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Compatibility of selected plant-based shortening as lard substitute: microstructure, polymorphic forms and textural properties

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SUMMARY: A study was carried out to determine the compatibility of three plant-based shortening mixtures to lard shortening (LD) in terms of microstructure, polymorphic forms, and textural properties. The shortenings of binary, ternary, and quaternary fat mixtures were prepared according to a standard procedure by blending mee fat (MF) with palm stearin (PS) in a 99:1 (w/w) ratio; avocado fat (Avo) with PS and cocoa butter (CB) in a 84:7:9 (w/w) ratio; palm oil (PO) with PS, soybean oil (SBO) and CB in a 38:5:52:5 (w/w) ratio, respectively. The triacylglycerol composition, polymorphic forms, crystal morphology, and textural properties of the shortening were evaluated. This study found that all three plant-based shortenings and LD shortening were similar with respect to their consistency, hardness and compression and adhesiveness values. However, all plant-based shortening was found to be dissimilar to LD shortening with respect to microstructure.

KEYWORDS: *Lard substitute; Microstructure; Polymorphic forms; Shortenings; Textural properties*

RESUMEN: ***Compatibilidad de grasas vegetales formuladas como sustitutas de la manteca: microestructura, formas polimórficas y propiedades texturales.*** Se realizó un estudio para determinar la compatibilidad de tres shortenings vegetales con manteca (LD) en términos de microestructura, formas polimórficas y propiedades texturales. Los shortenings de las mezclas de grasas binarias, ternarias y cuaternarias se prepararon de acuerdo con un procedimiento estándar mezclando la grasa de mee (MF) con estearina de palma (PS) en una relación de 99:1 (p/p); grasa de aguacate (Avo) con PS y manteca de cacao (CB) en la relación 84:7:9 (p/p); aceite de palma (PO) con PS, aceite de soja (SBO) y CB en la relación 38:5:52:5 (p/p), respectivamente. Se evaluó la composición de triacilgliceridos, las formas polimórficas, la morfología cristalina y las propiedades texturales de las grasas. Este estudio encontró que los tres shortenings a base de plantas y LD fueron similares con respecto a su consistencia, dureza y valores de compresión y adhesividad. Sin embargo, se encontró que todas las grasas a base de plantas eran distintas al shortening de LD con respecto a la microestructura.

***PALABRAS CLAVE*:** *Formas polimórficas; Manteca; Microestructura; Propiedades texturales; Sustitutos de la manteca*

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1. INTRODUCTION

Shortening and margarine are frequently used as ingredients in bakery products to achieve perfect baking creations. Although they are lipid products, they display different properties, which affect their end products. The physical properties of the shortening are important as it is directly incorporated into the dough or cream. These properties are determined by the chemical composition, crystal structure, polymorph, solid fat content (SFC), hardness and consistency of the fats (Marangoni and Narine, 2002; Campos *et al*., 2002). Good shortening consists primarily of β' crystals (Narine and Humprey, 2004; Ghotra *et al*., 2002), which are small and uniform in size helping to trap and hold air during whipping. If shortening consists of predominantly β crystals, it may tend to display graininess because of the larger crystal size and aerate poorly in the batter (de Man *et al*., 1991). The consistency is another important functional property of plastic shortening, which is determined by the physical properties of fats and oils (Lida and Ali, 1998). According to Buldo and Wiking (2012), the consistency and texture of plastic shortening could also be influenced by the processing parameters employed.

Fat and oil types used for preparation of plastic shortening would vary largely based on application requirements. There is sufficient evidence from previous studies to show that LD and hydrogenated LD were employed for the production of shortening intended to be used in meat based products (Cheong *et al*., 2010). Apart from meat products, LD shortening was found to have applications in the manufacture of bread, biscuits, crackers, cakes, cookies, etc. Owing to this situation, some segments of consumers have become sceptical about the *halal* or kosher status of food products containing different ingredients. As a consequence, efforts have been made in recent times to develop *halal*-based shortening to be used as an ingredient in food product formulations. For instance, attempts were made to formulate plant-based fat replacement for LD using combinations of lipids such as palm oil (PO), palm stearin (PS), cocoa butter (CB), and soybean oil (SBO). Based on the similarities in SFC profiles, a binary mixture of MF:PS (99:1) (Yanty *et al.*, 2014), a ternary mixture of Avo:PS:CB (84:7:9) (Yanty *et al.*, 2017) and a quaternary mixture of PO:PS:SBO:CB (38:5:52:5) (Yanty, 2016) were previously found to be the most suitable candidates for replacement of LD. However, the SFC profile cannot be the sole factor to determine the suitability of a fat blend to replace LD as processing parameters and crystal characteristics might also influence on the quality and consistency of the final product. Hence, the objective of this study was to compare the physical properties of formulated plant-based shortening such as MF:PS (99:1), Avo:PS:CB (84:7:9) and PO:PS:SBO:CB (38:5:52:5) to those of LD shortening in term of hardness, consistency, microstructure and polymorphism.

2. MATERIALS AND METHODS

2.1. Materials

LD was extracted using three batches of adipose tissues of swine collected from local slaughter houses. Dried fruit seeds of mee (*Madhuca longifolia*) were collected from three different locations in the North Central Province of Sri Lanka. Avocado fruits were collected from two locations in West Malaysia. Samples of palm oil and palm stearin were obtained as generous gifts from the Malaysian Palm Oil Board (MPOB). Samples of CB were purchased from Malaysian Cocoa Board while samples of SBO were purchased from a supermarket in Malaysia (Sime Darby Food Marketing Sdn Bhd, Selangor, Malaysia). All chemicals used in this experiment were of analytical or HPLC grade obtained from BDH Laboratories (Poole, England) and Merck (Darmstadt, Germany).

2.2. Sample pretreatment

Avocado fruits were cut open, and minced manually into fine pieces after removing the seeds. The minced pieces of the avocado mesocarp were dried in a tray type dryer (Memmert Model UFB 400, GmbH + Co. KG, Germany) for 24 h at 60 °C and subsequently ground into powder using a Warring blender Model 32BL80 (Dynamic Corporation of America, New Hartford, CT).

2.3. Extraction of MF and Avo

Fat extractions from finely ground samples of mee seeds and dried avocado were carried out via the soxhlet extraction method using petroleum ether (at 40–60 °C) for 8 h (AOAC, 2007). The extracted fats were used for the preparation of binary, tertiary and quaternary blends after expelling solvent under reduced pressure using a rotary evaporator system.

2.4. Blends preparation

Firstly, all fats were heated at 70 °C until completely melted to erase the memory crystals present in the matrix systems. All fats were weighed and mixed at different ratios in triplicate. The formulated blends were as follow: binary: MF:PS (99:1); ternary: Avo:PS:CB (84:7:9); quaternary: PO:PS:SBO:CB (38:5:52:5).

2.5. Preparation of shortening

Shortening was produced on a laboratory scale following a method described by Danthine *et al.* (2005) with some modification. Initially, 500 g of each fat blend was melted at 70 °C for 10 min to erase crystal memory. A pre-cooling stage was then introduced at 50 °C for 15 min before the blend was crystallized under shear at 20 °C and 125 rpm for 45 min. This procedure was performed in a 1L jacketed glass reactor connected to a water-bath (Lauda, Germany). The resulting slurry was transferred to a freezer at −20 °C for 45 min to complete the crystallization. The shortening was then stored in a thermostatic cabinet at 25 °C ± 1° C for 24 h prior to use for analysis. The same procedure was repeated for all fat blends and LD.

2.6. Determination of triacylglycerol (TAG) composition

The TAG compositions of the samples were determined according to the method described by Yanty *et al.* (2014) using a Waters Model 510 liquid chromatography equipped with a differential refractometer Model 410 as the detector (Waters Associates, Milford, MA). The analysis of TAG was performed on a Merck Lichrosphere RP-18 column (5 μm) (12.5 cm × 4 mm i.d.; Merck, Darmstadt, Germany) which was maintained at 30 °C. The mobile phase was a mixture of acetone:acetonitrile (63.5:36.5) and the flow rate was 1.5 mL/min. The injector volume was 10 μL of 5% (w/w) oil in chloroform. Each sample was chromatographed three times, and the data were reported as peak area percentages. The identification of the peaks of the samples was made using a set of TAG standards purchased from Sigma-Aldrich (Deisehofen, Germany) as well as the TAG profiles of LD, PS, and Avo reported previously.

2.7. Hardness, compression force and adhesiveness by texture analyzer

The determination of the hardness of the shortening was carried out using a TA.HD *Plus* Model texture analyzer (Stable Micro System, Surrey, United Kingdom) according to the method described by Kanagaratnam *et al.* (1995). Before analysis, samples were melted at 70 °C for 10 min, followed by chilling at −20 °C for 90 min, and then tempered at 25 °C for 24 h. Hardness of the samples was then determined as follows: A 5-mm cylinder (P/5) was used as probe with a 5-kg load cell. A 5 g surface trigger was attached to the probe. During the test, the probe was released to penetrate the sample to a depth of 5 mm with a pre-test speed of 1 mm/s, test speed of 2 mm/s, and post-speed of 1 mm/s. The measurements were performed in triplicate for each sample. The hardness of the shortening was indicated by the maximum force detected during compression. The positive area denotes the compression force while the negative area denotes the adhesiveness force.

2.8. Consistency evaluation by penetrator

The consistency of the shortening was determined in terms of penetration yield value (g/cm^2) (deMan *et al.*, 1991) using a cone penetrometer (Stanhope-Seta, Surrey, England) with a 40° angle, where the weight of the cone assembly was 79.03 g. The penetrating cone was placed just above the surface of the sample before it was released. The penetration time was 5 s and penetration depth was read directly from the instrument in 0.1 mm unit. Yield values were calculated using Equation 1:

$$\text{Yield value } (g/cm^2) = KW/P^{1.6} \quad (1)$$

where, K = constant (5840 for 40° cone angle), W = weight of the cone assembly (79.03), P = mean of penetration depth from two replicates (mm).

2.9. Determination of microstructure by polarized light microscopy (PLM)

PLM (Olympus, Model BH-2, Tokyo, Japan) was used to determine the microstructure of the shortening (Litwinenkoa *et al.*, 2002). The microscopical examination was conducted after placing a drop of shortening, which was removed immediately from the incubator (25 °C ± 1.0 °C) onto a glass slide covered by a glass slip and viewed under PLM connected to a video color camera (Leica Q500mc Qwin Vol 0.02, Leica Cambridge Ltd., Cambridge, UK).

2.10. Crystal polymorphism by XRD

The polymorphic forms of the shortening fat crystals were determined using a wide angle X-ray diffraction (WAXD) machine (D8 Advance Bruker AXS, Karlsruhe, Germany). The power used was 40 Kv, 40 mA with the source of beam from Cu Kα1 X-ray beam (λ = 0.15406 Å). The samples were scanned from 15°2θ to 25°2θ, increasing with a step size of 0.025°/0.1 sec (Ribeiro *et al.*, 2009). Short spacing on the X-ray film was measured with an Evaluation Diffract plus software. The short spacings of the β′ form were at 4.2 and 3.8 Å while that of the β form was at 4.6 Å (D'Souza *et al.*, 1991).

2.11. Statistical analysis

All analyses were carried out in triplicate and the results were expressed as mean value ± standard deviation. Data were statistically analyzed by one-way analysis of variance (ANOVA), by using Tukey's Test of MINITAB (version 15) statistical package at 0.05 probability level.

3. RESULTS AND DISCUSSION

3.1. Triacylglycerol compositions

The TAG distribution pattern of the three formulated shortenings and LD shortenings were compared as shown in Table 1. According to Litwinenkoa *et al.* (2002), TAG composition plays an important role in determining the physical and functional properties of shortening. LD had POL, POO, PPO, and StPO as the most dominant TAG molecules. The most dominant TAG molecule of binary and ternary shortening was POO while that of quaternary shortening was PPO. Although there were wide variations between the formulated plant-shortening and LD with regard to proportions of several TAG molecules, some similarities were still seen in some respects. For instance, there were no significant ($p > 0.05$) differences among the three formulated shortenings and LD with regard to the proportion of PPSt. Likewise, no significant ($p > 0.05$) differences were noticed between ternary shortening and LD with regard to amounts of LLL, OOL, and POO. Quaternary shortening and LD displayed the smallest difference with regard to the proportion of de-saturated TAG contents. This was because only small differences were seen between these two with regard to the proportions of TAG molecules such as PLL, OOL, OOO, and StOSt.

3.2. Hardness, compression force and adhesiveness of shortening by texture analyzer

The hardness values of the formulated shortening and LD shortening were compared as shown in Table 2. Hardness is the resistance to

Table 1. TAG composition of formulated plant-based shortening and LD shortening[1]

TAG	Binary	Ternary	Quaternary	LD
LLnLn	n.d	n.d	0.70 ± 0.01^{a}	n.d
LLLn	n.d	1.56 ± 0.01^{a}	3.93 ± 0.01^{b}	1.54 ± 0.21^{a}
OLnLn	n.d	n.d	0.01 ± 0.00^{a}	n.d
LLL	n.d	0.58 ± 0.01^{a}	12.23 ± 0.02^{b}	0.68 ± 0.21^{a}
PLLn	n.d	n.d	1.90 ± 0.01^{a}	n.d
OLL	0.51 ± 0.01^{a}	2.72 ± 0.02^{b}	9.28 ± 0.03^{d}	4.68 ± 0.08^{c}
MMM	n.d	n.d	0.16 ± 0.01^{a}	n.d
PLL	0.43 ± 0.01^{a}	3.58 ± 0.01^{b}	8.23 ± 0.04^{c}	7.05 ± 0.06^{d}
MPL	n.d	n.d	0.19 ± 0.01^{a}	n.d
POLn	n.d	n.d	0.06 ± 0.00^{a}	n.d
OOL	2.91 ± 0.01^{a}	6.98 ± 0.04^{c}	5.58 ± 0.04^{b}	6.93 ± 0.04^{c}
POL	5.11 ± 0.11^{a}	16.18 ± 0.22^{c}	11.31 ± 0.02^{b}	20.00 ± 0.27^{d}
PPL	1.66 ± 0.06^{a}	2.62 ± 0.02^{a}	5.02 ± 0.02^{b}	2.62 ± 0.20^{a}
OOO	9.11 ± 0.40^{c}	9.62 ± 0.04^{c}	3.14 ± 0.01^{a}	4.33 ± 0.21^{b}
POO	23.56 ± 0.06^{c}	19.36 ± 0.12^{b}	10.87 ± 0.04^{a}	20.67 ± 0.11^{b}
PPO	15.29 ± 0.06^{c}	13.28 ± 0.01^{b}	13.48 ± 0.20^{b}	10.63 ± 0.01^{a}
PPP	2.51 ± 0.01^{b}	7.07 ± 0.01^{d}	4.90 ± 0.04^{c}	0.38 ± 0.00^{a}
StOO	9.84 ± 0.08^{d}	0.71 ± 0.01^{a}	1.85 ± 0.02^{b}	3.62 ± 0.04^{c}
StPO	18.41 ± 0.06^{d}	10.56 ± 0.06^{b}	4.58 ± 0.02^{a}	12.52 ± 0.12^{c}
PPSt	0.79 ± 0.05^{a}	0.79 ± 0.06^{a}	0.86 ± 0.04^{a}	0.81 ± 0.04^{a}
StOSt	5.61 ± 0.13^{d}	3.54 ± 0.01^{c}	1.59 ± 0.01^{b}	0.83 ± 0.01^{a}
StStSt	0.59 ± 0.05^{c}	0.21 ± 0.01^{b}	0.02 ± 0.00^{a}	1.31 ± 0.01^{d}
Others	3.71 ± 0.10	0.69 ± 0.33	n.d	1.41 ± 0.33
UUU	12.53	21.44	34.89	18.16
UUS	38.94	39.83	34.22	51.34
USS	40.97	33.61	24.86	26.60
SSS	1.38	8.00	5.94	2.50

[1]Each value in the table represents the mean of three determinations. Means within each row bearing different superscripts are significantly different ($p < 0.05$). [2]Abbreviations: TAG, triacglycerol; Binary, MF:PS (99:1); Ternary, Avo:PS:CB (84:7:9); Quaternary, PO:PS:SBO:CB (38:5:52:5); LD, lard; O, oleic; P, palmitic; L, linoleic; Ln, linolenic; St, stearic; U, unsaturated; S, saturated; n.d, not detected.

deformation, which is a critical factor in determining the functionality and consumer acceptance of semi-solid fat systems (de Man *et al.,* 1991). There is a possibility that fat products with similar SFC profiles could tend to display similar hardness characteristics. According to Table 2, the hardness value of LD shortening was 25.67 g while those of the binary, ternary, and quaternary shortening mixtures were 26.19 g, 28.35 g and 26.66 g, respectively. According to statistical analysis, there was no significant ($p > 0.05$) difference among the hardness values of LD and those of the three formulated plant-based shortenings. Previously, Yanty *et al.* (2014) reported that the binary mixture of MF:PS (99:1) and LD had the smallest differences in their SFC profile at 5 and 25 °C. Likewise, the LD and ternary fat mixture of Avo:PS:CB (84:7:9) were found to display roughly similar SFC values at 5, 25 and 35 °C (Yanty *et al.*, 2016). In another study, the LD and quaternary fat mixture of PO:PS:SBO:CB (38:5:52:5) was also found to display similarities in the SFC at 5 and 25 °C (Yanty, 2016). These similarities in the SFC profiles of formulated plant-based mixtures and LD in various temperature regions could be attributed to the observed similarities in their hardness values. It has been stated that the hardness characteristic of plastic fats has a good correlation with their SFC profiles and could be the result of a structurally stronger network produced with the increasing solid content (Narine and Humphrey, 2004).

Compression force is of great interest with regard to the texture of plastic shortening. Researchers previously commented that the compression force of shortening is closely related to its SFC as well as the constituent TAG molecular groups (Liu *et al*., 2010). According to Table 2, the highest compression force was recorded for the ternary mixture shortening (190.34 g/s), followed by binary (190.00 g/s), LD (187.10 g/s) and quaternary (186.74 g/s) shortening mixtures. Although the compression force of quaternary and LD shortening were found to be lower than those of binary and ternary shortening, there were no significant ($p > 0.05$) differences among them statistically. As seen before, the observed similarities between the compression force values of LD and the formulated shortening mixtures could be attributed to the similarities in their SFC profiles at various temperatures. According to Marangoni (2002), however, polymorphism and microstructure are another two factors which might have some influence on compression force.

Another important property related to the texture of shortening is adhesiveness. According to Table 2, the adhesiveness value of binary, ternary, quaternary shortening and LD were 135.86, 137.00, 82.46 and 123.88 g/s, respectively. The adhesiveness values of binary and ternary were similar to that of LD while the adhesiveness value of quaternary shortening was significantly ($p < 0.05$) different from any other shortening type investigated. This could probably be due to the fact that quaternary shortening had a higher proportion of tri-unsaturated TAG while ternary shortening contained a higher proportion of tri-saturated TAG (Table 1). According to Kanagaratnam *et al.* (2013), the free liquid present inside shortening could also contribute to the increase in adhesiveness values of shortening.

3.3. Consistency of shortening by penetrator

The data presented in Table 2 shows the yield values of the shortening. 'Yield value' is the most used parameter to evaluate the consistency of fats. Consistency denotes those aspects of the food texture that relate to flow and deformation. The highest yield value belonged to the ternary shortening mixture (326.26 gf/cm^2), followed by LD (323.43 gf/cm^2), binary (320.89 gf/cm^2) and quaternary (319.20 gf/cm^2) shortening mixtures. However, no significant ($p > 0.05$) difference was noticed among the different shortening types. The consistency of the quaternary mixture shortening was the lowest when compared to any other shortening probably due to the highest amount of tri-unsaturated TAGs (34.89%) (Table 1). This observation was in accordance with Silva *et al.* (2008) who also found that interesterifed fat mixtures with higher amounts of

Table 2. Hardness, compression force, adhesiveness and consistency of formulated plant based shortening and LD shortening[1]

Shortening	Hardness (g)	Compression force (g/s)	Adhesiveness (g/s)	Consistency (g/cm^2)
MF:PS (99:1)	26.19 ± 2.57^a	190.00 ± 16.22^a	135.86 ± 12.55^b	320.89 ± 2.11^a
Avo:PS:CB (84:7:9)	28. 35 ± 3.55^a	190.34 ± 12.21^a	137.00 ± 11.43^b	326.26 ± 1.09^a
PO:PS:SBO:CB (38:5:52:5)	26.66 ± 2.10^a	186.74 ± 14.56^a	82.46 ± 10.43^a	319.20 ± 2.23^a
LD	25.67 ± 2.33^a	187.10 ± 16.11^a	123.88 ± 11.95^{a,b}	323.43 ± 1.22^a

[1]Each value in the table represents the mean of three determinations. Means within each column bearing different superscripts are significantly different ($p < 0.05$).
Abbreviation: MF, mee fat; PS, palm stearin; Avo, avocado fat; CB, cocoa butter; PO, palm oil, SBO, soybean oil; LD, lard.

tri-unsaturated TAGs had lower consistency values. According to Haighton's (1959) classification, the yield value of fats between 200-800 gf/cm^2 was categorized as plastic fats that can be spreadable. Since the three formulated plant-based shortenings of this study had yield values between 219.20 and 226.26 g/cm^2, they also could be classified as plastic and spreadable products.

3.4. Crystal morphology

The crystal morphology of binary, ternary, and quaternary shortenings and LD shortenings are compared as shown in Figures 1a, 1b, 1c and 1d, respectively. Crystal size property is important for final product consistency and acceptability since smaller crystals lead to firmer fat products, while larger crystals might produce a sandy feeling in the mouth. In an early report from the fifties, Hoerr and Waugh (1950) mentioned that native LD consisted of large crystals while chemically-rearranged LD displayed small crystals. According to Figure 1a, the crystal network of LD shortening was composed of a high amount of larger crystals with a lesser amount of smaller crystals in a lacy network. This was in accordance with the findings reported by Silva *et al.* (2008) as well as Campos *et al.* (2002) who reported that pure LD had a granular crystal structure composed of large crystals. According to a number of other reports, the crystal morphology of fats is also influenced by crystallization temperature, cooling rate and velocity of agitation (Campos *et al.*, 2002). Out of the three formulated plant-based shortenings, only binary (Figure 1b) displayed a crystal pattern somewhat similar to that of LD shortening. The crystal pattern of ternary shortening (Figure 1c) was found to contain smaller well-organized spherulites with a greater number of needle-shaped crystals. According to Figure 1d, quaternary shortening showed the greatest amount of tiny spherulites, which were more tightly packed with less space between adjacent crystals when compared to those found in binary, ternary and LD shortening. This could probably be due to TAG composition where quaternary shortening had a higher proportion of tri-unsaturated TAGs (34.89%) when compared to the other shortening types investigated (Table 1). This difference might also be due to the gap between the crystallization temperature and melting point of the shortening. According to Gamboa and Gioielli (2006), the crystal morphology of fats could be influenced by their melting points as for instance a greater number of smaller crystals are formed when the crystallization temperature is far from the melting point of the fat. According to our previous report (Yanty, 2006), the melting point of quaternary shortening was higher (41.25 °C) than those of binary (37.25 °C), ternary (40.50 °C) and LD (27.5 °C) shortening.

3.5. Polymorphism

The diffractograms of formulated plant-based shortening and LD shortening are compared as in Figure 2. LD displayed both β' and β-form polymorphs, of which the β' form was found to be dominant. This could probably be due to the presence of the monounsaturated TAG (USS) molecular species of LD such as PPL, PPO, StOP, and StOSt. The data presented in Table 2 show that these were important components of the TAG molecular

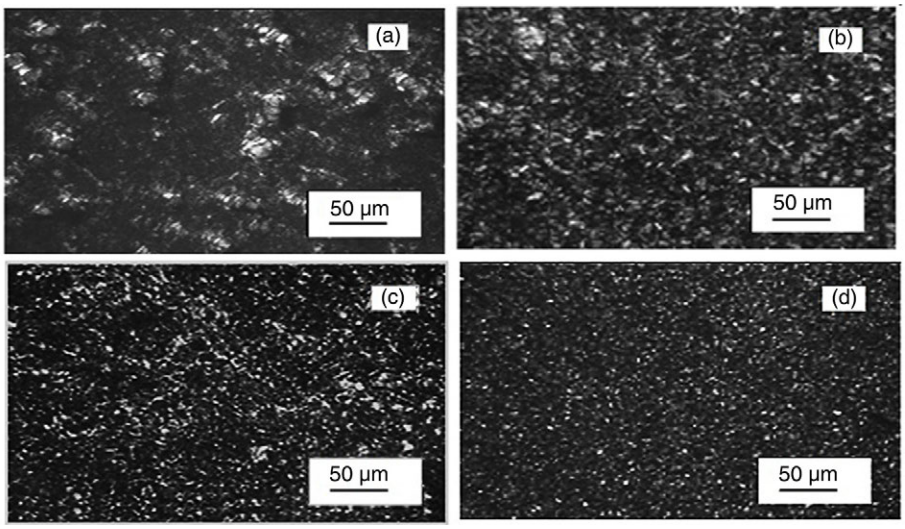

FIGURE 1. Crystal distribution of a) LD, b) binary mixture, c) ternary mixture and d) quaternary mixture shortening at magnification of 10x10

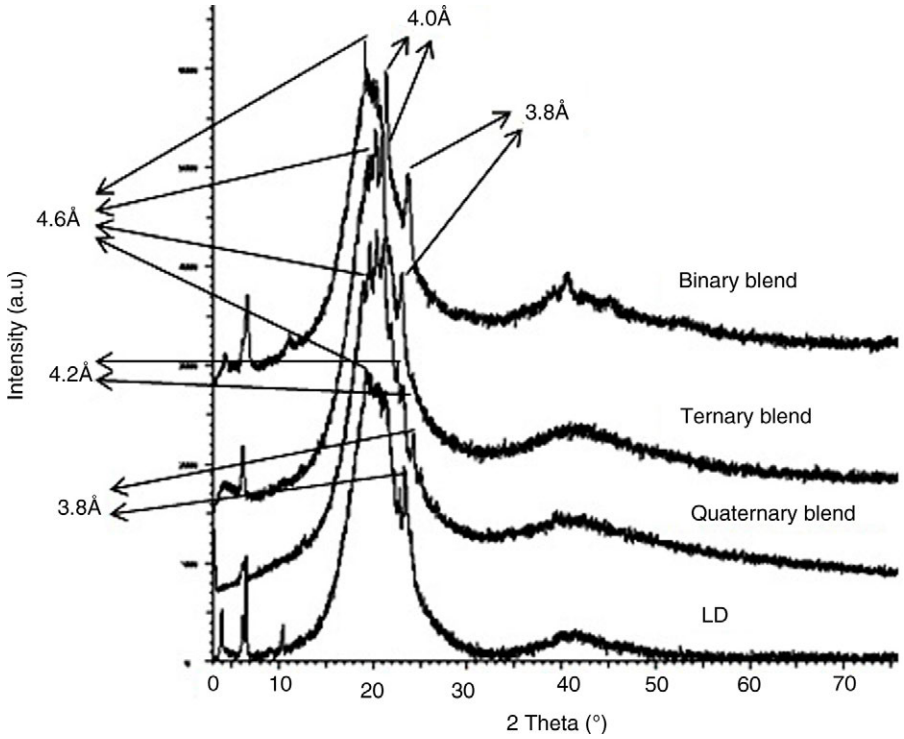

FIGURE 2. Diffractogram of LD and formulated plant based shortening
Abbreviation: LD, lard

species of LD, contributing to up to 26.6% of the total. According to Timms (1984), the development of the β' crystal polymorph in LD is mostly influenced by TAG molecules such as StPO (12.52%). Apart from the influence of molecular composition, crystallization conditions also play an important role. According to Campos *et al.* (2002), LD crystallized in either β' in rapid crystallization or both β' and β forms in slow crystallization. Apart from this, the heat treatment applied to LD may have an effect on the polymorphic forms (Herrera *et al.*, 1998). In this case, LD was exposed to a change in temperature from 20 °C to −20 °C. With the decrease in crystallization temperature, the rate of nucleation became rapid, leading to the formation of a large number of nuclei, which resulted in smaller crystals. The tendency of these smaller crystal formations has lead LD to take the β'-form of polymorph. In the meantime, all formulated plant-based shortening also displayed both the β polymorphic form at 4.6 Å and the β' polymorphic form at 3.8 Å and 4.2 Å. This kind of crystal form is consistent with small spherulites observed previously in the formulated plant-based shortening. According to O'Brien (2004), fats with the β'-form polymorph are softer and display good aeration and creaming properties. Because of this reason, the β'-form polymorph is preferred for the production of fat-rich foods such as cakes, biscuits and other confectionary products (Oh *et al.*, 2005).

4. CONCLUSIONS

This study demonstrated the feasibility of producing plant-based shortening to mimic the composition and functional properties of LD shortening. There were no significant ($p > 0.05$) differences among the three formulated shortenings and LD with regard to proportion of PPSt TAG molecules. Likewise, no significant ($p > 0.05$) differences were noticed between ternary shortening and LD with regard to amounts of LLL, OOL, and POO. All three formulated plant-based shortenings did not show significant ($p > 0.05$) difference with LD shortening with respect to consistency, hardness or compression values. However, only binary and ternary shortening did not show significant ($p > 0.05$) difference with LD shortening with respect to adhesiveness values. From a microscopic view, the number and crystal size of all formulated plant-based shortening were found to be dissimilar to those of LD shortening. However, all plant-based shortening and LD shortening displayed a mixture of β' and β-form polymorphs of which the β' form was the most predominant polymorph.

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