Effects of fatty acids composition and microstructure properties of fats and oils on textural properties of dough and cookie quality

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Abstract This study was carried out to investigate the effect of fatty acid composition and microstructure properties of fats and oils on the textural properties of cookie dough and quality attributes of cookies. Fatty acid composition and microstructure properties of six fats and oils (butter, hydrogenated fat, palm oil, coconut oil, groundnut oil, and sunflower oil) were analyzed. Sunflower oil was found to be the most unsaturated oil with 88.39% unsaturated fatty acid content. Coconut oil and palm oil differed from other fats and oils by having an appreciable amount of lauric acid (59.36%) and palmitic acid (42.14%), respectively. Microstructure size of all fats and oils ranged from 1 to 20 μm being the largest for coconut oil and the smallest for palm oil. In palm oil, small rod-shaped and randomly arranged microstructures were observed, whereas sunflower oil and groundnut oil possessed large, scattered ovule shaped microstructures. It was reported that sunflower oil produced the softest dough, the largest cookie spread and the hardest cookie texture, whereas hydrogenated fat produced the stiffest dough, the lowest spread and most tender cookies. Statistical analysis depicted that palmitic acid and oleic acid demonstrated a positive correlation with dough hardness. Linoleic acid exhibited positive link with cookie spread ratio ($r = 0.836^{**}$) and breaking strength ($r = 0.792^{**}$). Microstructure size showed a significant positive relationship with dough density ($r = 0.792^{**}$), cookie density ($r = 0.386^{*}$), spread ratio ($r = 0.312^{*}$), and breaking strength ($r = 0.303^{*}$).

Keywords Fatty acid composition · Microstructure · Fats/oils · Dough texture · Cookie quality

Introduction

Cookies hold an important place among bakery items because of their good nutritional value, variety of choices, long shelf life and affordable cost. The quality of cookie is governed by the quantity and quality of the ingredients used. Fats and oils are indispensable constituents of baked products. Some of their pivotal functions include improving palatability, assisting in lubrication of the various components, incorporating air, adding moisture barrier, producing structures, and increasing shelf-life of the products (Nor Aini et al. 1989). For consumers, textural characteristics of fats that emanate from their molecular states are of prime concern. Fats influence food texture via developing structures of crystalline networks and by interruption of the structure by intervening with non-fat systems.

Polymorphism is the quite significant feature of oils and fats. Morphology of fat and oil microstructure plays a decisive function in the ultimate qualities of fat products (Heertje and Leunis 1997). Smaller crystals will provide a smoother texture while larger crystals may result in a grainy texture (Rodriguez et al. 2001). The morphology of fat crystals can affect the rheological behavior and melting profile. The mechanical attributes of edible fats can be influenced by a set of aspects, involving solid fat content (SFC), the polymorphism of the solid phase as well as the microstructure of the network of crystalline particles (Marangoni and Narine 2002). The solid-like behavior of plastic fats is owing to the existence of a fat crystal network (Marangoni and Narine 2002).

Cookie making starts with the blending of the ingredients into the dough. In cookie making, dough rheology is

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important as it influences processability and quality of cookie (Piteira et al. 2006). Baltasvias et al. (1997) reported that the viscoelastic properties of dough significantly affected by the type of fats in cookie formulation. Earlier research of Rogers (2004) suggests that fat and oil type is not an essential variable for spread which is most eminent quality characteristic of cookies. Jacob and Leelavathi (2007) investigated that cookies made using oils had higher spread compared to cookies containing fats.

The functionality of fats and oils in the finished product depends on their fatty acid composition (FAC). It is imperative to consider the fatty acid composition and the morphology of microstructures of fats and oils to predict their functionality in more complicated food systems. Fatty acids influence the physicochemical properties of starchy foods (Singh et al. 1998). The changes brought about by fatty acids in starchy foods have been attributed to the amylose–lipid complex formation. Kaur and Singh (2000) investigated that stearic acid influenced pasting temperature and peak viscosity of rice starch the most significantly as compared to myristic acid and palmitic acid. It was observed that hydrogenated fat had the highest and peanut oil had the lowest ability for complex formation (Singh et al. 2000). This Variation in complex forming ability probably due to variation in their fatty acid composition. Most of the work reported till now is about the quality of cookies as affected by different levels or types of shortening or different emulsifiers. However, information on the various textural attributes of cookie dough and quality of cookie due to the difference in fatty acid composition of fat and oil is scanty. Therefore, this research was conducted to understand the effects of the fatty acid composition and microstructure properties of butter, hydrogenated fat, palm oil, coconut oil, sunflower oil, and groundnut oil on dough and cookie quality.

Materials and methods

Materials

Six different types of edible fat and oil samples were examined both from plant and animal origin. Palm oil was obtained from Ruchi Soya Industries Ltd., Gurgaon. Butter (Amul), hydrogenated fat (Dalda), sunflower oil (Nature Fresh), groundnut oil (Dhara), and coconut oil (Parachute) were procured from reliance fresh (Hisar, India).

Fatty acid composition (FAC)

Fatty acid composition of fresh vegetable oils was investigated by using GC–MS (Thermo Scientific TRACE 1300). By transesterification of fats and oils with methanol:

toluene: H₂SO₄ (88:10:2 v/v) at 80 °C for 1 h fatty acid methyl esters (FAME) were obtained as described by Bootello et al. (2011). Into the gas chromatograph, 1 µL of FAME sample was injected. GC separation was conducted on a capillary column (TG-5 ms). The carrier gas was nitrogen, and the column flow rate was 1.0 mL min^{−1}. Initially, the oven temperature was calibrated at 165 °C for 2 min, raised from 165 to 305 °C at a rate of 2 °C min^{−1} and then maintained at 305 °C for 5 min. Injection port and detector temperatures were 240 and 250 °C, respectively. The peaks were identified on the chromatogram according to retention data from analyzed standard samples run under the same operating conditions. Relative percentages of total fatty acids represented the results.

Confocal laser scanning microscopy analysis

The newest technique was used to study the morphology of microstructures of fats and oils as described by Gallier et al. (2010). The images of microstructures of the butter, hydrogenated fat, palm oil, coconut oil, groundnut oil, and sunflower oil, which were, crystallized under static conditions at 25 °C, were captured by Nikon Real-Time Confocal Laser Scanning Microscope (Model A1R). The fat samples were melted at 80 °C for 10 min. A small droplet of about 20 µL of the melted fats was placed on a glass slide preheated to 80 °C. To produce a film of uniform thickness a pre- heated glass cover slip was carefully placed over the sample. In a temperature-controlled cabinet, the slides were incubated for 24 h at 25 °C.

Textural analysis of cookies dough

The cookie dough was prepared in a Hobart mixer according to AACC Approved method 10-50D (American Association of Cereal Chemists, 2000) with slight modifications. The cookie formulation consisted of wheat flour (100 g), sodium bicarbonate (2.0 g), salt (1.5 g), skim milk powder (10 g), fat/oil (45 g), sugar (55 g) and water according to requirement. Shortening and sugar were mixed to cream followed by mixing of flour, sodium bicarbonate and skim milk powder to form dough. The textural characteristics of the cookie dough were analyzed using a texture analyzer (TAXT2i Stable Micro Systems, Surrey, UK) equipped with a 5-kg load cell in compression mode with a cylindrical probe (25 mm diameter). Pretest and posttest speeds were 2.0 mm/s, while test speed was 1.0 mm/s. Cookie dough piece of 50 mm diameter and 10 mm height was used to measure the hardness, adhesiveness, cohesiveness, and springiness. The force required to compress the dough by 80% was recorded, and the average value of six replicates was reported. The above experiments were conducted at ambient temperatures.

Cookie preparation and evaluation

Cookies containing six different fats respectively were prepared according to AACC Approved method 10–50D (American Association of Cereal Chemists 2000) with slight modifications. Fat/oil and sugar were mixed to cream followed by mixing of flour, sodium bicarbonate and skim milk powder to form dough. The dough was kneaded and sheeted to a uniform thickness of 5 mm and cut using a circular die of 60 mm diameter. Baking was carried out at 205 °C for 15 min in the baking oven. The cookies were cooled and stored in airtight containers. Cookie preparation was done in triplicate. Cookies were subjectively evaluated for diameter, thickness, spread ratio, and density. The density was determined according to the method used by Hasmadi et al. (2010) using solid replacement technique. The texture of cookies was determined by using texture analyzer (TA-XT2i, Stable Micro Systems, UK) in a compression mode in terms of the breaking force required to fracture the cookies using the three-point bending test. The probe used was Knife Edge Insert (HDP/BS) with 5 kg load cell Heavy Duty Platform (HDP/90) at pre-test speed, test speed and post-test speed of 2.5, 2.0 and 10.0 mm/s respectively with a data acquisition rate of 400. The peak force, an index of cookie break strength, was measured for at least eight cookies per batch.

Statistical analyses

All data were expressed as the mean $\pm$ standard deviation of quadruplicate analyses. The experimental data was analyzed for significant differences with the help of analysis of variance (ANOVA) and correlation analysis was conducted using SPSS 16.0 software.

Results and discussion

Fatty acid composition

The functional properties of commercial fats/oils are closely related to their fatty acid composition. The fatty acid composition of fats and oils improved the understanding of the fats and oils quality, stability and applicability. Table 1 showed the fatty acid composition of fats and oils. A range of major saturated and unsaturated fatty acids was found in all fats and oils. The total saturated fatty acid content percentage varied from 11.61% (sunflower oil) to 91.2% (coconut oil). Palm oil presented almost equal composition of saturated and unsaturated fatty acids, with 42.14% as palmitic acid. This balanced composition, besides the β polymorphism structure of the palmitic acid, makes it a good oil for deep frying, and an excellent source for

blending oils for achieving desired properties for several uses thus proving to be a source of margarine and bakery products application. Coconut oil was found to be the most saturated one, and lauric acid alone constitutes 59.36%. The major saturated fatty acids in coconut oil were medium-chain fatty acids (MCFA) (> 59%). Oleic (C18:1) and linoleic (C18:2) acids were the major unsaturated fatty acids present in all oils. Among the evaluated fats and oils the highest contents of saturated fatty acids were found in the coconut (91.2%). Sunflower oil had the highest content of unsaturated fatty acids (88.39%) followed by groundnut oil having 80.55% unsaturated fatty acids. Results are in line with previous data (reviewed by Devi and Khatkar 2016).

Fatty acid composition of butter is important for several reasons. It contained 18% of butyric and 24.56% of palmitic acid. The considerable amount of short-chain fatty acids confers to butter's quality as a softer fat with a lower melting point. This, in turn, ensures a rapid flavor release when melting. Hydrogenated fat also possessed a considerable amount of oleic acid (44.32%) and palmitic acid (39.46%). Soft oils like groundnut oil and sunflower oil which are rich in unsaturated fatty acids can easily oxidize. Thus they are chemically unstable. As a rule, the increase in the saturated fatty acid content of soft oils reduces the degree of chemical oxidation. Hard oils such as palm oil and coconut oil that are composed of triglycerides containing two or three saturated fatty acids which may be in a solid or semi-solid state at ambient temperatures.

Microstructure morphology

The microstructure was observed by the latest Laser microscopy technique to find out the peculiarities in the morphology of fats and oils microstructures. Plastic fats consist of a three-dimensional network structure of crystals in which liquid oil is trapped. The plasticity of fat is determined by the shape, average size and size distribution of the crystals (Chawla and De man 1990). Watanabe et al. (1992) reported that the crystal size was important for the quality of the final products. Characteristics of crystal size are essential in the consistency and acceptability of the final product. Small crystals can form a more rigid product, and crystals that were 30–200 μm in size caused a sandy mouth feel. Piska et al. (2006) observed that the size of the β' (beta prime) crystal was 1–5 μm , and the size of the β (beta crystal) was 20–100 μm . Smaller and finer beta prime crystals can stabilize more air and more liquid component than larger and coarser beta crystals (Podmore 2002). The larger crystal size increases the interaction between the particles, decreasing the value of solid fat content and reducing the crystals formed in space (Rye et al. 2005). Coconut oil, groundnut oil, sunflower oil and hydrogenated

Table 1 Fatty acid composition (%) of fats and oils

Fatty acids	Amount (%)					
	Butter	Hydrogenated fat	Palm oil	Coconut oil	Groundnut oil	Sunflower oil
4:0 (Butyric acid)	18 ± 0.08	–	–	–	–	–
12:0 (Lauric acid)	3.58 ± 0.03	0.37 ± 0.00	0.4 ± 0.07	59.36 ± 0.15	–	0.7 ± 0.00
14:0 (Myristic acid)	18.99 ± 0.07	0.42 ± 0.07	1.1 ± 0.04	11.39	–	0.87 ± 0.00
16:0 (Palmitic acid)	24.56 ± 0.07	39.46 ± 0.09	42.14 ± 0.13	7.76 ± 0.02	10.23 ± 0.07	5.29 ± 0.02
18:0 (Stearic acid)	9.07 ± 0.02	7.25 ± 0.04	4.4 ± 0.01	1.7 ± 0.02	4.78 ± 0.01	4.75 ± 0.05
18:1 (Oleic acid)	18.09 ± 0.11	44.32 ± 0.06	38.23 ± 0.2	6.49 ± 0.02	36.20 ± 0.34	11.37 ± 0.08
18:2 (Linoleic acid)	1.6 ± 60.04	0.26 ± 0.00	10.78 ± 0.02	1.91 ± 0.04	19.83 ± 0.07	73.24 ± 0.35
18:3 (Linolenic acid)	–	–	–	–	24.52 ± 0.07	–
Other Minors	6.05 ± 0.07	7.92 ± 0.14	2.95 ± 0.00	11.39 ± 0.06	1.98 ± 0.02	3.78 ± 0.04
SFA	80.25	47.50	50.45	91.2	19.45	11.61
USFA	19.75	52.5	49.55	8.8	80.55	88.39

Values are reported as the average ± standard deviation of the replications

Means followed by the same letter within a line indicate significant difference ($p < 0.05$)

SFA saturated fatty acids, USFA unsaturated fatty acids

fat were of beta form. Butter and palm oil possessed beta prime polymorphic form. These results are in accordance of Devi and Khatkar (2016).

After concluding the previous research of macroscopic physical properties of solid lipids, Narine and Marangoni (1999) reported that compared with other crystallization behaviors, the microstructure of fat is more significant for the macroscopic physical properties. According to the microscopic images, microstructure morphology of all fats and oils was different. Figure 1 showed that the microstructure size ranged from 1 to 20 μm . The microstructure size in palm oil was found to be the least (1–5 μm) that implies the presence of beta prime crystals only and shape of microstructures was found to be small rod-shaped and randomly arranged, and it can hold a massive volume of air. The microstructure network of palm oil was less dense (Fig. 1c) than that of butter and hydrogenated fat (Fig. 1b) but much denser than other oils. Butter microstructure ranged from 5 to 10 μm as shown in Fig. 1a. Microstructures were long needle-like, opaque framed and tightly packed.

Hydrogenated fat contained microstructure of the same size as that of butter i.e. 5–10 μm but microstructure network was most dense showing the highest microstructure interactions. Coconut oil had the largest microstructure size (20 μm) and symmetrically arranged (Fig. 1d). Sunflower oil and groundnut oil microstructures were of the same size of 10–15 μm , with ovule shape, and scattered as observed in Fig. 1e, f. Coconut oil, sunflower oil, and groundnut oil had few independent and larger microstructures with no microstructure interactions, and it resulted in the poor creaming performance of these oils.

Textural properties of dough

Rheological properties of wheat flour dough are essential for the successful manufacturing of baked products (Khatkar et al. 2002a, b). At some point when fat blended with the flour before its hydration, it prevents the development of gluten network and delivers poor elastic dough. Moreover, if dough lacks in its elastic properties, it is hard to form into required shape of the final product (Khatkar et al. 2013). According to Khatkar and Schofield (2002), starch and gluteins are the main fractions of wheat flour controlling the rheological properties of wheat flour dough. Gliadin deliberates viscous properties of gluten, while glutenin bestows the strength and elasticity that are crucial for retaining the gasses that are generated during baking (Khatkar et al. 1995). Handling properties of the dough especially during the kneading and sheeting procedure showed visible differences. Subjective observation showed that during dough preparation, the dough made with sunflower oil was too soft to handle and difficult to sheet and mould. The TPA results (hardness, adhesiveness, cohesiveness, springiness) of the six types of fats and oils are summarized in Table 2.

It can be interpreted from the results that fats and oils significantly influenced the textural properties of cookie dough. Among the different types of fat and oil used, hydrogenated fat was found to produce the hardest dough (13.5 N). On the other hand, dough prepared using sunflower oil was the softest (5.03 N). These results are in line with Manohar and Rao (1999), Mamat and Hill (2012) and O'Brien et al. (2003), they reported that hydrogenated fat produced the hardest dough in comparison to bakery

Fig. 1 Confocal images of microstructure of butter (a), hydrogenated Fat (b), palm Oil (c), coconut Oil (d), sunflower Oil (e), and groundnut Oil (f)

Table 2 Effect of fats and oils on the textural characteristics of cookie dough

Fat/oil	Textural properties			
	Hardness (N)	Adhesiveness (N/s)	Cohesiveness	Springiness
Butter	7.07b	– 0.83a	0.59a	0.37a
Hydrogenated fat	13.5f	– 1.08b	0.61b	0.40b
Palm oil	7.56c	– 3.33d	0.93c	0.89d
Coconut oil	8.75e	– 2.51c	0.95d	0.90e
Groundnut oil	7.72d	– 3.37e	0.94c	0.85c
Sunflower oil	5.03a	– 4.37f	0.95d	0.92f

Values with the same letter are significantly different ($p < 0.05$)

shortening and oil. Baltasvias et al. (1997) investigated that stiffness of cookie dough markedly decreased when fat content of the dough was decreased, or when liquid oils were substituted for solid fats. This explains the lower hardness observed in dough containing sunflower oil and groundnut oil. When the liquid oil is used in the dough, it gets dispersed throughout the dough in the form of tiny globules, which are far deprived effective in their shortening and aerative performance (Pyler 1988). Manohar and Rao (1999) also investigated that difference in dough hardness produced by fats and oils was due to variation in the solid fat index (SFI), which is the empirical value of SFC. Fats having a higher SFI produced stiffer dough. Adhesiveness is a surface property and depends on a combined effect of adhesive and cohesive forces. The adhesiveness ranged from 0.83 to 4.37 N/s being maximum for sunflower oil and the minimum for butter. Again,

adhesiveness of oils was observed higher than fats, indicating their sticky nature.

Cohesiveness followed a similar trend to adhesiveness. It was evident from the results that the dough prepared using oils were more cohesive than fats. Sunflower oil and coconut oil were most cohesive. On the contrary, butter was the least cohesive. Cohesiveness was a measure of the difficulty in breaking down the internal structure. Gluten network is formed by strong inter and extra disulphide bonds which provide resistance to breakdown which in turn leads to increase in cohesiveness. It has been well acknowledged that fats and oils play a shortening function in the dough by eliminating gluten development via breaking the continuity of the protein and starch structure. It possibly attributes to inferior shortening ability of oils that enhanced dough resistance. Cookie dough prepared using sunflower oil had the highest springiness, whereas

butter had the least springiness. Springiness describes the recovery behavior between two cycles. The present study revealed that the dough samples made with oils were more cohesive, adhesive, and softer. Analogous remarks were laid out by Manohar and Rao (1999) and Jacob and Leelavathi (2007).

Manohar and Rao (2002) investigated that density is the best predictor of the sensory texture of biscuits. Lower density means greater crispiness and superior texture. Dough density relies upon the type of fat and oil used in the formulation. The less aerated dough is denser than aerated dough bringing about stiffer dough. Figure 2a depicts that the cookie dough made with sunflower oil had the highest density, whereas palm oil had the least value for density. These observations are in accordance with Baltsavias et al. (1997). Oils do not have the capability to keep the air until mixing is finished. The insignificant volume of air leads to deprived volume of the dough and end product and consequently results into higher dough density. It can also be speculated here that the cookie dough samples containing oils were less aerated because unlike the solid or plastic fats, they do not aid in aeration of the dough or batter (Pylar 1988). Dough density and cookie density did not follow the similar trend. Cookie dough prepared using butter had the comparable density to dough prepared using palm oil, whereas cookie prepared by butter exhibited much higher density than made using palm oil. Among the oils, palm oil had the highest solid fat content (Devi and Khatkar 2017) which leads to more air incorporation at the dough stage (Maache-Rezzoug et al. 1998), and expansion of the gas cells during baking is more pronounced (Pareyt et al. 2009). No significant difference observed between densities of cookies prepared using hydrogenated fat and butter.

Subjective observation during dough preparation with butter, hydrogenated fat, palm oil, and coconut oil in the Hobart mixer showed that the fat and sugar form a very light, fluffy, well-aerated cream and with the addition of

flour transformed into a soft dough. However, sunflower oil and groundnut oil resulted into heavy, poorly aerated cream and oil smearing the sugar.

Cookie quality

Cookie diameter was significantly affected by different fats and oils (Table 3). Cookie diameter varied from 87.00 to 91.65 mm for different fats and oils. The diameter was found to be the highest for sunflower oil cookies while, it was the least for cookies made using butter. Jacob and Leelavathi (2007) reported that cookie diameter was higher for sunflower oil and lesser for hydrogenated fat. No remarkable difference was observed in diameters in cookie prepared with hydrogenated fat and coconut oil. Results revealed that the effect of different fats and oils on the thickness of cookies was insignificant (Table 3). The thickness of cookies ranged from 8.30 to 8.60 mm. The results of present study are in accordance with the previous studies conducted by Pareyt et al. (2009) who reported thickness ranged from 7.1 to 9.9 mm. Cookie thicknesses were the highest in cookies made using hydrogenated fat, while it was the lowest in cookies made using sunflower oil. These observations were in agreement with Jacob and Leelavathi (2007) who reported that there was the non-significant effect of fat types on cookie thickness. Similar investigations were also reported by Manohar and Rao (1999) who reported that no significant difference was observed in thickness of biscuits made of hydrogenated fat and oil.

Expansion due to leavening and the flow rate of the cookie dough during baking affects cookie spread (Hosey and Rogers 1994). Cookie spread, in turn, affects cookie height. After cookie dough is put in the oven, it starts to expand until it reaches its setting time (the point at which the dough stops spreading due to protein coagulation and starch gelatinization). Previous research suggests that lipid type is not an essential variable for cookie spread (Rogers 2004). However, it does influence spread by conferring a lubricant impact, which in turn influences flow rate. The effect of different fats and oils on cookie spread factor was found to be significant (Table 3). Spread ratio of cookies ranged from 10.29 to 11.04. The mean value for spread ratio of cookies was the highest in sunflower oil followed by groundnut oil, while the lowest spread values were observed in cookies made using hydrogenated fat. The earlier the lipid melts during the baking process, the larger is the cookie spread, and a flatter cookie is produced. Therefore, cookies made from liquid oils, such as sunflower oil and groundnut oil used in this study, tend to have larger spreads and lower heights. The results of the present investigation are in line with the previous findings (Jacob and Leelavathi 2007; Mert and Demirkesen 2016). The

Fig. 2 Effects of palm oil (PO), hydrogenated fat (HF), butter (B), coconut oil (C), groundnut oil (GO), and sunflower oil (SO) on the density of cookie dough (a) and cookie (b)

Table 3 Effect of fats and oils on cookie quality

Fat/oil	Cookie quality			
	Diameter (mm)	Thickness (mm)	Spread ratio (D/T)	Breaking strength (kg f)
Butter	87.00a	8.40c	10.36b	3.04b
Hydrogenated fat	88.50bc	8.60e	10.29a	3.03a
Palm oil	89.25d	8.44d	10.57 cd	3.06b
Coconut oil	88.00b	8.35b	10.54c	3.12c
Groundnut oil	91.25e	8.35b	10.93e	5.19d
Sunflower oil	91.65ef	8.30a	11.04ef	5.21e

Values followed by different letters are significantly different at $p < 0.05$

D/T diameter/thickness

result showed that cookies containing sunflower oil had relatively higher spread value. Cookies containing palm oil and coconut oil had similar spread values. On the other hand, a cookie containing butter had significantly less spread comparable to hydrogenated fat. The present observations are in contrast with Finney et al. (1950) and later Abboud et al. (1985), who concluded that fat type is not a significant variable for cookie spread. The cookie breaking strength showed significant differences for different fats and oils. Breaking strength of cookies ranged from 3.03 to 5.21 kg f. Measurement of the breaking strength revealed that cookies containing oils were the hardest. On the other hand, breaking strength of cookies containing the palm oil, butter, and hydrogenated fat was not significantly different from each other. It was observed that hardness of the dough (Table 2) did not necessarily control the texture of the cookies (Table 3).

Correlation of fatty acid composition and microstructure characteristics of fats and oils with textural properties of dough

Correlations of fatty acid composition and microstructure characteristics of different fats and oil with textural properties of dough are summarized in Table 4. There is a limited number of research papers that investigated the effects of fatty acid composition and microstructure properties of fat and oils on textural properties of cookie dough.

The impact of fat on dough elastic properties is related to lubrication, which limits the formation of a gluten network (Maache-Rezzoug et al. 1998). The resultant dough is referred as short dough. The rheological characteristics of dough are crucial as they influence the handling and processing of the dough as well as the quality of the end products. Dough that is too firm or too soft will not be processed satisfactorily on the appropriate dough forming equipment and will not produce a desirable product (Wade 1988).

Palmitic acid, oleic acid, and saturated fatty acids content were found to induce a positive correlation with dough

hardness ($r = 0.550$, $r = 0.576$, $r = 0.247$, respectively). In contrast, linoleic acid and USFA contributed negatively to dough hardness as indicated by their negative link ($r = -0.641$, and $r = -0.247$, respectively). Lauric acid, myristic acid, stearic acid, and microstructure size did not demonstrate any significant link with dough hardness. It can be concluded that saturated fatty acids contribute to dough hardness. These results are as expected because sunflower oil had the most unsaturated fatty acid composition (Table 1) and produced the softest dough as shown in Table 2. It can be inferred that dough hardness solely does not depend upon the FAC because the hardness of dough for coconut oil was much lesser than hydrogenated fat, butter, and palm oil which had lower SFA content than coconut oil. SFA and USFA contents showed an inverse correlation with textural properties of cookie dough.

Adhesiveness, which is a surface property, linked negatively with fatty acids except LA and USFA which induced positive impact on dough adhesiveness ($r = 0.804$ and $r = 0.670$, correspondingly). Microstructure size (MS) displayed poor positive link with dough adhesiveness. Results displayed that the unsaturated nature of liquid oils contributed to their sticky nature. Similar results were reported earlier by Mamat and Hill (2012). Cohesiveness, springiness, and cookie density followed a similar trend with adhesiveness. MS exhibited significant positive relation with the cookie dough density ($r = 0.792$), highlighting higher dough density demonstrated by sunflower oil, groundnut oil, and coconut oil. Lower PA and higher LA contents confers higher dough density as indicated by their negative and positive relation with DD ($r = -0.802$ and $r = 0.630$, respectively).

Correlation of fatty acid composition and microstructure characteristics of fats and oils with cookie quality

Table 4 cited correlation among major fatty acids, saturated fatty acids content, unsaturated fatty acids content, and microstructure size of fats and oils with the cookie

Table 4 Correlation matrix of textural properties of cookie dough and cookie quality with fatty acid composition and microstructure properties of fats and oils

	Dough textural properties					Cookie quality				
	HD	AD	CH	SP	DD	CD	D	T	SR	BS
FAC										
LuA	ns	ns	0.304*	0.301*	0.338*	− 0.267	− 0.376*	− 0.267	ns	− 0.312*
MA	ns	− 0.570*	− 0.430*	− 0.427*	− 0.325*	ns	− 0.768**	ns	− 0.478	− 0.486*
PA	0.550*	− 0.548*	− 0.515*	− 0.490*	− 0.802**	− 0.686*	− 0.430*	0.840**	− 0.686*	− 0.671**
SA	ns	− 0.635*	− 0.878**	− 0.877**	− 0.545*	0.204	− 0.334*	0.455*	− 0.437*	ns
OA	0.576*	− 0.238	− 0.278	− 0.296	− 0.470*	− 0.263	ns	0.727**	− 0.252	ns
LA	− 0.641*	0.804**	0.483*	0.505*	0.630**	0.625*	0.799**	− 0.580*	0.836**	0.792**
SFA	0.247	− 0.670*	− 0.345*	− 0.336*	− 0.408*	− 0.575*	− 0.928**	ns	− 0.749**	− 0.834**
USFA	− 0.247	0.670*	0.345*	0.336*	0.408*	0.575*	0.928**	ns	0.749**	0.834**
MP										
MS	ns	0.260	0.403*	0.374*	0.792**	0.386*	ns	− 0.491	0.312*	0.303*

**, * Significant at $p < 0.01$ and $p < 0.05$, respectively

FAC Fatty acid composition, *MP*, Microstructure properties, *LuA* lauric acid, *MA* myristic acid, *SA* stearic acid, *PA* palmitic acid, *OA* oleic acid, *LA* linoleic acid, *SFA* saturated fatty acid, *USFA* unsaturated fatty acid, *MS* microstructure size, *HD* dough hardness, *AD* dough adhesiveness, *CH* dough cohesiveness, *SP* dough springiness, *DD* dough density, *CD* cookie density, *D* Diameter, *T* thickness, *SR* spread ratio, *BS* breaking strength

quality. Cookie density established negative correlation with palmitic acid ($r = -0.686$) and saturated fatty acids content ($r = -0.575$), whereas positive association with linoleic acid ($r = 0.625$) and USFA ($r = 0.575$). Higher palmitic acid content supports more air incorporation during mixing stage, air leaving during baking makes cookies less dense and consequently lowered the density of final baked cookies. Results reflected that unsaturated fatty acid composition of fats and oils elevated cookie density. Due to higher USFA composition, sunflower oil and groundnut oil (Table 1) conferred higher cookie density as presented in Fig. 2b which is an undesirable texture quality parameters for cookies.

Cookie diameter is a crucial cookie quality parameter. Larger diameters are desirable for superior cookie quality. Most of the fatty acids linked negatively to the cookie diameters. LA and USFA linked positively to the cookie diameter ($r = 0.799$ and $r = 0.928$, respectively). Fats and oils with lower MA, PA, and SA tend to produce cookies with large diameters. However, OA and MS did not demonstrate any marked relationship with diameter. It is worth mentioning here that coconut oil displayed lower diameter than other oils as shown in Table 3. This is attributed to the lowest USFA contents of coconut oil (Table 1). It is well known that oils conferred higher diameters than fats in cookies but amongst oils which factor contributes to the baking performance of cookies is still not clear.

Cookie thickness followed the opposite trend with diameter. Cookie thickness exerted a pronounced alliance

with PA ($r = 0.840$), SA ($r = 0.455$), and OA ($r = 0.727$). LA and MS induced a negative correlation coefficient with cookie thickness ($r = -0.580$ and $r = -0.491$, respectively). Higher spread ratio is the prime desirable property of cookie quality. Most of the fatty acids contributed negatively to the cookie spread. Cookie spread followed an increasing trend with the increase in the LA and USFA contents as indicated by their positive correlations ($r = 0.836$ and $r = 0.749$, respectively). Unsaturated fatty acids cut down the melting point of fats and oils. The lower melting point makes the lubricant effect of fats and oils available sooner, resulting in the improved spread. An increase in microstructure size increased the cookie spread as reflected by their positive correlation ($r = 0.312$). These observations are in line with Zhong et al. (2014), who reported that when cookie dough was formulated with a shortening with smaller crystals resulted in the poor spread. Lauric acid, which is a major fatty acid in coconut oil, did not exert any noticeable correlation with cookie spread. Spread ratio was negatively influenced by MA ($r = -0.478$), PA ($r = -0.686$), SA ($r = -0.437$), and SFA ($r = -0.749$). The hardness of the cookies was measured in terms of breaking strength that increased as the LA and USFA contents were increased, indicated by their positive correlations ($r = 0.792$ and $r = 0.834$, correspondingly). A probable explanation for this is the poor shortening power of unsaturated fatty acids that leads to strong gluten network formation. A stronger gluten network imparts hardness to the cookie. It justifies the higher

breaking strength values delivered by cookies prepared using sunflower oil and groundnut oil.

It was also observed that as the microstructures size increased, the cookie breaking strength, which is major textural parameter also increased ($r = 0.303$). It could be attributed to the fact that larger microstructures size that could not hold air, and led to the stiffer texture of the cookie. Cookie breaking strength was negatively associated with LuA ($r = -0.312$), MA ($r = -0.486$), and SFA ($r = -0.834$). Stearic acid and oleic acid contents did not contribute much to cookie hardness. Higher values of palmitic acid contributed to softer cookies, denoted by its negative link with cookie hardness ($r = -0.671$). It is well known that palmitic acid contributes to superior creaming ability of fats and oils. Higher the air incorporation during mixing stage, air leaves during baking consequently resulting in softer cookies. In this study, it was evident from the data obtained that fats and oils with different fatty acid composition and microstructure size influenced remarkably the dough properties and cookie quality parameter. It can be concluded from the results that sunflower oil and groundnut oil characterized as unsaturated oils delivered stiffer cookies that make them inappropriate for cookie preparation. The desirable, tender cookies were found dependent on the higher proportion of saturated fatty acids and smaller microstructure size. These results suggested that fatty acid composition and microstructure properties of fats and oils are well suited for predicting the baking performance of fats and oils.

Conclusion

Fats and oils are essential ingredient in cookies as they play various functions in dough properties and cookie quality. Fatty acid composition and microstructure properties implied a significant variation among the fats and oils samples in terms of fatty acid contents and microstructure network. Sunflower oil was found the most unsaturated oil, whereas coconut oil was the most saturated one. The microstructure size ranged from 1 to 20 μm being the largest for coconut oil and the smallest for palm oil. Microstructures were rod-shaped, randomly arranged in palm oil, needle-like opaque framed and tightly packed in butter, long needle-like, denser, with the strongest microstructure network in hydrogenated fat, symmetrically arranged in coconut oil, and fewer, scattered, ovule shaped with no microstructure interactions in sunflower oil and groundnut oil. Textural profile data showed that dough prepared using sunflower oil was found the softest, whereas hydrogenated fat produced the hardest dough. Dough samples made using oils were more cohesive, adhesive, and softer. Dough made using palm oil had relatively lower

values for dough and cookie density than the others. Palmitic acid, linoleic acid, and microstructure size were found well correlated with dough and cookie density. Cookies made using sunflower oil had the highest cookie diameter, spread ratio, and breaking strength, whereas hydrogenated fat had the least spread and breaking strength. Results revealed that saturated fatty acids adversely affected cookie spread and hardness. However, microstructure size contributed positively to the spread and cookie hardness. Sunflower oil and groundnut oil were found inappropriate for cookie making as they produced harder cookies as compared to other fats and oils. The desirable cookie texture with softer bite was found to be associated with higher proportion of saturated fatty acids and smaller microstructure size as observed in palm oil, hydrogenated fat, and butter.

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