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ORIGINAL ARTICLE

Effect of fat types on the structural and textural properties of dough and semi-sweet biscuit

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Abstract Fat is an important ingredient in baking products and it plays many roles in providing desirable textural properties of baking products, particularly biscuit. In this study, the effect of fat types on dough rheological properties and quality of semi-sweet biscuit (rich tea type) were investigated using various techniques. Texture profile and extensibility analysis were used to study the dough rheology, while three-point bend test and scanning electron microscopy were used to analyse the textural characteristics of final product. TPA results showed that the type of fat significantly influenced dough textural properties. Biscuit produced with higher solid fat oil showed higher breaking force but this was not significantly different when evaluated by sensory panel. Scanning electron microscopy showed that biscuit produced with palm mid-fraction had an open internal microstructure and heterogeneous air cells as compared to other samples.

Keywords Semi-sweet biscuit · Texture profile analysis · Dough rheology · Palm oil fractions

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Introduction

One of the important features of a biscuit is its texture. The texture depends on the formulation and the used cooking regimes (Maache-Rezzoug et al. 1998; Kulthe et al. 2011). But, the key factor is the component that forms the main component in the matrix that links the different elements together. Starch is the major structural element in many foods. However, it is often considered as “inert filler” in biscuits, with the fat or sugar playing the structuring role. Fat plays a unique role in many food products. In the area of baked goods, biscuits belong to a group of products that contain considerable amount of fat and the overall quality is largely determined by the type of used fat. Flour, sugar, and fat are the main ingredients used in biscuit production.

Fats perform a shortening function in dough. The term shortening refers to the ability of fats to lubricate, weaken, or shorten the structure of food components to provide a food product with desirable textural properties. Fats act as a lubricant during mixing; they also prevent the formation of a gluten network in dough (Wade 1988). The water or sugar solution, in the absence of shortening, would interact with the flour protein to create cohesive and extensible gluten, but when shortening is present, the fats surround the proteins and the starch granules, isolating them from the water, thereby breaking the continuity of protein and starch structure (Ghotra et al. 2002). Fat is a principle ingredient responsible for tenderness of biscuits and it keeps the quality, grain and texture besides adding the rich quality of the biscuits (O’Brien et al. 2003). Fat interacts with other ingredients to develop and mould texture, mouthfeel, and overall sensation of lubricity of the product (Giese 1996; Stauffer 1998). Mechanical properties of biscuits are largely dependent on the fat component of the formulation (Baltsavias et al. 1999).

The fat type and the level of fat added to the dough have a strong effect on the final quality of biscuits. Manohar and Rao (1999) investigated the effect of fat type and level of fat on biscuit dough and quality of biscuits. They found that the thickness of biscuits was significantly higher when hydrogenated fat or oil was used, while biscuit produced with bakery shortening had better surface characteristics and higher crispness. Jacob and Leelavathi (2007) studied the effect of fat types on cookie dough and cookie quality. They found that cookies containing liquid oil had a relatively harder texture compared to bakery and hydrogenated fat. The ratio of the solid phase to the liquid phase, or the ratio of solid fat to the total fat (solid fat index (SFI)) is an important factor when considering the functionality of the fat/shortening in the dough. SFI determines the functional performance and textural quality of fats and fat-containing products. Normally, bakery fats (margarine and butter) contain about 80 % fat whereas shortening contains 100 % fat. Palm oil and palm oil fractions were used as the main fat source in this study. Palm oil has become one of the leading vegetable oils for edible applications because it has a balanced fatty acid composition in which the level of saturated fatty acids is almost equal to that of the unsaturated fatty acids. Palm oil, due to its natural balance of fatty acid content, can be used to establish the links between lipid type and textural properties of foods.

In this study, the role of fat in determining the structural and textural properties of semi-sweet biscuits is reported. Four types of fat, namely palm oil, palm olein, palm mid-fraction, and butter, which vary in composition and solid fat content, were used to produce semi-sweet rich tea type biscuits. The reason for choosing these palm oil fractions was to provide a reasonable alternative for the mainly hydrogenated shortening, in which the crystalline, solid form exists naturally. Another reason is to provide a cheap, natural solid alternative to the shortening that is commonly used in bakery products because of its plasticity and solid/liquid ratio. Butter fat was used as a comparison. The role of fat and type of fat were analysed in terms of the texture, appearance, and starch behaviour of the final baked biscuits. Rheological properties of the dough were also compared.

Materials and methods

Materials

Soft wheat flour for biscuit making was obtained from Smiths Flour Mills (UK) while palm oil and its fractions were provided by Loders Croklaan (the Netherlands). Butter was procured from local supermarket.

Creation of model biscuit

A model biscuit was created to investigate the effect of different types of oils on the biscuit texture. A total of four types of oils were used, namely butterfat, palm oil, palm olein, and palm mid-fraction. Butterfat was used as control.

Laboratory biscuit production

The formulation for the rich tea biscuit was based on the recipe of Manley (2000) with some modifications. The recipe for the biscuits produced was as follows: 57.6 % wheat flour (9 % protein content), 14.4 % sugar, 13.4 % distilled water, 11.5 % fat/oil, glucose syrup 2.3 %, 0.3 % salt, 0.15 % sodium bicarbonate, 0.2 % ammonium bicarbonate and 0.02 % sodium metabisulphite. The processing of the biscuits was according to the method of Cronin and Preis (2000) differing in the choice of leavening agent and amount of water added. The dough was prepared using a Kenwood mixer (Model KM200). The production process consisted of dough mixing, dough sheeting, dough kneading, dough relaxation, cutting and moulding, and biscuit baking. All the dry ingredients were mixed with flour and sifted twice to break up any clumps and to add air to the flour in order to produce lighter biscuit. Sugar and glucose syrup were then added to the flour. The fat was added at 50 °C, and the water at 45 °C. At the beginning, all the ingredients were mixed at slow speed (MIN) for 30 s. The dough was then mixed for another 3 min at slow speed (MIN), followed by 4 min at high speed (NO 4) and 1 min again at slow speed (MIN). The dough was then removed from the bowl and kneaded by hand for 3 min. Kneading gives the dough elasticity as protein molecules create stronger bonds and gluten is formed. After 30 min relaxation (to release stress produced by handling and to reduce significant differences in quality when the dough was used), the dough were then sheeted using a Roller Sheeter (Rollfix, West Germany). The initial roller gap-width of 25 mm was progressively reduced to 2.5 mm (the dough passed the sheeter gauge rolls four times at each gap width (25, 20, 15, 10, 5, and 2.5 mm). The sheet was allowed to relax for another 15 min. The dough pieces were cut out with a cutting ring of 6 cm diameter and baked for 8 min in an oven (Thomas Collins & Co, Bristol Ltd) at 190 °C with air circulation. The biscuits were left to cool for 30 min and placed in plastic containers for further analysis.

Evaluation of biscuit dough

Texture profile analysis (TPA)

Stickiness is a common problem in the baking industry and it causes a major problem during processing. Two-bite TPA was performed to measure the stickiness properties of biscuit dough using a SMS Texture analyser. TPA analysis was carried out according to Gallagher et al. (2005) with some modifications. Dough characteristics were evaluated using texture profile analysis with a texture analyser (Stable Micro Systems, Surrey, UK, 25 kg load cell). Cylinder dough disks of 50 mm diameter and 5 mm thick were prepared with a circular shape-cutter. A 25 mm diameter cylinder aluminium probe was used to compress the dough twice. The test speed was 1.0 mm/s, the compression distance was 2.5 mm, and the recovery period between the two strokes was 5 s. Values for hardness, springiness, and cohesiveness were calculated from the recorded force values (Texture Expert version 1.17). Dough firmness is defined as the force (Newton) exerted during the first compression cycle. Dough adhesiveness is calculated as the negative force area obtained from the first compression cycle, representing the work necessary to pull the compressing plunger away from the sample. Dough cohesiveness is calculated as the ratio of the positive force area during the second compression with that during the first compression (Bourne 1990; Yamul and Lupano 2003). The measurements were taken three times and the results were the mean values.

Kieffer gluten extensibility test

Texture is one of the most important attributes that strongly influences dough machinability and the quality of the final product. The water added to make dough may result in the formation of gluten from the flour protein particles. Gluten develops slowly in the biscuit dough system because of the low ratio of liquid to flour. The protein-protein interactions help to explain the basis for the dough development and gas retention. Extensibility tests were conducted on dough to evaluate their tensile strength and extensibility characteristics to study the effect of the oils on the gluten development in the biscuit dough.

Large deformation extensibility measurements were performed using the SMS/Kieffer dough and gluten extensibility rig with a TA-XT2 Plus (Stable Micro Systems, U.K.) texture analyser equipped with 25 kg load cell. A piece of test dough was made into a roll and rested for 10 min. Then, it was put on the lubricated (paraffin oil) lower plate of the Teflon mould and compressed with the lubricated top with a clamps (Kieffer et al. 1998). The dough was covered and rested at room temperature for 30 min before measurement. The sample was deformed to 50 mm at a speed of 0.5 mm/s. For each sample, at least 10 replicate measurements were performed.

Evaluation of biscuit

Density

The density was determined according to method used by Hasmadi et al. (2010) using solid replacement technique. A container of known weight and volume was filled with rapeseed and excess rapeseeds were trimmed off slowly. The bottom of the container was covered with rapeseed and biscuit of measured weight was placed in the container with the flattest surface downwards. The container was filled with rapeseed and the total weight was measured. For every biscuit, the mean of five determinations was taken as the density

Hardness

The hardness of the biscuits was measured using the three-point bend test performed on the TA-XT2 Texture Analyzer, equipped with the three-point bending rig (HDP/3PB). The span between the supports was 40 mm. The Texture Analyzer settings were: Pre-test speed at 1.0 mm/s, Test speed at 3.0 mm/s, Post-test speed at 10.0 mm/s, Distance at 10 mm, and data acquisition rate at 500pps. The load cell used was 5 kg. The maximum force and the distance to break off the sample were recorded and are referred to as the hardness of the biscuit. An average value of 10 replicates was reported.

Internal structure of biscuit by scanning electron microscopy

Scanning electron microscopy (SEM) was used to investigate the microstructure of baked biscuits. The samples were mounted on individual metallic stubs and sputtered with a Balzers SCD 030 conductive coating of gold (Balzers Union LTD. Liechtenstein). Samples were imaged using a JEOL 6060LV variable pressure SEM instrument (Jeol (UK) Ltd). Electron micrographs were produced for cross-section of each biscuit type at several different magnifications.

Sensory evaluation of laboratory biscuits

Ranking test is standard procedure to assess product preference. In this test, panellists are asked to rank coded samples for acceptance in order from the least acceptable to the most acceptable. A consumer panel (untrained panel) consisting of 31 judges was selected to evaluate biscuit hardness. Biscuit samples were presented with different code numbers to the panellists and they were asked to rank all the biscuits according to their hardness. 1 is the least hard and 4 is the hardest. The samples were bitten evenly with the molars and with the mouth open. Samples used in the sensory evaluation had the same thickness as those used in the instrumental testing. Friedman test was used to analyse the results obtained.

Statistical analysis

Mean and standard deviation (SD) were calculated for each measurement where applicable. All the tests were carried out for 10 samples unless stated otherwise. Significant difference and Pearson correlations were calculated using SPSS Windows 6.0.

Results and discussion

Texture analysis of biscuits dough

The rheological characteristics of dough are critical as they affect the handling and processing of the dough as well as the quality of the final products produced. Dough that is too firm or too soft will not process satisfactorily on the appropriate dough forming equipment and will not yield a satisfactory product (Wade 1988). Fat is the ingredient that is principally responsible for binding ingredients in the dough. The first step in the analysis was therefore to see the effect of fat in the mixing stage. Dough without any fat formed dry clumps, which would not stick to each other and was impossible to knead. Wade (1988) reported that the addition of fat to dough has the effect of reducing the level of water required to make dough of workable consistency. Similar finding was also reported by Abboud et al. (1985). Handling properties of the dough especially during the kneading and sheeting procedure showed visible differences. Subjective observation for the work currently being repeated showed that during dough preparation, the dough made with butter, palm oil, and palm olein was soft and easy to sheet, whereas dough made with palm mid-fraction (PMF) was stiff and difficult to sheet and mould. The dough was also assessed using texture profile analysis (TPA) and Kieffer analysis to measure the effect of oils on dough properties.

Texture profile analysis (TPA)

In TPA testing, a bite size piece of food (usually 1 cm cube) was compressed two times between two plates, usually to 80 % of its original size. Because this test was intended to reflect human perception towards the texture, the first and second compressions were referred to as first and second bites (Yener 2008). The TPA results of dough made of four different types of fats are shown in Table 1 where the hardness, adhesiveness, cohesiveness, and springiness values are summarised. The results obtained showed that different types of oil significantly changed the textural properties of dough. It is clear from the table (Table 1) that dough made of fat containing higher solid contents showed an increase in its hardness. Dough made of palm mid-fraction (PMF) was the hardest and required more strength to compress it to the required extent. Biscuit dough containing palm olein was the softest and required the least force to compress it. The results are in agreement with Manohar and Rao (1999). They studied the effect of level and types of fat on the rheological characteristics of biscuit dough and quality of biscuits. They found that hydrogenated fat produced the stiffest dough compared to bakery shortening and oil, which is supported by the finding of this study. O'Brien et al. (2003) also reported the same finding, concluding that the amount of solid in the fat influences the dough properties. Fats having higher solid component produce stiffer dough. Baltsavias et al. (1997) explained that during mixing, the firm fat will be broken down to large lumps, whereas the standard shortening fat will be smeared out over the particles. When liquid oil is used in the dough system, it gets dispersed on mixing throughout the dough in the form of minute globules, which are far less effective in their shortening and aerative actions than plastic fat films (Pyler 1988), thus soft dough is produced. Springiness values, which describe the recovery behaviour between two cycles, were similar for most of the dough, except for dough made of palm mid-fraction, which had significantly higher springiness values as compared to other dough. Dough made of palm mid-fraction also had higher adhesiveness and cohesiveness values, but dough made of palm olein showed the least values for these parameters.

Dough and gluten extensibility analysis

Extensibility tests are typically conducted on dough to evaluate their tensile strength and extensibility characteristics based on the wheat's protein and gluten quality. Extensibility testing on biscuit dough conducted in this study was used to investigate the effect of different oil types on the gluten formation. The concept is that fat plays an important role in determining the formation of gluten in wheat flour dough. When mixed with the flour before its hydration, the fat

Table 1 Effect of fat type on the rheological characteristics ($n=5$), resistance maximum force and extensibility distance ($n=10$) of biscuit dough

Sample	Hardness (g)	Adhesiveness (g/s)	Cohesiveness	Springiness	Max Force (N)	Distance (mm)
Butter	9066.4 ± 546.70^{c}	-142.5 ± 18.17^{b}	0.19 ± 0.00^{c}	0.49 ± 0.02^{b}	27.7 ± 1.86^{c}	-17.6 ± 2.76^{b}
Palm oil	9903.5 ± 282.92^{b}	$-135.2^{b}\pm36.59^{b}$	0.22 ± 0.00^{b}	0.47 ± 0.01^{b}	44.1 ± 3.45^{b}	-15.6 ± 1.18^{b}
Palm olein	5972.2 ± 419.21^{d}	-116.2 ± 9.96^{b}	0.18 ± 0.01^{c}	0.46 ± 0.02^{b}	21.0 ± 0.59^{d}	-15.5 ± 0.95^{b}
Palm mid-fraction	28819.8 ± 505.66^{a}	-380.9 ± 122.18^{a}	0.28 ± 0.02^{a}	0.68 ± 0.06^{a}	69.8 ± 4.22^{a}	-1.9 ± 0.29^{a}

Values with the same letter within the same column are not significantly different prevents the formation of gluten network and produces less elastic dough. Highly elastic dough is not desirable in biscuit making since it shrinks after lamination (Faubion and Hoseney 1990). Dough extensibility distance and maximum force required to tear the strip are shown in Table 1. Kieffer analysis results showed that the type of oil influenced the extensibility and maximum force required to tear the dough strip. Dough made of palm mid-fraction had the highest maximum force, while dough made of palm olein had the least. The results obtained showed a similar trend with TPA values. High amount of solid in the fat produced very stiff dough, whereas liquid oil produced soft dough. Dough made with butter had the highest elasticity, followed by palm oil, palm olein, and palm mid-fraction, accordingly.

Density

Density is considered the best index of sensory texture of biscuits (Manohar and Rao 2002). Lower density means greater crispiness and higher textural value. The densities of dough and biscuits studied are shown in Fig. 1. It can be seen that the dough density seemed to be affected by the amount of solid ratio of the fat used. Results obtained showed that dough and biscuits made of palm mid-fraction had the lowest and highest densities respectively and were significantly different from other samples. It is believed that the solid content of fat at the time of mixing affects dough density. Baltsavias et al. (1997) reported that dough with lower solid fat content has higher density.

Biscuit texture analysis

Three-point bend test values of the biscuits studied are shown in Fig. 1. The values were obtained from three different batches, which contained a total of 10 samples for each batch. The results obtained showed that biscuits made of palm mid-fraction and butter had the highest breaking force and were significantly different ($p<0.05$) from biscuits containing palm oil and palm olein. Biscuit made of olein had the lowest breaking force. It was of interest to observe here that the hardness of the dough seemed to influence the texture of the biscuits. As reported earlier, dough containing higher solid fat was the hardest and the least dough hardness was observed for that containing palm olein. Peak force required to break the biscuits was positively correlated to dough hardness ($r=0.633$, $p<0.05$). The same effect was noticed by O'Brien et al. (2003), who found that biscuit produced using lower free fat (high solid fat) had higher breaking strengths.

The present observations are in contrast to the findings by Manohar and Rao (1999), who reported that no significant difference was observed in breaking strength of biscuits made of hydrogenated fat and oil. But, they were significantly different with the biscuit made of bakery fats. Later, Jacob and Leelavathi (2007) reported that biscuits containing liquid oil had relatively harder texture. However, low breaking strength in sample containing palm olein may be explained by the influence of the fat on the gluten formation during mixing. According to Manley (2000), during the mixing process in biscuit production, the fat component and the aqueous phase compete for the surface of flour particles. If the fat coats the flour before it is hydrated, the gluten network is interrupted and a shorter less hard biscuit is produced. Thus the biscuits made of palm mid-fraction were not as effective in competing with the water for the flour particles; therefore a more extensive gluten network is formed leading to the production of harder biscuits. It should be remembered that the model biscuits have relatively high water content in the dough compared to many formulations.

Visual observation of the internal biscuits showed that biscuits made of butter had well-distributed air cells, as compared to other samples. Biscuits made of palm-mid fraction and palm oil contained less air cells and were not homogenously distributed. According to Manley (2000), dough made of semi-solid fat (oil) gives better structures during baking than dough made of liquid fat. The crystals in semi-solid fat during mixing are separated from the liquid (oil) phase and become enveloped in a protein membrane. This membrane allows large numbers of crystals to attach to air bubbles. During baking, the fat crystals melt and the protein membrane is incorporated into the surface of the bubbles as they expand thus increasing the resistance to rupture (Manley 2000). Burnt and Fearn (1983) and Ahmad et al. (2001) reported that the texture of biscuits varies even within the same biscuit due to non-uniform moisture distribution in the product.

Internal structure of biscuit by scanning electron microscopy

Scanning electron microscopy (SEM) is often employed to reveal the internal geometrical structure of a product in detail in food structure analysis. Structural characteristics such as cell size, density, and uniformity strongly influence the sensory properties of a product. In this study, microstructural analyses using SEM were carried out to examine and characterise the microstructure formed using different types of oil in the formulation. SEM images of the internal cross-sectional area of biscuits are shown in Fig. 2. The biscuits showed an open structure consisting of gaps in between the material layers. The expansion of bubbles of gases as a result of increasing temperature, which also increases the water vapour pressure within them, may result in an increased tensile stress in the membrane initiating rupture and the formation of holes and tunnels in the product through which the gas finds a way to the outside (Bloksma

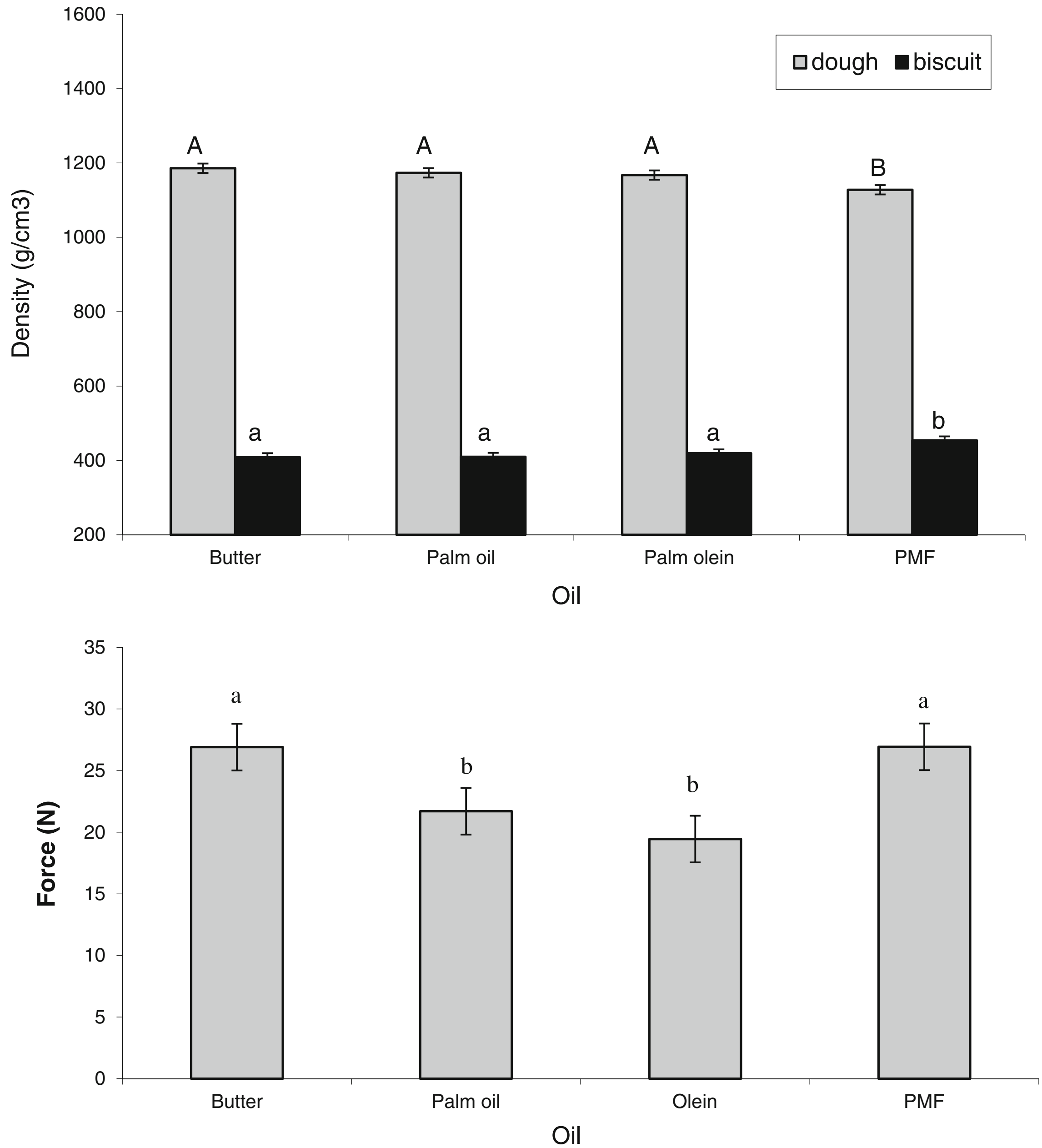

Fig. 1 Densities of dough and biscuit and biscuit hardness (Force) of produced biscuit produced with different type of oil. Different capital letters (Dough) and small letters (Biscuit) differ significantly ($P<0.05$) ($n=10$)

and Bushuk 1988). No major conclusion can be drawn in relation to the resultant cross-sectional openness where the results obtained were not correlated with the biscuit texture analysis finding. The size of the sample used during measurement using SEM might contribute to the results due to only a small portion of the biscuit was used. However, there are some differences in the porosity observed between biscuits made of palm olein, palm oil, and butterfat, where the air cells in the structure seem to be more homogenous, uniform, and well-dispersed in the butter sample compared to the palm mid-fraction sample. Biscuit made of palm mid-fraction seems to have heterogeneous air cells with rough large holes. This can be related to the distribution of the oil in the dough prior to baking.

Sensory evaluation of biscuits hardness

In this study, sensory evaluation of biscuits, which had also been used for hardness determination by instrumental measurements (three-point bend test), was undertaken. Instrumental methods of texture measurement have advantages over sensory methods, such as less time-consuming,

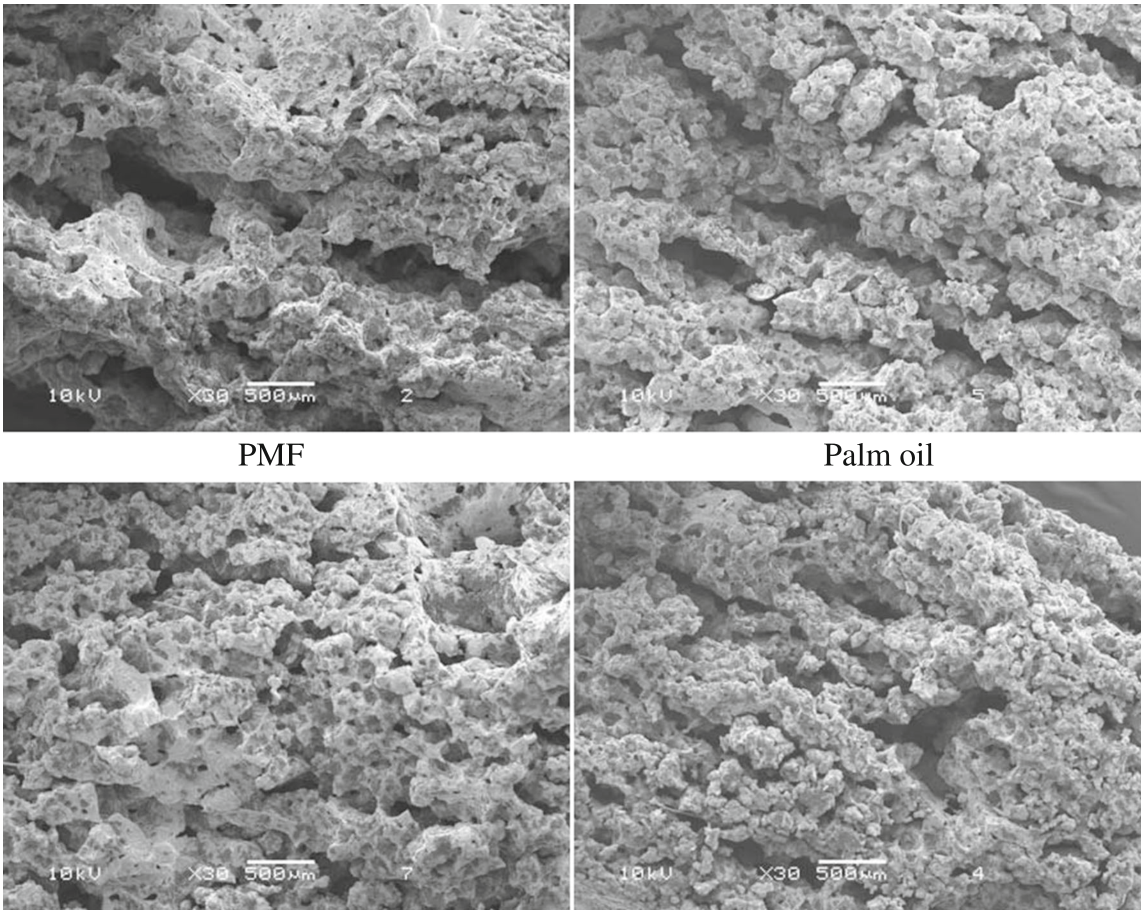

Fig. 2 Scanning electron microscopy photographs showing internal structure of biscuits. Bars=500 μm

cheaper, more repeatable, and free from variability caused by psychological, physiological, and environmental factors influencing the human responses. On the other hand, the advantage of sensory methods over instrumental methods of texture measurement is the complexity of perception, enabling an immediate analysis, integration, and interpretation of a large number of single textural sensations at the same time. From a sensory point of view, hardness of a solid food is defined as the force required to compress a substance when placed between molar teeth (Szczesniak 2002). In the study, a Friedman test was conducted to determine whether consumers (n=31) had a differential rank ordered perception for the four manufactured biscuit samples. Results of analysis indicated that there was no differential rank ordered perception for all samples (corrected F=0.41, p>0.05). It can therefore be concluded that consumers cannot detect any differences of hardness between the samples. Three-point bend test results showed that there was a statistical difference between biscuits made of butter and palm mid-fraction and those made of palm oil or palm olein. The actual force difference between the biscuits was small. The highest and the lowest peak force values required to break the biscuits differ by about 7 N and this may not be sufficient for the panellists to detect.

Conclusions

Fat is an important ingredient in baking products and it plays many roles in providing desirable textural properties of baking products, particularly biscuit. TPA results showed that the type of oil significantly influenced dough textural properties. Hardness measurement showed that biscuit produced with higher solid fat oil had higher breaking force, but this was not perceived when tested by sensory panel. Scanning electron microscopy showed that biscuit produced with palm mid-fraction had an open internal microstructure and heterogeneous air cells as compared to other samples. It is important to be able to understand the critical properties of oils within a biscuit so that sound decisions about the type and quantity of oil can be made. Fats appear to be important in the initial stages of biscuit manufacture and the study shows that mixing and pressing of the samples are influenced by the type of oil. Hard oils (e.g. stearine) do not bind the product so that it can be sheeted. Despite using very different types of oil, the biscuit textures produced were not very different. This leads to the view that aeration, using the chemical leaveners and the matrix between the voids, is not dominated by the effects of the oil. Therefore, if the biscuit dough can be formed, the texture can be satisfactory regardless of the hardness of the oil.

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