Effect of Scraped-Surface Tube Cooler Temperatures on the Physical Properties of Palm Oil Margarine

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ABSTRACT: The effects of scraped-surface tube cooler temperatures on the isothermal solid fat content (SFC) of palm oil margarine during processing and on margarine consistency (yield value, g/cm^2), SFC, and polymorphic changes in storage were studied. SFC was measured in the mixing tank after leaving the tube cooler and the pin worker. The SFC at the tube cooler exit was proportional to the amount of cooling; a higher SFC was produced by more extreme cooling treatment. The SFC of all margarines were reduced in the pin worker, and the reduction was related to the initial SFC profile of palm oil. Margarine samples were stored at 28°C for 28 d and tested daily. Margarine processed at 25°C in the tube cooler had the highest consistency and the least change in SFC, but by the second week crystals had transformed into the β form. Uniform product consistency and SFC were observed in margarines processed at 20 and 15°C. These margarines retained the β′ crystal form for 3 and 4 wk, respectively. The best palm oil margarine was obtained with a tube cooler temperature of 15°C and a residence time of 1.8 min.

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KEY WORDS: Consistency, crystals, margarine, palm oil, temperature, tube cooler.

A good margarine should be free of oil separation, discoloration, hardening, sandiness or graininess, and water separation (1). Oils and fats, processing conditions, and handling methods should be selected to avoid causing a strong crystal network arrangement (2), crystal migration, or transformation of β′ crystal to the β polymorph. Margarine should be in the β′ crystal form. β′ crystals produce a smooth, creamy, and homogeneous appearance, whereas β crystals produce hard, brittle, grainy, sandy, and greasy margarine (3,4).

Solidification of fats in margarine processing is not a simple process. Processing parameters, such as temperature, shear, agitation, and product flow rates, are critical (5). These factors affect the crystallization of oils and fats and determine the nature of the crystalline structure of fat products. When bulk oil is crystallized, the entire mass does not crystallize at the same time; in fact crystallization begins at discrete sites when the temperature reaches a level that creates crystallization nuclei (6). Thus, when molten fats are cooled, products with granular texture will be produced because of a gradual crystallization of individual glycerides (6). At fast cooling rates, the crystals are smaller and more uniform than at slow cooling rates (7). In the instantaneous chilling of oils and fats, the high- and low-melting TAG develop mixed crystals (8). On the other hand, a rapid cooling process assisted by stirring crystallizes the high- and low-melting TAG at the same time (9). Stirring and agitation also soften the texture of the product and lower the solid fat content (SFC) during storage (10). The process partially crystallizes the fats and creates many nucleation sites from which secondary crystallization, the most important point in crystallization, proceeds rapidly (5,9).

Impurities in the fat affect crystallization. Thus, margarine processing is quite complex owing to the choice of ingredients that contribute to the overall properties of the product. Crystallization and product maturation proceed not only while in the margarine machine but also during storage. Thus, in addition to proper selection of raw materials and processing conditions, suitable storage or tempering conditions are important. According to Moziar *et al.* (11), tempering of shortening can delay its transition from β′ to β crystal forms.

Pedersen's (12) research on the performance of pastry margarine offers useful information for margarine manufacturers. A study by deMan *et al.* (5) on instantaneous crystallization and tempering of fats have shown several effects of crystallization methods. The relationship between the SFC profile (SFCP) of a fat and products made from it, and the effects of processing conditions on storage properties are still not understood. Studies using palm oil as a single fat component in margarine should provide useful information on crystallization. Thus, the present study was undertaken to determine the effects of different processing temperatures in the tube cooler. The solid fat present and the temperature differences in the tube cooler during processing, as well as physical properties, SFC, consistency, and the polymorphic changes in margarine during storage, were determined.

MATERIALS AND METHODS

Materials. Refined, bleached, and deodorized (RBD) palm oil was obtained from Ngo Chew Hong, Semenyih, Selangor, Malaysia [slip melting point (SMP), 35.1°C; dropping point, 38.6°C]. Other ingredients included an emulsifier [distilled MG (90% monoester) from fully hydrogenated palm oil; SMP, 69°C; Danisco Ingredients, M. Sdn. Bhd Prai Industrial Estate, Penang, Malaysia], water (filtered municipal water supply), and vacuum-dried salt.

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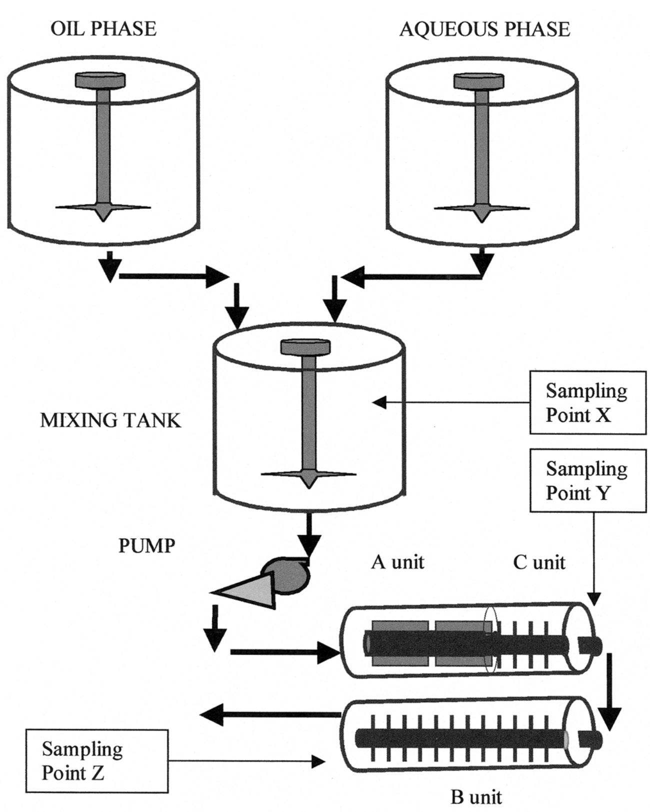
Chemical and physical analysis. SMP, SFCP of palm oil, and isothermal SFC of margarine were determined by PORIM Test Methods (13,14) and Pernille (15), respectively. Margarine consistency (yield value, g/cm^2) was measured by a cone penetrometer (Stanhope Seta, Surrey, United Kingdom (2,16), dropping point was measured with a Mettler FP90 thermosystem (Mettler Toledo AG, Greifensee, Switzerland) (17), and crystal polymorphs were determined by X-ray diffraction at 25°C (5,18).

Production of margarine. A basic recipe (81.3% RBD palm oil, 0.2% emulsifier, 16% water, and 2.5% salt) was used. Palm oil was melted in a drying oven at 65°C. The melted oil was weighed and placed in the mixing tank, and premelted emulsifier in palm oil (1:4) was added. The water phase containing salt (room temperature, 28°C) was then added slowly to the oil phase with agitation to form a good emulsion. The emulsion temperature was lowered to 40°C and mixed for 10 min in the mixing tank. The margarine was processed in the pilot plant of the Malaysian Palm Oil Board (MPOB) laboratory. The cooling surface area of the scraped-surface tube cooler (A unit) (Perfector; Gerstenberg and Agger, Copenhagen, Denmark) was 0.062 m^2. The volume of the intermediate crystallizer (C unit) was 0.75 L, and the volume of the pin worker (B unit) was 3 L (Scheme 1). The flow rate of the emulsion as it passed through the A, C, and B units was fixed at 15 kg/h. The rotation speeds of the A and B units were 500 and 200 rpm, respectively. The emulsion was cooled rapidly by the refrigerated surface of the A unit to either 15 (coded 01), 20 (coded 02), or 25°C (coded 03).



SCHEME 1

Sampling procedure. Sampling was carried out at three different points to determine SFC development during the process: in the mixing tank (point X), at the point between the C and B units (point Y), and after leaving the B unit (point Z) (Scheme 1). The SFC was immediately measured in duplicate by NMR at each location (15,16). The time from sample collection to measurement was 55–60 s. No further measurements were carried out on samples from sampling points X and Y. Margarine was collected at point Z in 400-mL tubs for storage studies.

Product measurement. Samples were placed in a 28°C incubator for 28 d. Consistency was determined using a 40° cone having a cone assembly weight of 79.03 g. Penetration time was 5 s, and yield values were calculated by using the formula $KW/P^{1.6}$, where $K = 5840$, $W = 79.03$ + added weight, and P = mean of penetration readings from six replicates. SFC was determined by sampling the margarine using a stainless steel piston to press the sample into NMR tubes 0.8 cm in diameter and 2 cm in height; no air space was allowed between the sample and the tube wall. Dropping point was measured using a Mettler FP90 thermosystem heating rate of 1°C/min (17).

Statistical analysis. ANOVA was carried out using Microsoft Excel 2000.

RESULTS AND DISCUSSION

Product temperatures in the tube cooler and other processing conditions are shown in Figure 1. Temperature is a useful quantitative measurement to determine the quality of margarine, especially during filling. Consistency is temperature dependent; thus, filling temperature can provide a good estimate of the proper consistency for filling margarine into containers (1).

Margarine should be of the desired consistency for easy filling into cartons or tubs. It should be neither too hard nor too fluid (1). A hard and brittle product, caused by very low filling temperatures, will create difficulty in closing the containers; an overly fluid product caused by high filling temperatures will cause difficulty in stacking the cartons.

In an automated system, the refrigerant charges in and out of the cooler system automatically at preset temperatures. The retention time of the emulsion in the tube cooler was 1.8 min. This is consistent with the observations of Chateris and Keogh (1) that the product has a short induction time to crystallization when the cooling rate in the tube cooler is high owing to the low refrigerant temperature. Emulsions passing at a constant flow rate through the tube cooler at various refrigerant settings received different cooling treatments (Fig. 1). Sample 01 received the most extreme cooling treatment, followed by sample 02 and sample 03.

The SFC resulting from different degrees of cooling are shown in Figure 1. Margarine samples 01, 02, and 03 contained 23.5, 17.7, and 13.2% SFC, respectively, at the tube

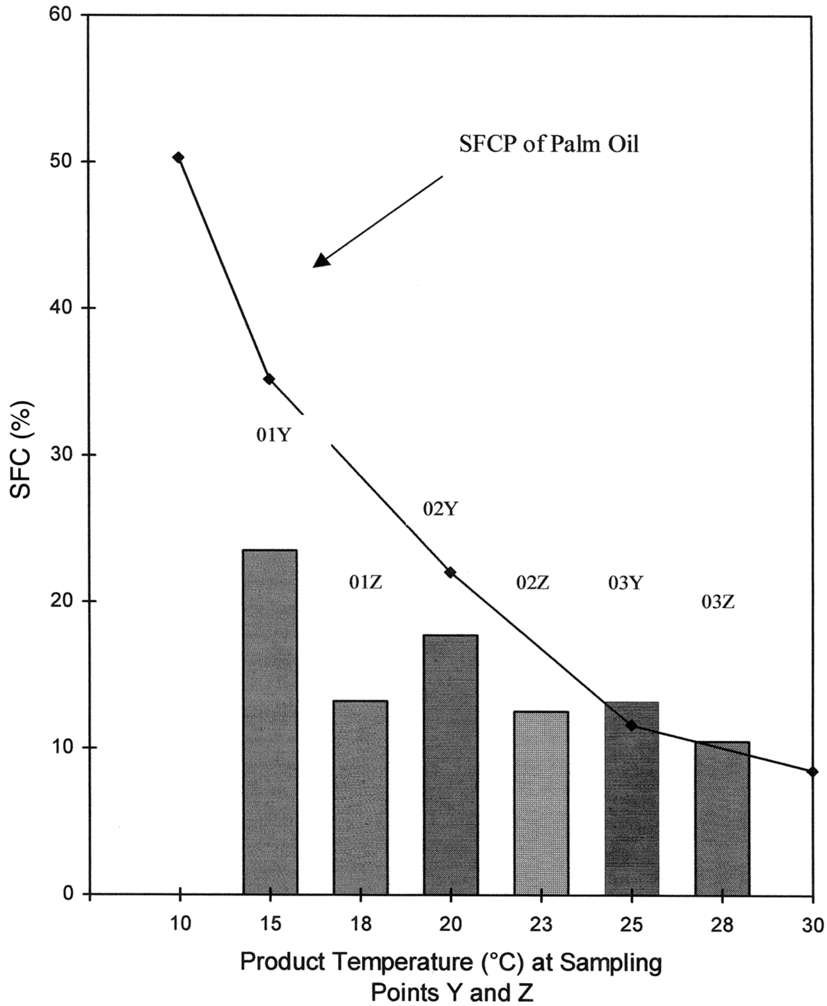


FIG. 1. Solid fat content (SFC, %) at the exits of the tube cooler (Y) and pin worker (Z) during the production of margarine and the SFC profile (SFCP) of palm oil. The flow rate of the emulsion was 15 kg/h. The rotation speeds of the tube cooler and pin rotor were 500 and 200 rpm, respectively.

cooler exit. The highest SFC at the exit of the tube cooler was in sample 01 because it received the most extreme cooling treatment, thus allowing the most crystals and crystal nuclei to form. This observation was similar to the report by Nawar (4) that rapid cooling can increase the SFC. Haighton (3) reported a similar observation when a fat was cooled quickly by transferring a dilatometer from a 60°C to a 0°C bath. Crystal aggregates formed by the supercooling temperature could have increased the SFC in both cases (7).

The development of SFC in the tube cooler was high when the treatment temperature was low. However, several changes, such as crystal growth, crystal destruction, and melting of crystals, occurred as the product passed through the pin worker (B unit). The greatest reduction in SFC in the pin worker unit occurred in sample 01, followed by samples 02 and 03. As sample 01 passed through the tube cooler, crystallization took place very rapidly, allowing minimal crystal growth in the pin worker. Pin workers are known to contribute to some crystal destruction and reduction in SFC (19). In sample 02 crystal development in the tube cooler was less rapid. However, crystal development in the pin worker increased. The least crystal development in the tube cooler was shown in sample 03. However, agitation by the working unit promoted further crystallization, which increased the SFC.

In general, with the exception of sample 03, the development of SFC in the tube cooler and the pin rotor during processing at various tube cooler temperatures was lower than the SFCP of palm oil at the same temperature. These differences in SFCP are attributable to variations in product compositions, mechanical activities, and crystallization methods. Che Man and Swe (7) reported that the presence of impurities in oil also caused changes in crystal development. Margarine contains several components that may contribute to the unpredictability of the crystallization properties of hardening and softening. As mentioned earlier, mechanical activities in processing, such as the mechanical action of the scraped-surface tube cooler blade, the intermediate crystallizer, and the pin worker, can contribute to some destruction of the crystals (19). The crystallization of palm oil to determine SFCP involved completing steps in the PORIM Method, however (14). Similarities in the SFC of sample 03 and the SFCP of palm oil at 25 and 28°C were mainly due to the crystal network formed during processing. The crystal network was able to increase the SFC to slightly higher than the normal SFCP. This is consistent with the observation of deMan *et al.* (5) regarding an increase of 4°C in SMP of shortening relative to the starting oil.

Changes in the SFC of margarine during storage are shown in Table 1. The SFC of margarines stored at 28°C was in the range of 6.16–7.82%; the SFCP of palm oil was 7.23% at 28°C. SFC was highest on the day of production (Fig. 1) and decreased as the crystals transformed into a more stable form. By the end of the second week of storage, the SFC of all samples had decreased to below the SFCP of palm oil at the same temperature. This difference was clearly due to the transformation of crystals to a more stable state and to the different compositions of margarine and pure palm oil. According to Manley (19), excessive changes in SFC during storage are undesirable. Ideally, the SFC should not change from the time of filling into containers throughout the storage period. Our observations were not consistent with studies on shortening by Moziar *et al*. (11). No significant increase in the SFC of shortening took place after 5 wk of storage at 23°C, although consistency and firmness increased. SFC during storage is a good estimate of product consistency in pastry margarine (20). According to Haighton (3) and deMan *et al.* (5), product hardness or consistency is closely related to crystal network.

The consistency, or penetration yield value, of palm oil margarine during storage is shown in Table 2. Sample 03 had the highest consistency during storage, particularly after the first week. Processing at low tube cooler temperatures is desirable for soft margarines, and high tube cooler temperatures are preferred for hard margarine. As mentioned earlier, different rates of crystallization caused different effects in crystal destruction and growth in the pin worker. These effects influenced the consistency of all samples. The SFC of sample 03 changed little during processing, indicating that only minimal destruction of primary bonds of the crystal network had occurred but that there was more crystal growth. Early crystal development was shown by the high penetration yield value at week 1; the penetration yield value of 200–800 g/cm^2 was close to that of commercially available margarine. Crystal destruction in samples 01 and 02 probably caused the crystal size to decline and the crystals to disperse more evenly. Penetration yield values for the two samples were low but gradually increased as storage time increased; sample 01 showed the most consistent product.

The polymorphic crystal development of palm oil margarine during storage is shown in Table 3. These samples showed a mixture of β′ and β crystal forms during storage, with more β′ in sample 01, more β in sample 02, and much more β crystal forms in sample 03 at the beginning of the storage test. The β′ crystal form was predominant in sample 01 until week 3 of storage, and by week 4 it had transformed into a more stable form with an equal number of β and β′ crystals. The sample had a high SFC during processing and storage, as shown in Figure 1 and Table 1, respectively, which indicated highly developed crystals in relation to the formation of crystal network (19). As the crystal network formed in sample 01, it limited mobility of the crystals and delayed their transformation from β′ to the β crystal form. According to Andersen and Williams (20), if too many small crystals (of the α crystal type) are present in fats, the fat structure will be

TABLE 1
Isothermal Solid Fat Content (SFC) of Palm Oil Margarine Processed at Different Tube Cooler Temperatures and Stored at 28°C

Product code	Product temp. in tube cooler (°C)	SFC (%) at storage time at 28°C[a]			
		Week 1	Week 2	Week 3	Week 4
01	15	7.4 ± 0.3^{a,A}	7.1 ± 0.3^{b,A}	6.6 ± 0.4^{c,B}	6.6 ± 0.2^{d,B}
02	20	7.4 ± 0.4^{a,C}	6.7 ± 0.4^{b,C}	7.0 ± 0.2^{c,C}	6.5 ± 0.2^{d,C}
03	25	7.5 ± 0.2^{a,D}	7.1 ± 0.7^{b,D,E}	6.2 ± 0.4^{c,E}	6.2 ± 0.5^{d,E}

[a]Mean of 10 determinations ± SD obtained from two determinations daily for 5 d/wk. Means within rows with different capital letters (A–E) are significantly different ($P < 0.05$). Means within columns with different lowercase letters (a–d) are significantly different ($P < 0.05$).

TABLE 2
Penetration Yield Value (consistency in g/cm^2) of Palm Oil Margarine Processed at Different Tube Cooler Temperatures and Stored at 28°C

Product code	Product temp. in tube cooler (°C)	Penetration yield value at storage time at 28°C[a]			
		Week 1	Week 2	Week 3	Week 4
01	15	118.0 ± 18.7^{a,A}	139.1 ± 20.6^{c,A}	133.5 ± 2.7^{f,A}	134.1 ± 8.2^{i,A}
02	20	99.7 ± 14.6^{a,B}	106.0 ± 11.2^{d,B}	123.6 ± 6.6^{g,C}	127.3 ± 7.8^{i,C}
03	25	170.4 ± 57.8^{b,D}	249.1 ± 15.6^{e,E}	241.4 ± 36.6^{h,E}	171.9 ± 4.8^{j,D}

[a]Mean of 30 determinations ± SD obtained from six determinations daily for 5 d/wk. Means within rows with different capital letters (A–E) are significantly different ($P < 0.05$). Means within columns with different lowercase letters (a–j) are significantly different ($P < 0.05$).

TABLE 3
Polymorphic Transformation of Palm Oil Margarine Processed at Different Tube Cooler Temperatures[a]

Product code			Transformation at storage time at 28°C		
		Å	Week 2	Week 3	Week 4
01	Long spacing	14.41	W	W	W
	Short spacing	4.61	W	M	S
		4.55	VW	W	M
		4.46	VW	W	W
		4.37	M	M	M
		4.29	W	W	W
		4.21	S	S	S
		4.13	W	W	W
		4.02	W	W	VW
		3.91	VW	VW	VW
		3.81	S	S	S
	Polymorph		β + β′ (β′ >> β)	β + β′ (β′ > β)	β + β′ (β = β′)
02	Long spacing	14.41	W	W	W
	Short spacing	4.61	W	M	S
		4.55	VW	W	M
		4.46	VW	W	W
		4.37	M	M	M
		4.29	W	W	W
		4.21	S	S	M
		4.13	W	W	W
		4.02	W	W	W
		3.91	VW	VW	VW
		3.81	S	S	S
	Polymorph		β + β′ (β′ > β)	β + β′ (β = β′)	β + β′ (β > β′)
03	Long spacing	14.41	W	W	W
	Short spacing	5.37	W	W	W
		5.20	W	W	W
		4.61	S	S	S
		4.55	M	M	M
		4.46	W	W	W
		4.34	VW	VW	VW
		4.20	W	VW	VW
		4.00	VW	VW	VW
		3.89	S	M	M
		3.80	M	W	W
		3.75	VW	VW	VW
	Polymorph		β + β′ (β >> β′)	β + β′ (β >>> β′)	β + β′ (β >>> β′)

[a]S, strong; M, medium; W, weak; VW, very weak.

too close. The capillaries between the solids are reduced, causing the crystals to interlock with liquids between them (7). According to Manley (19), this phenomenon causes difficulty in the movement of solids in a viscous liquid. Samples 02 and 03, which had lower SFC during processing, may have had looser crystal networks that allowed further crystallization in an uncontrolled manner, thus favoring the formation of a strong crystal network and the transformation of β′ into β crystals during storage (3). Processing and storage conditions for samples 02 and 03 were undesirable for the particular type of margarine studied owing to the transformation of crystals into the β form in spite of the well-known tendency of palm oil to promote formation of β′ crystals.

The high consistency of margarines (Table 2) was in agreement with the formation of the β crystal polymorph (Table 3). Sample 03 had both the highest consistency and β crystal content after the second week of storage. Sample 01 remained in the β′ crystal polymorph until the fourth week and had good consistency and uniform SFC. Sample 02, with the lowest SFC, was least consistent and did not maintain the β′ crystal form more than 2 wk. Thus, predominance of β crystal polymorphs caused the margarine to be hard and brittle.

Margarine sample 03, processed at a tube cooler temperature of 25°C, had the lowest SFC during processing. However, it had the highest consistency and little change in SFC during storage. Owing to the processing conditions involved in this sample, the β′ crystal form was not maintained longer than 2 wk, and β′ crystals had transformed into the β form by the second week. A uniform product consistency and SFC were observed in samples 02 and 01, processed at temperatures of 20 and 15°C, respectively. Margarine sample 01 was in the β′ crystal form for 4 wk, whereas sample 02 maintained β crystals for 3 wk.

At this stage of study, we are unable to specify the best processing conditions for palm oil margarine. However, for the processing conditions under study, palm oil margarine processed at a tube cooler temperature of 15°C was optimal.

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