in weight before and after the punctured DSC pans were dried after the second scanning. The T_g value was determined from the onset of an endothermic shift of baseline using TA-60 software (Shimadzu DSC-50, Japan) interfaced with the DSC.

Sample preparation and frying process

The wheat flour batter model samples were prepared from 0, 5, and 10 h ball-milled wheat flour at an initial moisture level of 600 g kg^{-1} (wet basis). This level was achieved by mixing the flour with distilled water at room temperature (25 °C) for 15 min. The samples were weighed at 4.50 ± 0.05 g into a 5 cm diameter Teflon-coated circular mould, as shown in Fig. 1. The samples were deep-fat fried in an oil bath (TM-4; As One, Osaka, Japan) containing 4.5 L of soybean oil (Nisshin, Tokyo, Japan), at 150 °C for 1, 3, 5 and 7 min. After frying, the samples were immediately dipped in a beaker containing 100 mL of petroleum ether for 2 s to remove the oil adhering to the surface.[20] The absorbed oil and residual moisture content were determined as described in detail in our previous work.[13] The residual moisture and the oil contents of samples were based on the dried sample weight. Two replicates were used for all experiments. The SPSS software program was used to perform the ANOVA and Duncan new multiple range tests[21] on the resulting data. In state diagrams, the residual moisture content of the fried sample was expressed on a wet basis.

Physical property assessments

Diameter

Diameter was measured by a digital calliper (Mitutoyo, no 500-111, Kanagawa, Japan). The accuracy of the device was ±0.02 mm. About 20 readings were made for five samples of each treatment.

The degree of diameter shrinkage was calculated according to the equation $[d_0 - d(t)/d_0] \times 100$, where d_0 is the original dimension of the sample (the diameter of the aluminium mould), and $d(t)$ is the dimension of the sample with frying time.

Scanning electron microscopy

Sample preparation was determined as described in detail in our previous work.[5] After frying, samples were immediately dipped in petroleum ether for 24 h for extraction of oil. The defatted samples were dried, mounted on stubs, and coated with platinum gold. The cross-sectional surface of the coated samples was observed using a scanning electron microscope (Hitachi S-4000, Tokyo, Japan) with an accelerating voltage of 15 kV.

Texture measurements

Fried samples were kept in the Ziploc bag after the temperature had reached room temperature. Texture assessment was performed as reported by Thanatuksorn *et al.*[5] A tensipresser (TTP-50BX; Taketomo, Tokyo, Japan) was used to evaluate the texture of fried samples. Puncture tests were performed (at 25 °C) by using a 3 mm diameter flat-ended cylindrical probe with a cross-head speed of 1 mm s^{-1}. The plunger was pressed through a sample to a depth of 1.5 cm, and this was repeated 15 times for each treatment.

RESULTS AND DISCUSSION

Thermal properties of ball-milled wheat flour

Figure 2 shows the state diagrams of wheat flour with various ball-milling times. This state diagram was constructed from thermal properties obtained by DSC assessment. The thermal properties of ball-milled wheat flour have been reported in our previous studies.[5,13] The two transitions were observed in the second scan of wheat flour thermogram. This suggests that the transition of lower temperature is the glass transition of the gluten-rich phase, and that the transition of the higher temperature is of the starch-rich phase.[22–26] The T_g of the starch-rich phase and that of the gluten-rich phase have a tendency to decrease with ball-milling time. These results coincide with the lowering of T_g in the starch and crude gluten separated from ball-milled wheat flour[10] and the decrease in T_g of ball-milled potato starch.[8] Similarly, T_m of ball-milled wheat flour tends to decrease with increasing ball-milling time. T_m of wheat flour increases with decreasing moisture content. At a moisture content of more than 650 g kg^{-1}, T_m was independent of the moisture level, known as gelatinisation.[5] Table 1 shows the gelatinisation enthalpy (ΔH) and gelatinisation temperature of wheat flour. Gelatinisation enthalpy is normally regarded as the quantitative parameter that corresponds to the crystallinity of starch. The change from the crystalline to the amorphous state in wheat starch can also be observed from ΔH.

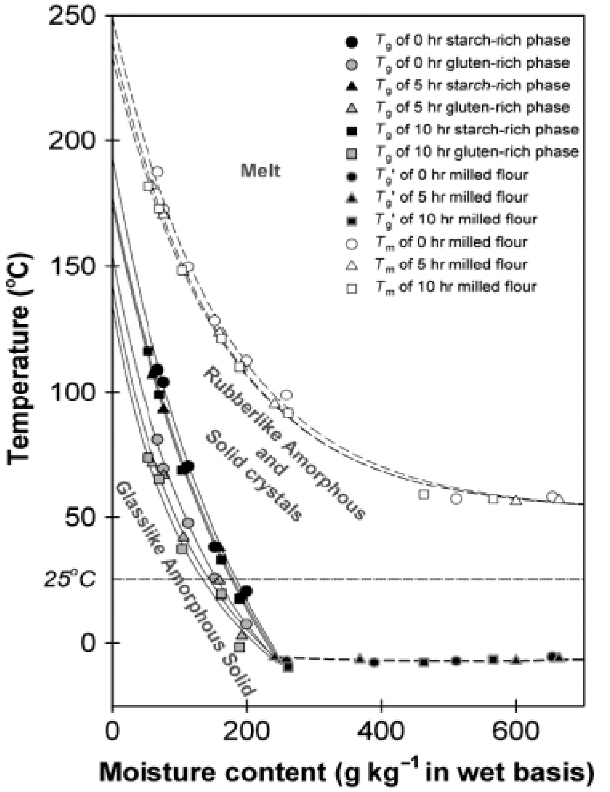

Figure 2. State diagram of wheat flour with the various ball-milling times.

Table 1. Temperature and enthalpy of gelatinisation of ball-milled wheat flour

Ball-milling time (h)	ΔH (J g^{-1})	T_0 (°C)	T_p (°C)	T_c (°C)
0	−9.08	58.11	64.07	78.24
5	−5.49	57.86	63.68	77.64
10	−4.97	57.00	63.58	75.13

T_0, T_p and T_c are onset, peak and conclusion temperature, respectively.

The ΔH values of wheat flour were obtained from the wheat flour mixed with excess water. The gelatinisation enthalpy and the onset of gelatinisation temperature (T_0) decreased with increasing ball-milling time. This suggests a decrease in the crystallinity of starch granules in wheat flour.[10,27]

Diameter

The diameters of all fried samples are shown in Fig. 3. The sample prepared from 5 and 10 h milled flour decreased in size from the original diameter (the size of Teflon-coated aluminium mould) in the first minute of frying, whereas that of the sample prepared from 0 h milled flour initially increased and then gradually decreased to smaller than the initial size. The fried samples prepared from 0, 5 and 10 h ball-milled wheat flour at 7 min of frying show degree of diameter shrinkages of 0.97, 3.67 and 5.46%, respectively. Donelson and Gaines[12] reported that cookie diameter decreases with addition of ball-milled or pre-gelatinised starch. The decrease in diameter of fried dough made of ball-milled wheat flour was also observed.[13] The high temperature of frying resulted in the formation of an outer dry layer that fixes the volume. The stiff glassy

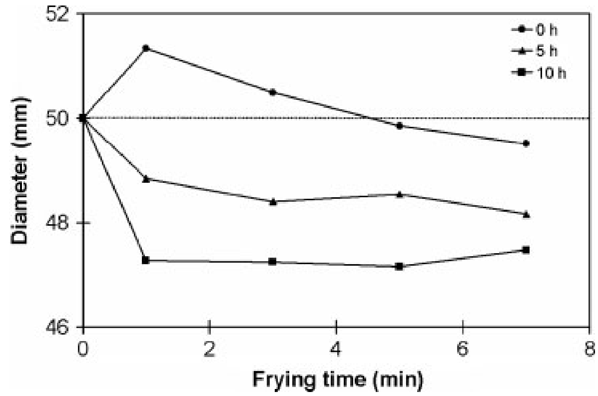

Figure 3. Diameter of fried sample prepared from 0, 5 and 10 h ball-milled wheat flour.

surface has the ability to resist further macroscopic contraction.[28] The T_g depression in ball-milled wheat flour caused the slowing of 'case hardening' during frying, leading to the high level of shrinkage in the fried sample.

Microstructures of fried samples

The microstructures of fried samples prepared from milled flour were observed by SEM as shown in Fig. 4. The porous structures of all samples at the final frying time varied in size. Both closed and connected pores were observed. For a given frying time, the fried sample made of 10 h ball-milled flour was remarkably larger in pore size than the samples prepared from 0 and 5 h ball-milled flour.

Starch and gluten are the major components of wheat flour, and govern important physical properties of products. For the initial moisture content in this sample, gluten does not develop substantially, and starch is the likely continuous phase.[29] Starch is considered to play an important role in the microstructure formation in wheat flour batter. At this level of initial moisture content, starch gelatinisation can take place when the wheat flour batter was heated.[5] The porous structure is generated by vapour evaporation out of the starch gel, which can trap the evaporated water temporarily, resulting in continuous development in both size and quantity of the cellular structure. The decrease in gelatinisation temperature and ΔH (Table 1) with the longer ball-milling time leads to lower heat energy required to destroy the crystallinity in starch and facilitates gelatinisation in the sample prepared from ball-milled wheat flour. The decrease in gelatinisation temperature and ΔH leads to earlier formation of the gel with subsequent resistance against water evaporation. Once the system exists above T_g, the pores still extend due to the free mobility of the polymer chain. With prolonged frying time, the moisture within the sample decreased, and the sample consequently went through the glassy state, thereby ending the expansion of pores inside the sample. The T_g depression in milled flour provides a longer time for the chain segment mobility, and the expansion of porous structure still took place at the lower moisture content. Therefore, these factors probably resulted in the larger porous structure in the sample prepared from the wheat flour of longer ball-milling time.

Oil absorption and residual moisture content

Previous studies[30] found that oil absorption occurs in both the frying and post-frying process. The porosity within the sample

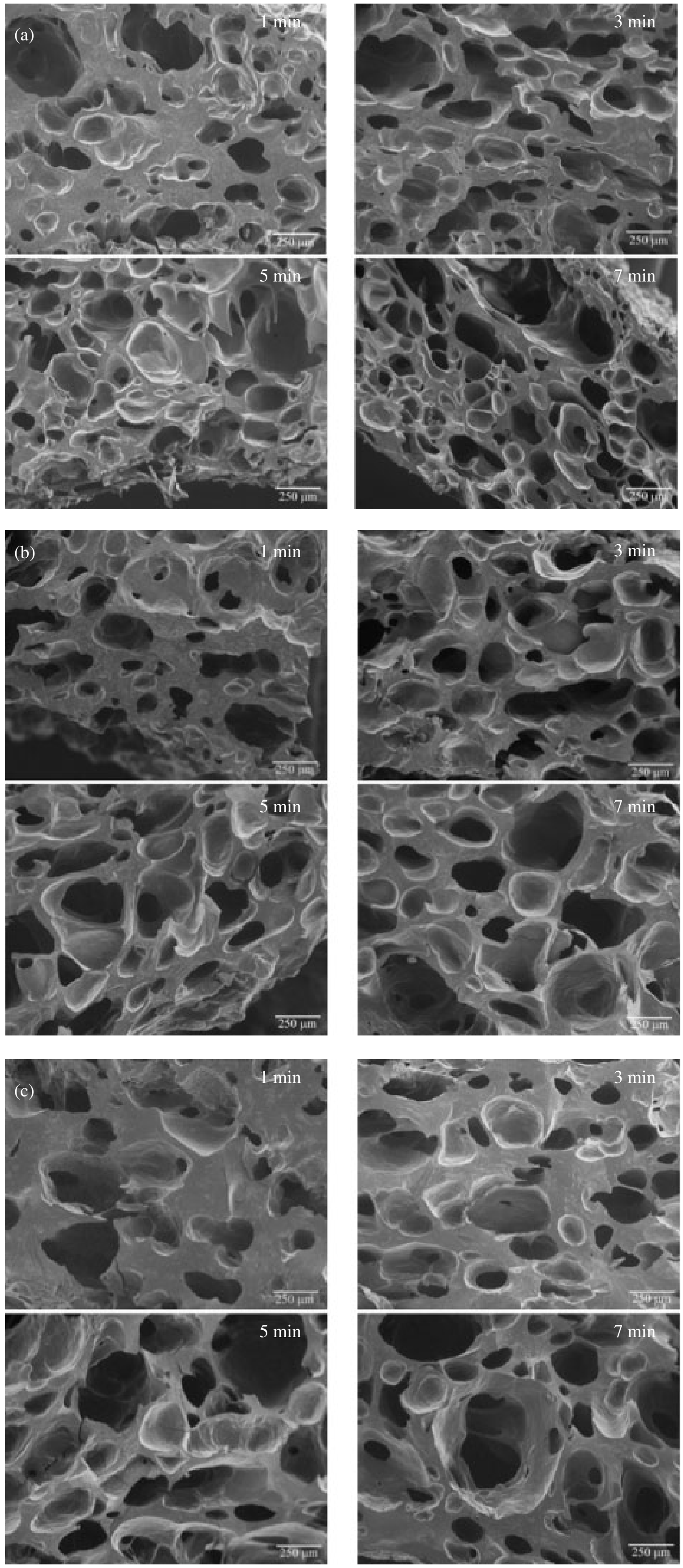

Figure 4. SEM photos of samples prepared from (a) 0, (b) 5 and (c) 10 h ball-milled wheat flour fried for 1–7 min (×60).

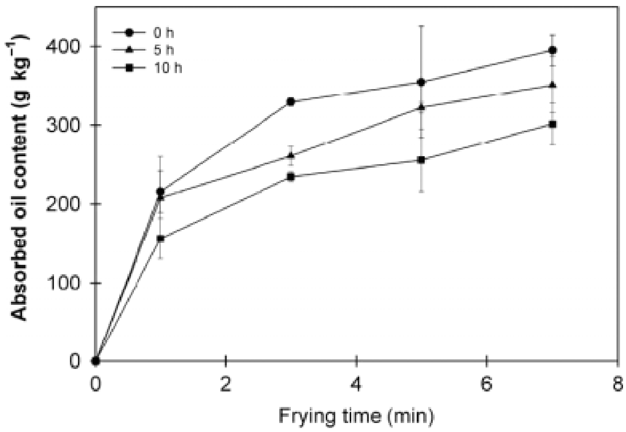

Figure 5. Absorbed oil content of a fried sample containing 0, 5 and 10 h ball-milled wheat flour.

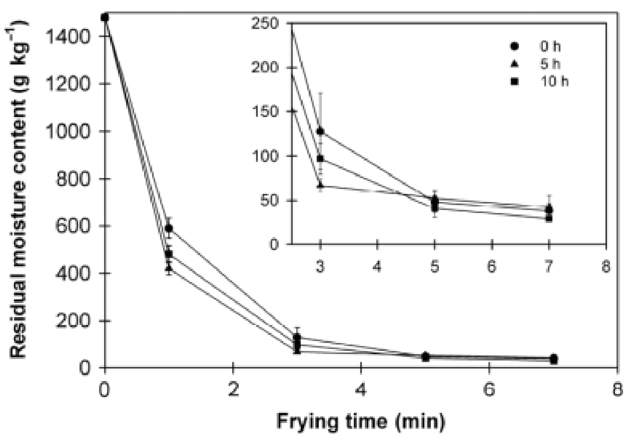

Figure 6. Residual moisture content of a fried sample containing 0, 5 and 10 h ball-milled wheat flour.

mainly governed oil absorption during the frying process.[31] Therefore, only the absorbed oil content in the frying process is assessed in the present study. The absorbed oil and moisture content of the fried sample is shown in Figs 5 and 6, respectively. Throughout the process, the fried sample made of 10 h milled flour absorbed less oil than did the other samples. For the moisture content, the sample prepared from 0 h milled flour loss less moisture than the sample prepared from milled flour in the first 3 min of frying. The moisture content of a sample prepared from 10 h milled flour is the lowest at the end of frying.

The structure formation during the frying process influences oil absorption and moisture loss. Oil absorption is controlled by capillary pressure, which is used regularly for explaining the infiltration of liquid into the cellular structure.[32–34] The pore sizes and distribution govern the amount of oil absorption. The wider pores result in weaker capillary pressures and, subsequently, lower oil absorption.[35] The larger pores and the decreased surface area due to shrinkage occurred in the sample made of milled flour brought about the decrease in oil absorption. For the residual moisture content, moisture loss during frying is considered as diffusion controlled, which in turn is related to the microstructure within the sample. The development of channels during heating increases the effective moisture diffusivity, facilitating the transport of water vapour from the interior of the sample to the surface.[36] This implies that the effective diffusivity increases with increasing pore size.[37] The larger pores in the sample made of 10 h milled flour resulted in a lower moisture content in the end of process. In addition, the starch gelatinisation of a sample prepared from 10 h milled flour that took place previously probably retards the moisture loss and also inhibits oil penetration into this sample during the initial period of process.

Texture analysis

The fracture force and hardness are the parameters which often evaluates the texture in snack foods. The fracturability is defined as the force at the first significant break in the first peak in one bite area, whereas the height of the highest peak is the hardness.[38] The lower force to fracture the sample corresponds to the higher fracturability. The texture profiles, the fracture force and the maximum force of fried samples are shown in Figs 7, 8 and 9, respectively. For all samples at 1 min of frying, no fracture peak was observed. For the sample prepared from 0 h milled flour, it was seen that few fracture peaks and a higher maximum peak force was observed at 3 min. A jagged line in the texture profile was observed for the samples fried for 5 or 7 min. That is, the fracture behaviour appeared at 5 min of frying. The texture profiles obtained from the sample made of 5 and 10 h milled flour showed that a number of fracture peaks started to appear for the 3 min fried sample. In addition, a higher number of fracture peaks and lower fracture forces were observed in the sample prepared from 10 h milled flour fried for 7 min (Figs 7 and 8). However, it was seen that a maximum force was higher for this sample (Figs 7 and 9). This suggested that the 7 min fried sample made of 10 h milled flour was higher in crispness and hardness than the other samples.

Crispness is a desirable characteristic to be controlled for low-moisture foods.[39] This textural quality is considered to correspond to glass transition.[40] In order to observe the relationship between textural properties and glassy state, the moisture content of all fried samples from 1 to 7 min frying time was replotted against room temperature as shown in Fig. 10. The moisture content of all samples fried for 3–7 min existed in the glassy state. We observed that the sample prepared from ball-milled flour has a tendency to have greater crispness, especially samples fried for 5 and 7 min (Figs 7 and 8). The faster move into the glassy state suggests a more rigid macrostructure. However, the moisture content in the 7 min fried sample prepared from 0 and 5 h milled flour, and the 5 min fried sample prepared from 10 h milled flour are similar, but differed in the fracture force. That is, moisture content is not the only factor that affects crispness. The results obtained suggested that not only the lower moisture content, but also the larger pore size in its structure could be considered to result in more crispness. The larger pores within these samples meant that the samples could not resist the force as long, and therefore they required the less energy for fracture. Moreira *et al.*[41] reported that the increased crispness approached brittleness at high levels of damaged starch. With regard to the hardness of fried sample (Fig. 9), the force required to break the 7 min fried sample made of 10 h milled flour was the highest, even though its moisture content was the lowest. Castro *et al.*[42] reported that the glass transition temperature itself is not a good predictor of mechanical properties in the amorphous starch system. The force at the maximum depended on the material composition and the structure.[43] Salvador *et al.*[44] reported an increase in the values of maximum peak force for the fried batter with the addition of dextrin. The increase in low molecular weight amylopectin content

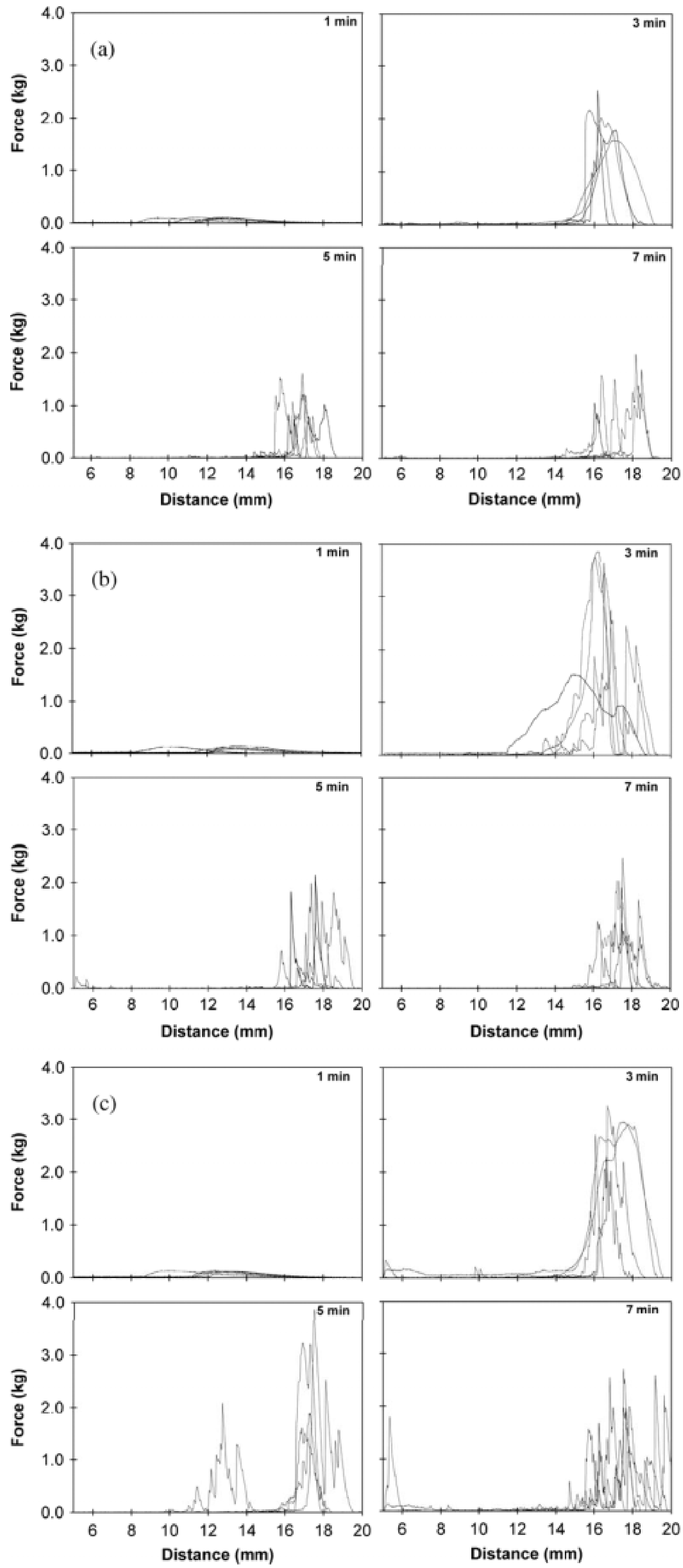

Figure 7. The texture profile of a fried sample prepared from (a) 0, (b) 5, and (c) 10 h ball milled wheat flour.

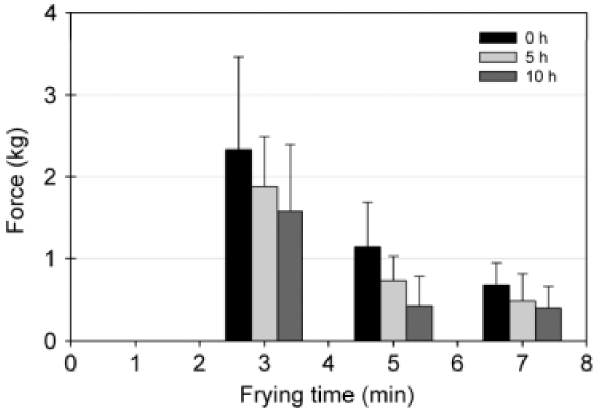

Figure 8. The fracture force of a fried sample containing 0, 5 and 10 h ball milled wheat flour as a function of frying time.

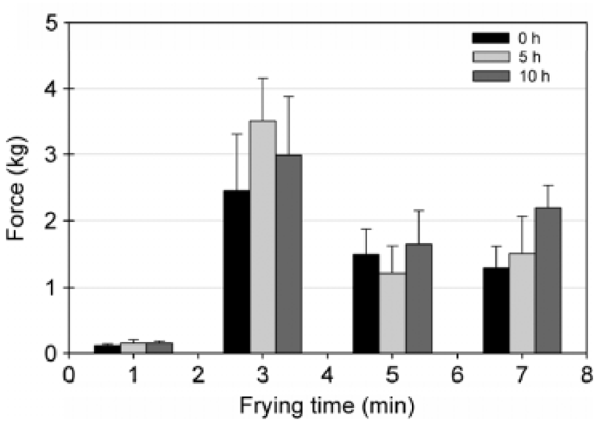

Figure 9. The hardness of a fried sample containing 0, 5 and 10 h ball milled wheat flour as a function of frying time.

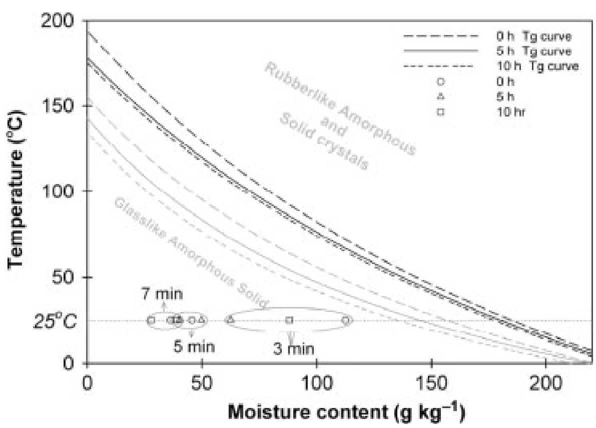

Figure 10. Pathway of a fried sample prepared from 0, 5 and 10 h ball-milled wheat flour of the texture assessment.

in ball-milled starch[8] possibly brought about the rearrangement of polymer chains, consequently resulting in the increase in hardness.

CONCLUSION

Characteristics of fried batter made of mechanically modified wheat flour were investigated. Starch gelatinisation is an important factor for enhancing the microstructure formation in fried batter. The ball-milling process manifesting the depression of T_m and T_g plays an important role in the microstructure formation of a fried wheat flour batter model. The generated microstructure plays key roles that affect moisture loss, oil absorption, and textural properties. Use of ball-milled wheat flour could provide greater crispness by using a shorter frying time, and subsequently reducing the absorbed oil during the frying process. In addition, only T_g depression can not explain the greater crispness and hardness in the sample prepared from milled flour. Chemical composition and microstructure also affect these characteristics.

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