GRASAS Y ACEITES 73 (2)
April-June 2022, e463
ISSN-L: 0017-3495
https://doi.org/10.3989/gya.0439211

Recent advances in plant-based fat formulation as substitute for lard

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Submitted: 08 April 2021; Accepted: 08 July 2021; Published online: 14 June 2022

SUMMARY: Lard is one of the main animal fats used as shortening and frying medium. Religious prohibitions and negative health perceptions regarding animal fats have caused concerns about the consumption of lard among communities living around the world. Various research efforts have been made in the past to formulate plant-based fats and shortenings as substitutes for the exclusion of lard from food. This would eventually help countries to regularize food formulations according to their religious compliance. As the existence of a single plant fat as substitute for lard has not been discovered from nature, researchers attempted to study the possibility of mixing native fats and oils such as enkabang fat, canola oil, guava oil, palm oil, palm stearin, soybean oil and cocoa butter as raw materials. The compatibility of the formulated plant-based fat substitute for lard was assessed in terms of chemical composition and thermo-physical properties. The formulated plant-based shortenings and lard shortening were simply plastic fats based on their consistency value and existence of β' and β-form polymorphs of which the β' -form was dominant. The functional properties of formulated plant-based shortenings and lard were also compared in the formulation of cookies. Although a substantial amount of work has been done over the past decade, there was hardly any discussion on the pros and cons of the approaches used for raw material selection and the criteria adopted in the assessment of the formulated products. Hence, this review intended to bring an update of the progress of studies with regard to these two aspects.

KEYWORDS: *Avocado fat; Cocoa butter; DSC; Lard substitute; Palm stearin; Thermal analysis*

RESUMEN: ***Avances recientes en la formulación de grasas a base de plantas como sustituto de la manteca de cerdo.*** La manteca de cerdo es una de las grasas animales que se utiliza principalmente como manteca y como medio para freír. Las prohibiciones religiosas y las percepciones de salud negativas con respecto a las grasas animales han causado preocupación sobre el consumo de manteca de cerdo entre las comunidades que viven en todo el mundo. Se han realizado varios esfuerzos de investigación, en el pasado, para formular grasas y mantecas vegetales como sustitutos de la exclusión de la manteca de cerdo de los alimentos. Esto eventualmente ayudaría a los países a regularizar las formulaciones de alimentos de acuerdo con el cumplimiento religioso. Como todavía no se ha descubierto en la naturaleza la existencia de una sola grasa vegetal como sustituto de la manteca de cerdo, los investigadores intentaron estudiar esta posibilidad mezclando grasas y aceites nativos como grasa enkabang, aceite de canola, aceite de guayaba, aceite de palma, estearina de palma, aceite de soja y manteca de cacao como materia prima. Se evaluó la compatibilidad del sucedáneo de grasas vegetales formuladas con la manteca de cerdo en términos de composición química y propiedades termofisicas. Las mantecas vegetales formuladas y la manteca vegetal eran simplemente grasas plásticas basadas en su valor de consistencia y la existencia de polimorfos de las formas β 'y β de las cuales la forma β' era dominante. También se compararon las propiedades funcionales de las mantecas vegetales formuladas y la manteca de cerdo en la formulación de galletas. Aunque se ha realizado una cantidad considerable de trabajo durante la última década, apenas hubo discusión sobre los pros y los contras de los enfoques utilizados para la selección de materias primas y los criterios adoptados en la evaluación de los productos formulados. Por tanto, esta revisión pretendía aportar una actualización del avance de los estudios en relación con estos dos aspectos

PALABRAS CLAVE: *Análisis térmico; DSC; Estearina de palma; Grasa de aguacate; Manteca de cacao; Sustituto de manteca de cerdo*

Citation/Cómo citar este artículo: Marikkar JMN, Yanty NAM, Musthafa S, Miskandhar MS. 2022. Recent advances in plant-based fat formulation as substitute for lard. *Grasas Aceites* **73** (2), e463. https://doi.org/10.3989/gya.0439211

1. INTRODUCTION

In recent times, animal fats have received much attention from the scientific community throughout the world. Lard and tallow, in particular, have been used in international trade over several decades due to their widespread availability and use in food-processing. Various research reports have highlighted the use of lard in Europe (Paleari *et al*., 2004), North America (deMan *et al*., 1991) and Asia (Hsu and Yu, 2002). Apart from being used as a medium for deep-frying, animal fats are also used as shortening in bakery products due to their lower cost. According to a food analysis report, some commercial biscuit formulations were found to contain lard as an ingredient (Yanty *et al.*, 2014b). According to Kamel (1992), the inclusion of lard in bread making formulations was mainly due to the unique liquid-to-solid content ratio. Its performance characteristics during food processing as well as flavors imparted to fried products are said to be other reasons (Marikkar and Yanty, 2014). In a separate study, Seriburi and Akoh (1998) formulated a variety of plastic shortenings by blending lard with sunflower oil in different ratios due to these reasons. Although the use of lard has always been popular among certain ethnic groups, its consumption has become a controversy for communities whose religious restrictions command the exclusion of swine-based products (Regenstein *et al*., 2003). Other than this, the negative health implication of animal fats in general has caused some concern about the consumption of lard among various communities. One proactive approach for the exclusion of lard in food is to provide a potential alternative substance which would mimic its properties. During the last couple of years, a number of research reports have emerged to study the partial replacement of lard in various meat products (Delgado-Pado *et al*., 2011; Rodriguez–Carpena *et al*., 2011; Choi *et al*., 2010; Muguerza *et al*., 2003). A brief survey of the recent literature would give evidence for initiatives taken to fully replace lard by screening various raw materials and evaluating formulated substitutes (Table 1). However, there was hardly any attempt to revisit the pros and cons of the approaches used in raw material selection and the criteria adopted for the assessment of these efforts. Hence, it is pertinent to critically analyze these as-

Table 1. Lard substitute formulations using a variety of native fats and oils[1]

Raw materials	Blending types	Formulated blending ratios	Assessment methods	Observations	References
MF and PS	Binary	MF:PS (99.5:0.5); MF:PS (99:1); MF:PS (98:2)	SMP and IV; Chemical compositional data; DSC thermal properties; SFC and polymorphic profiles	MF:PS (99:1) and lard had closest compatibility	Yanty *et al.,* 2014a
EF and CO	Binary	EF:CO (25:75); EF:CO (30:70); EF:CO (35:65); EF:CO (40:60)	-do-	EF:CO (35:65) and lard had closest compatibility	Nur Illiyin *et al.,* 2014; Nur Illiyin *et al.,* 2013
PS and GO	Binary	PS:GO (40:60); PS:GO (45:55); PS:GO (50:50); PS:GO (55:45)	-do-	PS:GO (55:45) and lard had closest compatibility	Raihana *et al.,* 2017a
Avo, PS and CB	Ternary	Avo:PS:CB (88:7:5); Avo:PS:CB (86:7:7); Avo:PS:CB (84:7:9)	-do-	Avo:PS:CB (84:7:9) and lard had closest compatibility	Yanty *et al.,* 2017a
PO, PS, SBO and CB	Quaternary	PO:PS:SBO:CB (38:5:52:5); PO:PS:SBO:CB (36:5:54:5); PO:PS:SBO:CB (34:5:56:5)	-do-	PO:PS:SBO:CB (38:5:52:5) and lard had closest compatibility	Marikkar *et al.,* 2018

[1]Abbreviations: MF, mee fat; PS, palm stearin; GO, guava seed oil; CO, canola oil; Avo, avocado oil; CB, cocoa butter; EF, engkabang fat; PO, palm oil; PS, palm stearin; SBO, soybean oil; LD, lard.

pects by bringing an update of the progress of studies in this arena.

More than 100 different varieties of plant species in nature with oil-bearing seeds and fruits (Raihana *et al.,* 2015) have been detected. Among these, the availability of a single plant fat as substitute for lard is yet to be discovered mainly due to the natural differences in compositions. Nevertheless, the judicious mixing of different plant fats and oils in appropriate ratios could yield a formula that would mimic lard. Producing novel fat products by blending oils and fats is the easiest and most economical way without involving any chemical treatment. In addition, this approach could preserve their natural flavors, organoleptic characteristics and nutritional attributes. Fractional crystallization and interesterification could become complementary to these endeavors if they could help modify physical properties by changing either fatty acid or TAG compositions (Marikkar and Ghazali, 2011). The outcome of any effort in this direction needs to be assessed according to some meaningful criteria. It should be devoid of any component of animal origin and mimic lard in composition as well as physical characteristics. The analytical approaches used should be comparable to those adopted for the assessment of *trans*-free fats (Miskandar, and Nor Aini, 2010), structured lipids (Norizzah *et al.*, 2004), and cocoa butter equivalents (Jahurul *et al.*, 2014; Wassell and Young, 2007). Generally, in the assessment of any novel fat formulation, researchers pay attention to aspects such as fatty acid and triacylglycerol compositions, melting and crystallization behavior, solidification and polymorphic characteristics (Jun Jin *et al.*, 2018). The nutritional status of fats along with their other functional characteristics can also be decided using fatty acid and triayclgylcerol compositions. In the fractionation of fats and interesterification of structured lipids or formulation of cocoa butter equivalents, these two aspects have been investigated (Ramli *et al.*, 2008; Jahurul *et al.*, 2014; Marikkar and Yanty, 2014). According to some previous reports, thermal analysis by DSC has been shown to be a useful approach to determine a variety of thermal properties involving fat modification (Yanty *et al.*, 2013a; Yanty *et al.*, 2013b; Nur Illiyin *et al.*, 2014). Other parameters such as solid fat content (SFC) measurements by pulse NMR spectroscopy have helped to monitor the changes in hardness as a function of the percentage of solids at different temperatures (Nor Lida *et al.*, 2002). Crystal morphology, using polarized light microscopy and polymorphic behavior using the powder X-ray diffraction method are examined to identify their suitability as shortenings. In this article, we intend to review the usefulness of different analytical approaches, namely GC/GLC, HPLC, DSC, and pulsed nuclear magnetic resonance spectroscopy in the assessment of the formulated plant-based fat substitutes for lard.

2. CHEMICAL COMPOSITION AND PHYSICAL CHARACTERISTICS OF LARD

A great deal of effort has been devoted to compiling the chemical composition and physical properties of lard and its modified forms such as its fractions (Nina Naqiyah *et al.,* 2017; Marikkar and Yanty, 2014). Similar to most oils and fats, lard and its fractionated component are mainly composed of TAG molecules. Unlike other oils and fats, TAG species occurring in higher amounts in lard are esterified with palmitic acid, predominantly in the sn-2 position of the glycerol backbone (Marikkar *et al.,* 2021; Rashood *et al.,* 1996). According to previous studies, lard generally consists of more unsaturated fatty acids (51.3 to 65.9%) than saturated (34.1 to 48.7%) fatty acids (Marikkar and Yanty, 2014). Among its saturated fatty acids, palmitic and stearic acids are more prominent and among the unsaturated fatty acids, oleic acid (40.17%) has emerged as the most dominant fatty acid, followed by linoleic acid (17.25%) (Table 2). The observed variations in fatty acid composition are said to be due to sample-to-sample differences caused by the diet of the animals, breed type, etc. Native lard usually exists in semi-solid form at room temperature and its slip meting point is found to vary from 28 to 32 °C (Marikkar *et al*., 2017; Marikkar *et al*., 2021). Its shorter plastic range, sharp melting point and larger crystal size are said to be due to the unique composition of lard.

In the study on the physical properties of lard, DSC thermal analysis is one of the approaches adopted by several research groups. As of date, this has contributed immensely to the understanding of the thermal behavior of several lipids, including the melting and crystallization behavior of both plant and animal fats (Marikkar, 2015). Over the years, the DSC thermal curves of various animal fats have been compiled by several research groups, and are

Table 2. Basic physico-chemical characteristics and fatty acid compositions (%) of formulated substitutes for lard from different studies[1]

Parameter	EF:CO (30:70)	PS:GO (55:45)	MF:PS (99:1)	Avo:PS:CB (84:7:9)	PO:PS:SBO:CB (38:5:52:5)	LD
SMP	29.3[a]	49.70[d]	38.50[b]	40.50[c]	41.25[c]	29.5[a]
IV	101.85[f]	42.78[a]	56.04[b]	65.47[c]	92.26[e]	73.68[d]
Fatty acids						
Lauric	n.d.	0.12[a]	n.d.	n.d.	0.11[a]	n.d.
Myristic	n.d.	0.74[a]	0.02[a]	0.03[a]	0.54[a]	n.d.
Palmitic	8.10[a]	37.82[e]	23.53[b]	32.97[d]	27.88[c]	23.78[b]
Palmitoleic	0.17[a]	0.08[a]	n.d.	2.66[a]	0.11[a]	2.00[a]
Stearic	16.32[d]	4.86[a]	21.29[e]	4.57[a]	7.83[b]	12.96[c]
Oleic	51.92[e]	18.05[a]	47.05[d]	44.04[c]	29.39[b]	40.17[c]
Linoleic	15.06[b]	37.84[e]	8.11[a]	14.28[b]	30.78[d]	17.25[c]
Linolenic	4.94[b]	0.11[a]	n.d.	1.02[a]	2.96[a]	n.d.
Arachidic	1.06[a]	0.39[a]	n.d.	0.44[a]	0.43[a]	0.74[a]
Gadoleic	0.86	n.d.	n.d.	n.d.	n.d.	-
Others	-	-	-	-	-	2.46
Reference	Nur Illyin *et al*., 2013	Raihana *et al*., 2017a	Yanty *et al*., 2014a	Yanty *et al*., 2017a	Marikkar *et al*., 2018	Nur Illyin *et al*., 2013

[1]Each value in the table represents the mean of three replicates. Means within each row bearing different superscripts are significantly ($p < 0.05$) different.
Abbreviations: MF, mee fat; PS, palm stearin; GO, guava seed oil; CO, canola oil; Avo, avocado oil; CB, cocoa butter; EF, engkabang fat; PO, palm oil; PS, palm stearin; SBO, soybean oil; LD, lard; SMP, slip melting point; IV, iodine value; n.d, not detectable.

now available for authentication purposes (Marikkar *et al*., 2021; Dyszel and Baish, 1992). Chemical compositional differences arising from adulteration practices are known to cause clear deviations in the original DSC profiles of pure lipids (Marikkar and Sohel Rana, 2014). According to several reports, the DSC cooling and heating thermograms of lard were unique when compared to those of other common animal fats (Marikkar *et al*., 2021). According to Yanty *et al.* (2011a), lard was found to have two major exothermic thermal transitions, which are widely separated into two distinct temperature regions (Table 3). Unlike other animal fats, lard is found to display two sharp thermal transitions as the peak at the region below 10 °C in the cooling thermogram is designated as high-melting group (HMG); while the peak at the region above 10 °C can be termed as low-melting TAG group, and vice versa in the

Table 3. DSC thermal transitions of formulated substitutes for lard reported from different studies[1]

DSC Curve type	Sample	Thermal transition (°C)				Reference
		1	2	3	4	
Cooling	EF:CO (30:70)	4.4[a]	-	-	-46.5[c]	Nur Illyin *et al*., 2013
	PS:GO (55:45)	28.2[e]	-	-4.5[c]	-	Raihana *et al*., 2017a
	MF:PS (99:1)	23.0[d]	-	0.0[a]	-30.6[b]	Yanty *et al*., 2014a
	Avo:PS:CB (84:7:9)	20.1[c]	-	-2.0[b]	-	Yanty *et al*., 2017a
	PO:PS:SBO:CB (38:5:52:5)	-	-	-	-	Marikkar *et al*., 2018
	LD	16.8[b]	10.3	-	-18.7[a]	Yanty *et al*., 2011a
Heating	EF:CO (30:70)	28.6[a]	-	-6.9[c]	-19.9[b]	Nur Illyin *et al.,* 2013
	PS:GO (55:45)	50.0[c]	-	-		Raihana *et al*., 2017a
	MF:PS (99:1)	30.1[a]	5.0	-5.0[b]	-	Yanty *et al*., 2014a
	Avo:PS:CB (84:7:9)	37.1[b]	-	-	-18.5[a]	Yanty *et al*., 2017a
	PO:PS:SBO:CB (38:5:52:5)	29.1[a]	-	-	-20.0	Marikkar *et al*., 2018
	LD	29.0[a]	-	-3.6[a]	-21.4[c]	Yanty *et al*., 2011a

[1]Abbreviations: DSC, differential scanning calorimetry; MF, mee fat; PS: palm stearin; GO, guava seed oil; CO, canola oil; Avo, avocado oil; CB, cocoa butter; EF, engkabang fat; PO, palm oil; PS, palm stearin; SBO, soybean oil; LD, lard.

melting thermogram (Table 2) (Marikkar and Yanty, 2014; Yanty *et al.*, 2011a).

The solidification behavior of any semisolid fat in a temperature region is characterized by its solid fat content (SFC), which is the solid-to-liquid ratio of a fat at a particular temperature (Mahjoob *et al.,* 2018). As such, SFC curves of fats are found to serve as useful guides to determine the suitability of a fats or oil in a particular application (Graef *et al*., 2012). Until today, several reports have appeared on the SFC profile of lard to understand its thermal behavior under varied circumstances. According to Ospina-E *et al*. (2010), the SFC curve of lard displayed a gradual drop in SFC values in the initial phase starting from 0 to 25 °C; SFC values at 0, 20 and 40 °C were 30.8, 18.0 and 0%, respectively. Somewhat similar results were later found by Yanty *et al*. (2011a) while studying the fractional crystallization behavior of lard. This later study showed that the SFC value of lard at 0 °C was 30.8% and tended to display a gradual drop in the initial phase starting from 0 to 25 °C and become 0% at 40 ºC. According to Nur Illyin *et al.* (2013), the hardness value of lard was 7.7 g, which was found to correlate well with the increasing SFC values. With regard to polymorphism, lard generally possesses larger crystals of β and β' polymorphs which are important in lubricity since they impart tenderness and richness while improving eating qualities with a feeling of satiety after eating (O'Brien, 2005).

3. CHEMICAL COMPOSITION AND PHYSICAL CHARACTERISTICS OF SUBSTITUTES

In pursuit of finding a substitute for lard, a variety of native plant fats and oils were chosen to blend with a set of liquid oils. According to Table 1, fats and oils from various plants such as oil palm (PO and PS), cocoa (CB), engkabang juntung (EF), avocado (Avo), *Madhuca longifolia* (MF), canola (CO) and soybean (SBO) were used for this purpose. Among these, PS, CB and EF are hard fats since they usually exist in solid form at tropical temperature conditions. PO, Avo, and MF are grouped together as semisolid fat category while canola oil, soybean oil and guava oil represent the liquid oil category. The blending of fats and oils has been done in the form of binary, ternary and quaternary mixtures in different ratios to formulate novel fat substances. The evaluation of the physical properties of the formulated plant-based fat blends was based on parameters such as melting point (SMP) and iodine value (IV), solid fat content (SFC) profile and thermal properties. However, the analysis of fatty acid and triacylglycerol (TAG) compositions was also inevitable as they were keys to understand the physical behaviors of formulated plant-based fat substitutes. According to several other reports, this approach has already proven to be sound for assessing the suitability of plant fat blends in numerous other industrial applications (Miskandar and Nor, 2010; Ribeiro *et al*., 2009).

3.1. Binary mixtures of EF:CO

EF is a tropical hard fat extracted from the seeds of *Shorea macrophyilla.* This has been previously known for its characteristic properties being similar to cocoa butter. Canola oil, a major vegetable oil, has been previously identified as a suitable candidate for novel fat formulations (Campbell *et al*., 2002; Marangoni and Rousseau, 1998). Several efforts have been made in the past to expand the use of EF as it is considered an under-utilized plant lipid (Yanty *et al.,* 2013b; Nesaretnam and Mohd Ali, 1992). In a previous attempt, Gani *et al*. (2011) demonstrated the usefulness of EF as a raw material for preparing moisturizers used in cosmetic products as well as hair conditioners. In a separate study, EF was fractionated into a hard stearin and a liquid olein to explore its suitability in other applications (Yanty *et al.*, 2013b).

In the search for lard substitutes, engkabang fat was mixed with canola oil in proportions ranging from 25 to 40% (w/w) (Table 1). The formulated blends appeared pale yellow in color, but displayed varying degrees of unsaturation (IV from 104.7–92.5). In fact, the IV of the formulated blends of EF:CO resulted higher than that of lard (IV, 73.6), affecting the oxidative stability. Among the physical characteristics, SMP is a parameter of considerable importance as it is indicative of the point of transition from solid to liquid. According to Nur Illyin *et al.* (2013), the SMP of the formulated blends of EF:CO fell within the range of 24.8–31.9; while the SMP of lard was 29.5. As shown in Table 2, the SMP of the EF:CO=30:70 (w/w) blend was found to tally with that of lard, despite some deviation in the degree of unsaturation.

Blending canola oil with engkabang fat brought significant deviations in chemical compositions, as shown in Tables 2 and 4. According to several previous reports, trioleoyl glycerol (OOO), dioleoyl-3-linoleoyl glycerol (OOL), and dioleoyl-3-linolinoyl glycerol (OOLn), were the major TAG molecular species of canola oil (Marikkar and Sohel Rana, 2014; Nur Illyin *et al.,* 2013; Marikkar *et al.,* 2005). The addition of engkabang fat into canola oil caused gradual but significant increases in the proportions of palmitoyl-oleoyl-stearoyl glycerol (POS) and disearoyl-2-oleoyl glycerol (SOS) with concurrent decreases in the proportions of OOO, OOL and OOLn (Table 4). For instance, the proportions of triunsaturated TAG molecular species decreased remarkably as the proportion of engkabang fat in canola oil was increased from 25 to 40% (w/w) (Nur Illyin *et al.,* 2013). When compared to canola oil, the binary blends of EF:CO were found to possess a high amount of saturated fatty acid with reduced amounts of unsaturated fatty acids. From the nutritional point of view, this would have a negative effect on the availability of essential fatty acids. This was mainly due to the increases in the proportions of palmitic and stearic acids with concurrent reductions in the amounts of oleic and linoleic acids (Nur Illyin *et al.*, 2013). Similar situations were reported previously for blending canola oil with butter oil (Marangoni and Rousseau, 1998) and canola oil with lard stearin (Marikkar and Sohel Rana, 2014). In addition to this, blending canola oil with other fats was found to steadily change the unsaturated to saturated fatty acid ratio.

The impact on DSC thermal profiles and solidification characteristics of canola oil caused by changing chemical compositions is another important aspect. As reported previously, the DSC curve of canola oil is characterized by the occurrence of two overlapping endotherms: a large-higher temperature transition at -17.86 °C and a small -lower temperature transition at -28.50 °C (Marikkar and Rana, 2014). Since the end-set of the melting of canola oil was at -6.79 °C, thermal transition beyond this point was hardly seen. All formulated fat blends, however, displayed a high-melting thermal transition in the temperature region above 10 °C and the enthalpy and peak temperature of this high-melting peak were found to increase proportionately with the increasing proportion of EF in the fat blends. This would be most probably due to the increases noticed earlier in the proportion of saturated TAG molecules in the

Table 4. TAG composition of formulated fat substitutes for lard from different studies[1]

TAG	EF:CO (30:70)	PS:GO (55:45)	MF:PS (99:1)	Avo:PS:CB (84:7:9)	PO:PS:SBO:CB (38:5:52:5)	LD
LLLn	2.49[a]	n.d.	n.d.	1.56[a]	3.93[a]	0.93[a]
LLL	5.51[b]	22.47[d]	n.d	0.58[a]	12.23[c]	0.68[a]
OLL	n.d.	6.69[c]	0.51[a]	2.72[a]	9.28[d]	4.68[b]
OLLn	6.06[b]	n.d.	n.d.	n.d.	1.97[a]	n.d.
OOLn	7.70[a]	n.d	n.d	n.d	n.d.	n.d
PLL	n.d.	8.63[c]	0.43[a]	3.58[b]	8.23[c]	7.05[c]
OOL	16.04[d]	0.16[a]	2.91[b]	6.98[c]	5.58[c]	6.93[c]
POL	3.6[a]	8.26[c]	5.11[b]	16.18[e]	11.31[d]	20.00[f]
PPL	n.d	4.24[b]	1.66[a]	2.62[a]	5.02[b]	2.62[a]
OOO	20.18[d]	1.59[a]	9.11[c]	9.62[c]	3.14[b]	4.33[b]
POO	4.54[a]	7.59[b]	23.57[e]	19.36[d]	10.87[c]	20.67[d]
PPO	2.51[a]	17.26[e]	15.29[d]	13.28[c]	13.48[c]	10.63[b]
PPP	n.d	14.68	2.51[b]	7.07[d]	4.9[c]	0.38[a]
SOO	1.53[b]	0.48[a]	9.84[d]	0.71[a]	1.85[b]	3.62[c]
SPO	11.1[d]	2.23[a]	18.41[e]	10.56[c]	4.58[b]	12.52[d]
PPS	0.18[a]	2.78[a]	0.79[a]	0.79[a]	0.84[a]	0.81[a]
SOS	15.44[d]	0.18[a]	5.61[c]	3.54[b]	1.59[a]	0.83[a]
SSS	0.27[a]	0.34[a]	0.59[a]	0.21[a]	0.02[a]	1.31[a]
Others	n.d.	n.d.	3.71[a]	0.69[a]	n.d.	1.41[a]
Reference	Nur Illyin *et al.*, 2013	Raihana *et al.*, 2017a	Yanty *et al.*, 2014a	Yanty *et al.*, 2017a	Marikkar *et al.*, 2018	Nur Illyin *et al.*, 2013

[1]Abbreviations: TAG, triacglycerol; O, oleic; P, palmitic; L, linoleic; Ln, linolenic; St, stearic; U, unsaturated; S, saturated; MF, mee fat; PS: palm stearin; GO, guava seed oil; CO, canola oil; Avo, avocado oil; CB, cocoa butter; EF, engkabang fat; PO, palm oil; PS, palm stearin; SBO, soybean oil; LD, lard; n.d, not detectable.

admixtures. Out of the four blends, the peak maxima of EF:CO (35:65) showed the closest value to that of lard, which had its maximum peak at 29.3 °C (Table 3). The SFC profiles usually describe the solidification behavior of fatty substances within a specified temperature range. For fat blends of the EF:CO series, the SFC values tended to increase throughout the temperature range with the increasing proportion of EF. Further, the increase in SFC values were found to correlate well with the increasing proportion of disaturated TAG molecules in the fat blends (Table 4). According to Rao *et al.* (2001), the SFC of a fat at 25 °C should be within the range of 15-35% to achieve the desired spreadability and texture. Further, SFC at 20 °C needs to be adjusted to more than 10% in order to avoid any oil separation in the blend. Although the SFC values of EF:CO (30:70) and lard were not similar at 0 °C, they were found to be quite similar within the range of 30-40 °C and become tallied at 25 °C. Apart from this, the results from X-ray diffractograms also showed both EF:CO (30:70) and lard possessed both β and β' polymorphs, which were ideal for a plant-based shortening (Nur Illyin *et al.*, 2013). This was because both lard and EF:CO (30:70) had roughly similar amounts of SPO (Table 4). According to Timms (1984), the presence of SPO could significantly contribute to the β' crystal polymorph's development in lard.

3.2 Binary mixtures of PS:GO

Guava seeds (*Psidium guajava* L.), discarded after juice production can be a useful material for oil extraction. According to a previous study reported from India, the Guava seed is rich in essential fatty acids such as linoleic acid (76.4%) (Prasad and Azeemoddin, 1994). Although guava oil is known for this important nutritional attribute, its commercial exploitation has not been advanced to product formulations. In search for a substitute for lard, mixing guava oil with palm stearin has been performed in varying proportions ranging from 45 to 60% (w/w) (Table 1). The SMP of all fat blends were found to be higher (SMP = 43.6 to 50.3) than that of lard (29.25), but lower than that of palm stearin (52.7) (Table 2). With regard to the degree of unsaturation, all fat blends displayed significantly lower IV values ($p < 0.05$) (IV= 42.3 to 50.6) than that of lard (73.76) (Table 2). Hence, none of the binary mixtures of PS:GO was found to have either SMP or IV similar to those of lard. As the added portion of palm stearin into guava oil increased from 45 to 60%, a clear change in the unsaturated to saturated fatty acid ratio was noticed. For instance, there was a gradual decrease in linoleic (from 46.16 to 33.91%) acid content with a concurrent increase in palmitic acid content (from 31.35 to 40.72%) (Table 2). This pattern of change was very similar to those previously observed for the EF:CO blend formulation (Nur Illyin *et al.,* 2013). Simultaneously, decreases in the proportions of TAG molecules such as LLL, OLL, PLL and POL occurred with concurrent increases in the amounts of PPO, tripalmtoyl glycerol (PPP), POS and dipalmitoyl-3-stearoyl glycerol (PPS) (Table 4). The changes were happened in such a way that the proportions of triunsaturated TAG molecular species declined from 36.79 to 27.79 % (Table 4). In fact, increases in the proportions of disaturated and trisaturated TAG molecular species led to the increase in palmitic acid content as noticed before in the overall fatty acid distribution (Table 2). As noted previously in EF:CO blend formulations (Nur Illyin *et al.*, 2013), the proportions of POS and SOS were increased while those of OOO, OOL and OOLn were decreased. In this aspect, both of these formulation efforts yielded somewhat similar patterns of changes (Table 4).

Serval previous studies indicated that the SFC values of fats are mainly influenced by their respective fatty acid and TAG compositions. According to Graef *et al.* (2012), the proportional distribution of disaturated and trisaturated TAG molecular species would have greater influence on the SFC values of fats as more saturated TAG molecules would create a stronger crystal network. Raihana *et al.* (2017a) observed that the SFC value at 5 °C of the formulated blends of PGO-1 (PS:GO=60:40), PGO-2 (PS:GO = 55:45), PGO-3 (PS:GO = 50:50) and PGO-4 (PS:-GO = 45:55) were 47.19, 47.19, 38.16 and 34.38%, respectively. The increasing values of SFC presented herein were found to correlate well with the increasing proportion of disaturated TAG molecules in the fat blends (Table 4). This observation is in conformity with the previous findings reported on EF:CO fat blends (Nur Illyin *et al.,* 2013; Nur Illyin *et al.,* 2014). Of these blends, PGO-2 was found to display a SFC value similar to lard at temperatures 15, 20, and 25 °C. Particularly, at 30 °C, the SFC value for lard (12.43%) was between the SFC values for PGO-

3 (13.70) and PGO-4 (11.81%). Based on some calculations performed with regard to least difference in SFC values, out of the four blends, PGO-1 and PGO-2 were found to display the smallest differences compared to lard in terms of SFC values.

Several previous studies pointed out that even a little change in fatty acid and TAG compositions would affect the DSC thermal profile of pure oils (Marikkar, 2015). Aziz *et al.* (2011) indicated that the mixing of palm stearin with palm oil would affect the DSC cooling profile of the formulated shortening because the high melting TAGs are introduced by palm stearin. Separately, Nur Illyin *et al.* (2013) and Nur Illyin *et al.* (2014) noticed that a little mixing of enkabang fat into canola oil caused fatty acid and TAG compositional changes which affected the thermal profile of canola oil. Likewise, the mixing of palm stearin into guava oil affected the DSC profile in such a way that all fat blends displayed high melting thermal transitions above 10 °C. The maximum peak of the high-melting thermal transitions corresponding to PGO-1, PGO-2, PGO-3 and PGO-4 shifted from 46.26 to 50.32 °C. According to this observation, out of the four formulated-blends, the peak maxima of PGO-4 (PS:GO=45:55) was at 44.20 °C and that of PGO-2 (PS:GO=55:45) was at 50.0 °C (Table 3). The results of the SMP and SFC, as well as fatty acid composition indicated that PGO-2 would become a better fat blend to substitute lard. Apart from this, the result of X-ray diffractograms also showed both PGO-2 and lard possessed with β and β' polymorphs, which were ideal for a plant-based shortening. This was quite similar to what was previously observed in the case of EF:CO (30:70), which exhibited both β and β' polymorphs (Nur Illyin *et al.*, 2013). The occurrence of a large amount of disaturated TAG molecules such as PPO in PGO-2 (Table 2) contributed to the existence of β and β' polymorphs in PGO-2.

3.3. Binary mixtures of MF:PS

Mee fat extracted from the seeds of *Madhuca longifolia* is said to be an analogue of Indian Mahua butter (Ramadhan *et al.*, 2016; Marikkar *et al.*, 2010). Although mee fat is preferred as a fat ingredient in the formulations of balms and ointments used in folk medicine (Ramadhan *et al.*, 2016), its edible uses are yet to be realized (Marikkar *et al.*, 2010). In an effort to find a substitute for lard, Marikkar and Yanty (2012) compared the solid and liquid fractions of mee fat with those of lard. Although both of these exhibited compatibility in terms of SFC values at some temperatures, they displayed some disparity at certain other temperatures. Despite this, these findings provided the impetus to formulate three fat blends by mixing mee fat with palm stearin in proportions ranging from 0.5 to 2 % (w/w) (Yanty *et al.*, 2014a). Although the IV of formulated-blends of MF:PS were significantly lower (54.27 to 57.81) ($p < 0.05$) than that of lard (73.76), their SMP were significantly higher (37.25 to 40.25) ($p < 0.05$) than that of lard (29.5 °C) (Table 2). In conformity to this, Raihana *et al.* (2017a) also noticed that the fat blends of PS:GO displayed significantly lower IV values ($p < 0.05$) (IV= 42.3 to 50.6) than that of lard (73.76). However, Nur Illyin *et al*. (2013) and Nur Illyin *et al*. (2014) reported that all formulated blends of EF:CO were found to display (104.7–92.5) higher IV values than lard (73.76). This could be due to the high contribution of monounsaturated fatty acids such as oleic in the formulated blends. When considering the thermal properties, the SMP of all fat blends of MF:PS were found to be higher (37.25 to 40.25) than that of lard (29.25) in conformity with Raihana *et al.* (2017a), who also subsequently noticed that all fat blends of PS:GO had significantly higher SMP values ($p < 0.05$) (SMP= 43.60 to 50.3) than that of lard (29.5). In contrast to these two studies, some formulated blends of EF:CO were found to display roughly similar SMP (24.8 – 31.1.5) to that of lard (29.5) (Table 1). As the proportion of palm stearin mixed into mee fat increased from 0.5 to 2%, the proportions of POL, dioleoyl-3-palmitoyl glycerol (POO), dioleoyl-3-steroyl glycerol (SOO) and SOS were decreased in such a way that the proportions of di-unsaturated TAG molecular species declined from 43.13 to 34.65 % (Table 4). In the meantime, the proportions of disaturated TAG molecular species increased, leading to the increase in palmitic acid in the overall fatty acid distribution.

As fractional crystallization would yield novel solid and liquid fractions of mee fat and lard, they were compared in terms of their physicochemical parameters and thermal properties (Marikkar and Yanty, 2012). According to this study, the mee fat and lard used had displayed compatibility in terms of SFC profiles, especially, SFC values at 5, 20 and 25 °C. However, their SFC values differed within the temperature ranges from 10 to 15 °C as well as 30 to 35 °C, which could be due to their differences in TAG distributional pattern as discussed previously (Yanty *et al.*, 2012). Owing to this fact, Yanty *et al.* (2014a) hypothesized that mixing a small amount of palm stearin into mee fat would adjust the SFC values of mee fat at those temperatures. With increasing proportion of palm stearin from 0.5 to 2%, the SFC values of the three formulated blends increased gradually. The observed increases in SFC values were well-correlated with the increasing proportions of di- and tri-saturated TAG molecules (PPO, PPSt, and StPO) in the binary blends (Table 4). Out of the three formulated-blends, MF:PS (99:1) showed better compatibility with lard at most temperatures within the specified range. The pattern of changes in the SFC profiles of these fat blends was more or less comparable to those of the binary blends of EF:CO (Nur Illyin *et al.*, 2013; Nur Illyin *et al.*, 2014) and PS:GO (Raihana *et al.*, 2017a) as reported previously. However, changes in the fatty acid composition during blend formulation were only marginal (Table 2). For instance, with increasing proportions of palm stearin in the blends, only slight changes occurred in the contents of total SFA (from 44.25 to 45.77%) and total USFA (from 55.75 to 54.23%). This led to slight increases in the amount of palmitic acid with concurrent decreases in the amounts of stearic, oleic and linoleic acids.

The DSC thermal profiles of pure lipids are generally influenced by chemical compositional changes. Hence, the changes in both fatty acid and TAG compositions would affect the DSC thermal profiles of the formulated binary blends in such a way that the maximum peak of all melting transitions were shifted to higher temperature regions, resulting in higher end-sets of melting (T_{endset}) (Yanty *et al.,* 2014a). The T_{endset} value is often regarded as an alternative for slip melting point. Nur Illyin *et al.* (2013) previously noticed a high-melting thermal transition in the temperature region above 10 °C in all binary blends of EF:CO. Since there was hardly any thermal transition in the original DSC curve for canola oil above 10 °C, it was considered as a remarkable feature in the formulated-blends. Owing to the increasing amounts of more saturated TAG molecules, the maximum peak of the high-melting thermal transitions present in the blends were increased gradually (Table 3). This is in conformity with the previous findings reported by Raihana *et al.* (2017a), who observed that the maximum peak of the high-melting thermal transition of PS:PGO blends also shifted from 46.26 to 50.32 °C. In a separate study, Norizzah *et al.* (2004) made a similar observation in the case of palm olein blended with palm stearin, giving rise to the appearance of a broad peak in the high-melting region of the thermal curve of palm stearin. Yanty *et al.* (2017b) conducted a X-crystallographic study and reported that both LD and MF:PS (99:1) blends displayed both β' and β-form polymorphs, of which the β' form was dominant. These researchers believed that the occurrence of the disaturated TAG (USS) molecular species such as PPL, PPO, StOP, and StOSt in both of these could be the probable reason for this similarity.

3.4. Ternary mixtures of Avo:PS:CB

In recent years, the oil of avocado pulp has received much attention due to its uses in food, cosmetics and health care products (Qin and Zhong, 2016). Although avocado oils from some varieties exist in liquid form, avocado lipids of some Malaysian cultivars were found to exist in a semi-solid state at room temperature. This difference in their physical state could be due to the compositional differences based on TAG and fatty acid profiles (Yanty *et al.,* 2011b). Qin and Zhong (2016) made some further comments regarding this matter in a survey presented on the efficiency of different extraction methods of avocado fat. A plant-based substitute for lard was proposed by Yanty *et al.* (2017a) by making use of avocado fat as the major component and palm stearin / cocoa butter as minor components. According to a previous study by Yanty *et al.* (2013b), Malaysian cocoa butter was found to possess POP, POS, and SOS as its major TAG molecular species. Likewise, another previously mentioned that when compared to lard, Avo of different Malaysian cultivars exhibited lower SFC values throughout the temperature range (Yanty *et al.,* 2014a). As such, the addition of hard fats such as cocoa butter and palm stearin is inevitable to complement or adjust the SFC profiles.

When studying the properties of novel fat blend formulations, the degree of unsaturation is an index of considerable importance as it is an indicator of the oxidative stability of food lipids. With regard to degree of unsaturation, Avo:PS:CB blends displayed slightly lower IV (65.47 to 70.27) ($p < 0.05$)

than the lard (73.76) (Table 2). This characteristic feature was somewhat similar to those reported earlier by Yanty *et al.* (2014a) and Raihana *et al.* (2017a) in binary blends of MF:PS and PS:GO, respectively. The SMP of the ternary blends studied by researchers were also found to be higher (38.25 to 40.5 °C) than that of lard (29.25) (Table 2). Hence, the SMP and IV of these ternary blends and lard were not found to be similar. Additions of palm stearin and cocoa butter into avocado fat caused slight increases in the amounts of palmitic (from 30.37 to 33.08%), stearic (from 1.30 to 4.57%) and oleic (from 43.64 to 44.04%) acids with concurrent decreases in the amounts of linoleic acids (from 17.45 to 14.28%). The increases in palmitic and stearic acids of these ternary blends was probably due to the presence of higher amounts of palmitic and stearic acids in palm stearin and cocoa butter, respectively.

DSC thermograms are generally helpful in monitoring the thermal properties of natural fats and their blends (Marikkar, 2015). The addition of palm stearin and cocoa butter into avocado fat would affect the melting peaks of avocado fat throughout the temperature region. Compositional changes such as increases in saturated fatty acids (Table 2) and disaturated/trisaturated TAG contents in the formulated blends are attributed to this (Table 4). On a comparative basis, the melting transitions of lard and the formulated ternary blends were found to display more differences than similarities. For instance, the end-sets of melting (T_{endset}) transition of all three Avo:PS:CB blends were higher (at around 47 °C) than that of lard (37.5 °C). However, there was a similarity noticed between Avo:PS:CB (84:7:9) blends and lard with regard to the maximum peak of thermal transitions at around -3.59 °C. Although it was a positive attribute, this alone cannot be sufficient to make a decision regarding which blend would be best in compatibility. A more relevant parameter to measure the compatibility of the ternary blends with lard would be the SFC profile as monitored by NMR. The sample containing the NMR tube was melted at 70 °C for 15 min, followed by chilling at 0 °C for 60 min, and then held at each measuring temperature for 30 min prior to measurement.

Past studies found that the SFC values of avocado fat of Malaysian cultivars were always lower than those of lard throughout the specified temperature range (Yanty *et al.*, 2012). The incorporation of a hard fat like palm stearin or cocoa butter could help enhance the SFC values of avocado fat to a level compatible with those of lard. By the addition of palm stearin (7%) and cocoa butter (5 to 9%) in small quantities into avocado fat, some of the TAG molecular groups were increased (e.g. PPO, PPP, SOO, SPO and PPS) while others tended to decrease (e.g. LLn, LLL, OLL, PLL, OOL, POL, PPL, OOO and POO) (Table 4). As PPP, PPO and SPO were originally present in high amounts in PS, their amounts would certainly go up. The excessive presence of these TAG molecules in PS had been previously confirmed by other researchers (Podchong *et al.*, 2018; Miskandar and Nor, 2010). In addition, Segall *et al.* (2005) stated that the excessive amounts of SPO, PPO and SOS TAG molecules present in cocoa butter would create a strong fat crystal network. With the gradual increases in the proportion of cocoa butter and palm stearin, the SFC values of the ternary fat mixtures tended to increase throughout the temperature region (Yanty *et al.*, 2017a). In fact, there was a good correlation ($r=+0.97$; $p < 0.05$) between the increasing SFC values of the fat blends and the increasing proportion of disaturated/trisaturated TAG molecules (Yanty *et al.*, 2017a). Of the three fat blends formulated, Avo:PS:CB (84:7:9) showed better compatibility to lard at most of the temperatures in the range. In addition to this, both lard and Avo:PS:CB (84:7:9) were found to possess almost similar proportions of PPO and SPO (Table 4). The occurrence of these two TAG molecular species in significant amounts caused both LD and Avo:PS:CB (84:7:9 blends to display both β' and β-form polymorphs, of which the β' form was dominant.

3.5. Quaternary mixtures of PO:PS:SBO:CB

Palm oil is a semi-solid that has been used worldwide for its multifaceted food and nonfood applications. The ever-increasing popularity of palm oil across the globe has resulted in its inclusion in various products. As palm oil can undergo fractionation, it would be an ideal substance for novel product formulation for specific needs (Nor Aini and Miskandar, 2007). For instance, palm oil has been used for different types of shortenings, margarines, vanaspati, deep-frying fat and other specialty fats. Nevertheless, it cannot become a direct substitute for lard due to the occurrence of PPO and POO in high amounts, which can cause an unusually high solidification profile (Siew, 2002). The SFC values for palm oil were found to be higher than that of lard within the temperature ranges of 0 to 20 °C (Yanty *et al.,* 2012). In fact, a tremendous gap existed between these two at the beginning of solidification and melting end-point. For instance, at 0 ºC the SFC of lard and palm oil were 30.8 and 68.63%, respectively, but their SFC values tended to become 0% at 40 and 55 ºC, respectively. It is generally assumed that by blending an appropriate amount of liquid oil such as soybean oil with palm oil, the SFC value can be adjusted to similar to that of lard at all temperatures (Siew, 2002).

Soybean oil can be an oil of choice to be used for blending with palm oil because the SFC value of soybean oil at 0 ºC was 0.31%, and would become 0% at 5 ºC. Based on this hypothesis, an attempt was made to develop a quaternary fat blend comprising of palm oil and soybean oil as its major components (Marikkar *et al.*, 2018). The question related to how much soybean oil would be just enough to make a proper blending with palm oil indeed needs to be worked out experimentally. For this purpose, the SFC profiling of fat blends at various temperatures would be inevitable. SFC is generally expressed as the percentage that corresponds to the total meltdown of a fat into liquid (Madison and Hill, 1978). The SFC profiles of three binary blends of PO:SBO made at the beginning are shown in Figure 1, which might give some indication for the selection of the best blending proportions. Out of these three binary blends prepared, the addition of 50% of soybean oil into palm oil resulted in SFC values similar to lard from the range 30 to 45 °C, but lower than that of lard within the temperature range 0 to 30 °C (Figure 1B). This deviation, however, could be overcome by adding a hard fatty substance like palm stearin or cocoa butter in smaller amounts due to their role in the adjustment of various physical and functional properties. Although the additions of 5% of PS into PO:SBO blends tended to increase the SFC values at 0 to 27 °C, the SFC values were found to increase higher than those of lard in the range of 27 to 35 °C, as shown in Fig. 1C. However, the addition of 5% CB into PO:SBO blends was found to help adjust the SFC values of the formulated fat blends and lard to become similar within the range of 27 to 35 °C, as shown in Figure 1A.

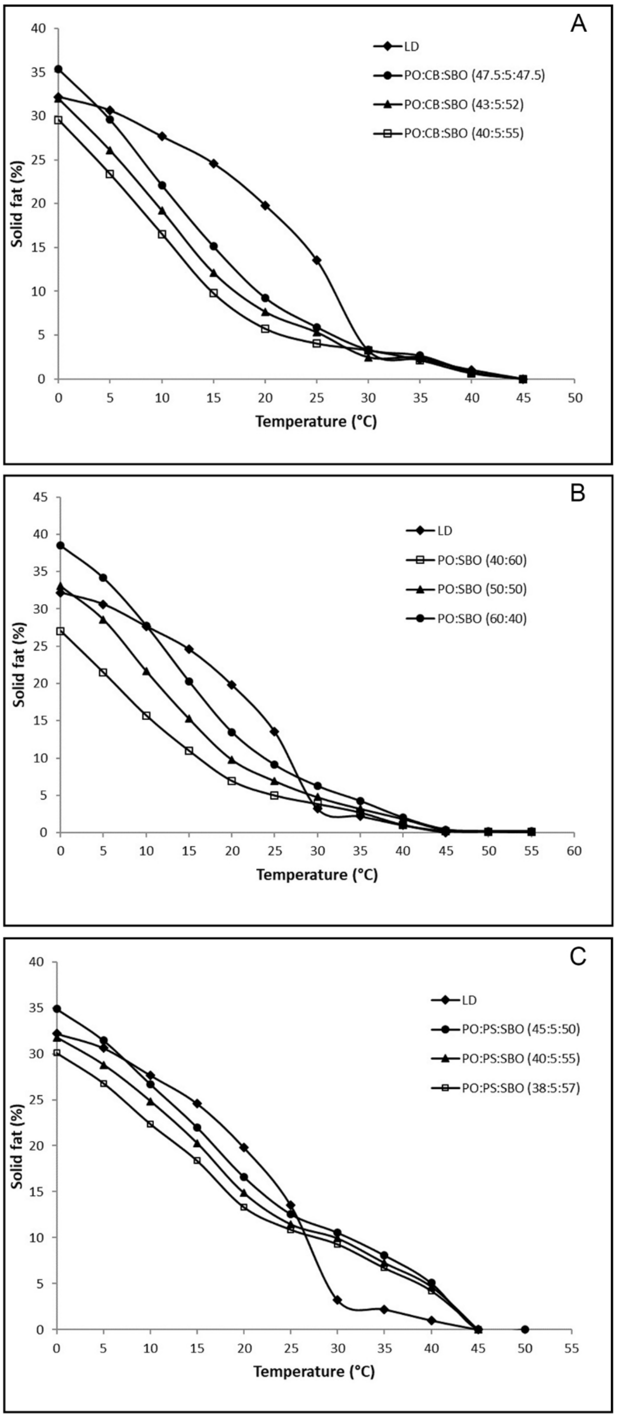

FIGURE 1: Comparison of solid content profiles of different binary and ternary blends and lard

[1]Abbreviations: MF, mee fat; PS: palm stearin; CB, cocoa butter; PO, palm oil; PS, palm stearin; SBO, soybean oil; LD, lard.

With regard to degree of unsaturation, IV of all quaternary fat blends were found to be significantly ($p < 0.05$) higher (92.26 to 96.95) than that of lard (73.76) (Table 2). This characteristic feature was somewhat similar to the observation made previously in the case of EF:CO binary blends (Nur Illyin *et al.*, 2013). This was primarily due to the presence of a high amount of soybean oil in the blends. On the other hand, SMP values for all quaternary blends (18.0 to 21.25 °C) were lower than that of lard (29.25) (Table 2). Hence, the SMP and IV of none of the quaternary blends were found to become similar to that of lard (Marikkar *et al.*, 2018). The additions of soybean oil into palm oil would cause significant increases in the amounts of linoleic acid (from 10.25 to 34.44%) with concurrent decreases in the proportions of palmitic (from 43.99 to 25.72%) and oleic acids (from 39.24 to 27.56%). The palmitic and linoleic acid contents in the quaternary blends were significantly higher ($p < 0.05$) than in lard. These changes in the degree of unsaturation and fatty acid composition led to changes in the IV of these mixtures as noted in Table 2.

The preparation of quaternary fat blends by adding palm stearin, soybean oil and cocoa butter into palm oil caused some increases in certain TAG molecules (Marikkar *et al.*, 2018). Increases in the proportions of PLL, OOL and POL could be due to the influence of soybean oil in the blends as soybean oil possesses TAG molecules namely, LLL (23.56%), OLL (17.77%), PLL (15.82%) and POL (13.69%) in high amounts (Table 4). Significant increases in the proportions of PPP and SOS were also noticed in the fat blends due to the fact that these two were major TAG species of palm stearin and cocoa butter (Nor Aini and Miskandar, 2007; Segall *et al.*, 2005). Among the TAG molecular species, PPO (ranging from 13.48 to 12.09%) and POO (from 10.87 to 9.70%) showed reductions in proportions (Table 4). These changes in composition would certainly have an impact on the melting peaks of the DSC thermograms of the fat blends.

The melting profiles of the formulated fats blends were considerably different from that of the original palm oil sample. For instance, they have one additional minor peak at around -20 °C with a shoulder peak (Table 3). This emerging feature in the melting curve of quaternary blends could be due to compositional changes caused by soybean oil. According to previous studies, soybean oil was reported to have all of its thermal peaks in the low-melting region of the DSC curve. Moreover, the T_{endset} was found to shift to the higher temperature region after the addition of palm stearin and cocoa butter into palm oil. When compared to the melting profile of lard (T_{endset} =37.5 °C), all three quaternary blends had higher end-set of melting (T_{endset}) (at around 44 °C) as well as lower onset of melting T_{onset} (at around -45 °C). These DSC features could be attributed to the influence of the low melting TAG molecules of soybean oil, which tended to crystallize at lower temperatures. Although there were great differences in melting transitions between lard and the three quaternary blends, a closer similarity was seen between them at the maximum peak of some peaks at around -3.59 °C (Marikkar *et al.*, 2018).

4. FOOD APPLICATIONS

Generally, in compatibility assessments, chemical composition and physical properties such as melting point, DSC thermal profiles, solid fat content profile, and polymorphic forms were considered in order to select the best fat blend. Nevertheless, it is essential to apply the formulated plant-based fat blends in real foods such as formulated meat products, bakery and confectionary products. This type of assessment would evaluate the actual performance of the plant-based fats in comparison to lard. Ultimately, it is the desired sensory attributes and consumer acceptance which will guarantee the commercial success of any formulated fat substitutes. Researchers in the past considered only partial replacers for lard in meat product formulations as total replacement would affect the meat products' sensorial attributes. For instance, investigations on the partial replacement of lard with plant fats were reported on products like fermented sausages (Ospina *et al.*, 2010), Pâtés (Delgado-Pado *et al.*, 2011; Rodriguez-Carpena *et al.*, 2011), low-fat Kung-wans (Hsu and Yu, 2002) and frankfurters (Choi *et al.*, 2010). As the primary motive behind the partial replacement of lard in these products was to provide more nutritious food for consumers, this approach would not help to comply with the requirements set by the food laws namely *kosher* and *halal.* Since inclusion of lard in biscuit formulations is strictly prohibited in *halal* and *kosher* food regulations, researchers attempted to test the formulated lard substitute on cookies. After ascertaining that PGO-2 [45:55 (GO:PS)] was the closest substitute for lard, Raihana *et al.* (2017b) converted the formulated plant-fat blend into a shortening to evaluate it as a fat ingredient in cookies. According to this study, the general acceptability of cookies was highly influenced by parameters such as hardness, fracture-ability and appearance. Among the different samples of shortenings, those prepared with PGO-2 [45:55 (GO:PS)] displayed the best quality attributes such as hardness, size and thickness, cracking size and color. In a separate study, Yanty *et al.* (2019) evaluated the formulated lard substitutes in cookies by following the baking procedure described in the AACC Method 10-50D (AACC, 2000). The results showed that there were no significant ($p > 0.05$) differences among the cookies prepared with all three types of shortenings and lard with regard to width and thickness. This was because the cookies made with formulated plant shortenings and lard shortening expanded uniformly. This could be due to the fact that both of these shortenings exhibited similarities in SFC at 25 °C (working temperature).

5. FUTURE PROSPECTS AND CHALLEGES

The food industry is one the single largest industries which is expanding rapidly worldwide. The recent trend shows that ethnic and religious foods have increasingly become an inevitable part of the total food industry. This is mainly due to the ever-increasing migration from Asia, Africa and the Middle East to America and other Western European countries. This trend coupled with globalization has opened up many doors for a new market segment for religious and vegetarian foods which are devoid of components of animal origin. Religious and ethnic foods, hence, occupy a small but rapidly expanding niche in every level of the food supply chain in these countries. As a result, there has been a growing recognition for ethnic and religious foods in Canada, North America, Australia, New Zealand and other Western European countries. This is evidently seen from the incorporation of ethnic and religious foods as a study component of the food science curricular of some universities. Although the world's major religions do not hold exactly the same ideology, they do embrace some similarities with regard to food consumption and dietary habits. For instance, they do take a common stand on prohibiting the consumption of pork and lard by their adherents. Consequently, any innovation leading to technology development on pork-free products or alternatives for lard will be welcome by all communities. In this context, some resistance from the existing piggery industry cannot be ruled out owing to the risk posed to their supply chain on pork products and lard.

The plant-based fat substitutes for lard are novel innovations, which show high potential in replacing lard extracted from porcine sources. As the technology involved is simple, it will easily fulfill the call for a healthy fat substitute for animal fats including lard and can be utilized widely in the 'halal' food production, bakery, meat, cosmetic products and so on. As all raw materials for the lard substitute are of plant origin, they will have the additional advantages of being rich in fat soluble vitamins and other phyto-nutrients. However, cost and ready availability of fat ingredients such as avocado fat, meet fat and cocoa butter are a real concern. This is mainly due to the imbalance between supply and demand as the plantations producing these fat ingredients are mainly limited to Asia and Africa. Apart from this, the ready-availability of lard alternative fats to some ethnic minorities living in certain countries might not be possible right now due to low demand or smaller market segments.

6. CONCLUDING REMARKS

This review highlighted the effectiveness of various blending strategies and the selection of fats and oils in formulating substitutes for lard. Instead of finding a single lipid source as substitute for lard, trying binary, ternary and quaternary blend formulations was found to be a rewarding experience. The choice of multiple lipids such as enkabang fat, canola oil, guava oil, palm oil, palm stearin, soybean oil and cocoa butter from various sources was indicative of the great benefit of diversity as well as inclusiveness. Evaluating formulated plant-fat blends and lard after processing into shortening to assess their properties in terms of hardness, consistency, microstructure and polymorphism has offered excellent results. Among different binary, ternary and quaternary blends developed so far, MP:PS (99:1), Avo:PS:CB (84:7:9) and PO:PS:SBO:CB (38:5:52:5) were found to be best in terms of melting and solid content profiles. The consistency of formulated plant-based shortenings and lard shortening indicated that they could be categorized as plastic fats, which are spreadable. Although the formulated plant-based shortenings and lard shortening were dissimilar in crystal morphology, they displayed a mix of β' and β-form polymorphs of which the β' form was dominant. When their functional properties were tested as fat ingredients in the production of cookies, the consistency of the dough made using binary blend shortening was found to be closer in value to that of lard shortening. The elasticity value of the dough made out of the binary fat shortening was also found to be similar to that of dough made from lard shortening.

7. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support from a grant (Grant No. 02-01-10-0889 RU) received under the Research University Grant Scheme of Universiti Putra Malaysia.

8. REFERENCES

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