Quality of Reduced-Fat Dairy Coffee Creamer: Affected by Different Fat Replacer and Drying Methods

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Abstract

This work aims to investigate the effects of inulin (0, 2.5, 5 and 7.5%, w/w) and maltodextrin (0, 15, 20 and 25%, w/w) as wall materials and fat replacers and drying techniques (i.e. spray drying and fluidized-bed drying) on physicochemical properties of regular and instant reduced-fat dairy creamers. The regular reduced-fat dairy creamer was produced by one-stage drying (i.e. spray drying), while the instant reduced-fat dairy creamer was produced by two-stage drying (i.e. spray drying followed by fluidized-bed drying). In this study, control (0% inulin and 0% maltodextrin) and two commercial regular and instant coffee creamers (A and B) were also considered for comparison purposes. The results showed that the regular creamer containing 25% maltodextrin and 7.5% inulin had the largest particle size, highest viscosity and most desirable wettability among all formulated regular creamers. The yield of reduced-fat coffee creamer was significantly increased from 43.55 to 94.60% by increasing the amount of fat replacers to the maximum level (25% maltodextrin and 7.5% inulin). The current study revealed that the application of fluidized-bed drying for agglomeration led to significantly improve the wettability and instant properties of the instant creamer. In this study, the formulated instant creamer containing 25% maltodextrin and 7.5% inulin was the most desirable product as compared to all creamers.

Keywords: reduced-fat dairy creamer, inulin, maltodextrin, spray drying, fluidized-bed drying

1. Introduction

Coffee is one of the most vastly consumed beverages. Coffee drink is usually consumed in black or white form, depending on the taste of the consumer. Coffee creamers, also known as "coffee whitener" or "coffee sweetener", are liquid or granular substances intended to substitute for

milk or cream as an additive to coffee or other beverages [18, 28]. As stated by Tuot et al. [51], a desired coffee creamer should have specific physicochemical and functional characteristics particularly in terms of solubility, viscosity and stability. In addition, it should provide a good whitening effect after adding to hot coffee or similar hot beverages [41]. During the past few years, the demand of consumers for healthier products has significantly increased, lowering the tendency for consumption of high-fat foods. Hence, one of the main health issues for coffee drinkers is the presence of high percentage of fat in creamer formulation. As reported by Lambert [33], coffee creamer mainly contains high amount of vegetable fat (37–51%) and corn syrup (41–46%). Sudha et al. [47] suggested that the replacement of fat with various fat replacers led to the reduction of fat content and calories in food products.

There are some difficulties for the drying of coffee creamer due to the low glass transition temperatures (T_g) of the components such as high sugar and caseinate that leads to stickiness problems. In order to prevent stickiness and caking issue during storage, specific drying aids or wall materials (such as gum arabic, xanthan gum, maltodextrin, inulin, etc.) with high glass transition temperature (T_g) are used [21]. Maltodextrin is a carbohydrate polymer made up of D-glucose units with dextrose-equivalent (DE) of under 20 [40, 52]. Maltodextrin is used as a dispersing aid, flavor carrier, bulking agent, fat replacer, volume enhancer, texture modifier, encapsulating agent and wall material [12]. It has many advantages such as highly soluble, relatively low cost, neutral aroma, taste, mouth feel and good protection of flavors against oxidation as compared to other drying aids [50].

Inulin is a non-digestible prebiotic soluble carbohydrate with very low energy value [17]. It is used as a sweetener component, especially in combination with high-intensity sweeteners, texture modifier and fat replacer [23]. Dietary fibers such as inulin are functional ingredients which are commonly used in different food products in order to modify physical and structural properties of hydration, viscosity, texture, sensory characteristics and oil holding capacity and also prolong the shelf life of products [30, 37].

The final characteristics of the dried products are broadly affected by the drying type and condition. The spray drying techniques are one of the most commonly applied techniques for manufacturing creamer [4]. Spray drying involves the transformation of feed from a liquid or slurry form to dry powder [34]. Spray-dried powders may have small particles with low bulk density, leading to inadequate flowability and poor reconstitution properties, thus causing difficulties in handling, transportation and storage. Manufacturers require free-flowing powders without any dust, and these requirements are met just by applying agglomeration process [42]. Agglomeration is a combination of wetting and nucleation, consolidation and growth and attrition and breakage [25]. Fluidization is a promising alternative technology, which allows the simultaneous drying, encapsulation and agglomeration in a single stream, reducing operation costs, saving time, simultaneously reducing the caking issue and improving the physicochemical properties (i.e. flowability, density, dissolution and dispersion characteristics) of the powder [2, 5, 11, 39].

The present study was conducted to investigate the effect of inulin (0, 2.5, 5 and 7.5%, w/w) and maltodextrin (0, 15, 20 and 25%, w/w) and fluidized-bed drying on the characteristics of

the reduced-fat creamers. Inulin and maltodextrin have been used as a proper drying agent, fat replacer and wall material in powder technology and processing. It was hypothesized that there is a possibility to produce the reduced-fat coffee creamer with more nutritional benefit by partial replacement of its fat with proper fat replacer (like inulin and maltodextrin). In this study, water activity (a_w), wettability, apparent viscosity, solubility, particle size and color of differently formulated regular and instant reduced-fat creamers were examined. The one-stage drying (i.e. spray drying) was applied to produce the regular reduced-fat dairy creamer (RRDC), while two-stage drying (i.e. spray drying followed by fluidized-bed drying) was employed to manufacture the instant reduced-fat dairy creamer (IRDC). All formulated creamers were compared with the properties of control (0% inulin and 0% maltodextrin) and commercial creamers (A and B). To the best of our knowledge, non-data of the different drying process and components were reported about reduced-fat dairy creamer.

2. Materials and methods

2.1. Materials

The following components were used in creamer formulation: Maltodextrin (DE = 10, Roquette Freres Co, Lestrem, France), long-chain inulin (Fibruline Xl, Warcoing, Warcoing, Belgium), silicon dioxide (Sigma Aldrich, St. Louis, MO, USA), dipotassium hydrogen phosphate (Nacalai Tesque Co, Kyoto, Japan) and soy lecithin (Kordel's Co, CA, USA). Other ingredients such as commercial skim milk powder, an instant coffee (Brazilian freeze-dried Gold Bon CAFÉ), regular commercial coffee creamer (A) and instant commercial coffee creamer (B), hydrogenated palm kernel oil, sugar and vanilla were purchased from the supermarket (Kuala Lumpur, Malaysia). **Table 1** shows the composition of regular and instant commercial creamers applied for comparison purposes.

2.2. Creamer preparation

Reduced-fat creamer emulsions were produced according to a method described by Hedayatnia et al. [22] with minor modification (**Figure 1**). Initially, the dispersed phase (**A**) containing the hydrogenated palm kernel oil (8% w/w) and soy lecithin (emulsifier, 0.5% w/w) was mixed in a 100-mL beaker and kept in a thermo-controlled water bath (70°C and rotated at 100 rpm for 20 min). The aqueous phase (**B**) which consists of sodium caseinate (2.5% w/w),

Composition	Regular commercial creamer A	Instant commercial creamer B
Fat (%)	34.0	34.6
Carbohydrate (%)	57.1	56.9
Protein (%)	2.0	1.3

Table 1. The composition of regular and instant commercial creamers applied for comparison purposes.
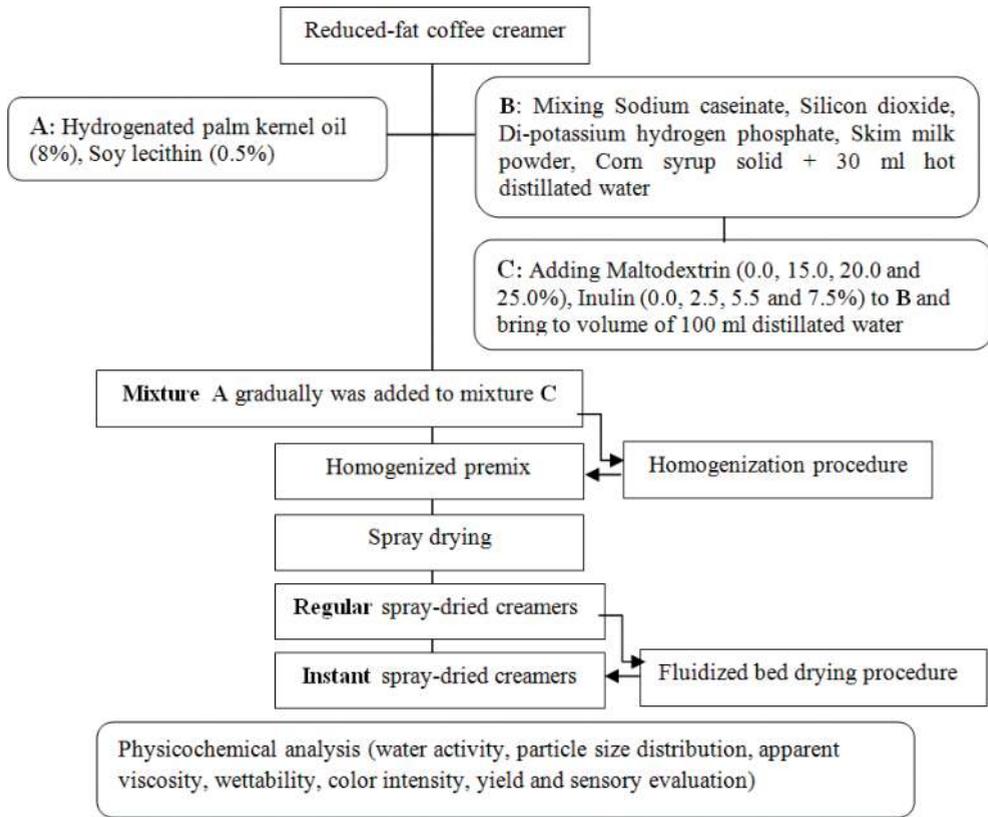
Figure 1. Schematic description of the preparation of reduced-fat creamer.

silicon dioxide (1.0% w/w), dipotassium hydrogen phosphate (2.5% w/w), skim milk powder 7% (w/w) and corn syrup solid (15% w/w) was prepared by gradually dispersing them into 100-mL hot distilled water (70 ± 5°C) and stirred consequently with a magnetic at 100 rpm for 5 min. Subsequently, different concentrations of inulin (0.0, 2.5, 5.0 and 7.5% w/w) and malto-dextrin (0, 15, 20 and 25%) (**C**) were gradually added to the aqueous phase (**B**) to prepare the emulsion continuous phase. Hot distilled water (70 ± 5°C) was added to each creamer formu-lation up to 100%. In the final stage, upon mixing the ingredients, dispersed phase (**A**) was gradually added to the premix and gently stirred for 10 min. Subsequently, the coarse creamer emulsion was homogenized by a high-pressure homogenizer (at 200- and 180-MPa pressure for 2 cycles) prior to the drying process. All formulated reduced-fat creamers and control were prepared under the same drying condition depending on the regular or instant case.

2.3. Spray drying procedure

After homogenization, the creamer emulsion was fed into a lab scale mini spray dryer (BÜCHI model B-290, Flawil, Switzerland). The samples were atomized with a rotary atomizer into the

drying chamber. In the present study, spray drying procedure was set at the following condition: inlet temperature, 180 ± 5°C; outlet temperature, 80 ± 5°C; pressure, 552 kPa; and feed rate, 10 mL/min.

2.4. Fluidized-bed drying

In this study, a laboratory scale fluidized-bed dryer (Aeromatic-Fielder AG, GEA Co, Copenhagen, Denmark) was used for agglomeration process under the following experimental condition: 50°C (inlet fluidizing air temperature), 5 mL/min (solution feed rate) and 1.5 m/s (atomizing air pressure) for 30 min. In this study, the creamer powder (150 g) was placed in a container. Then, 30-mL aqueous solution of lecithin concentration (2%, w/w) was fed by a peristaltic pump and sprayed from a spray nozzle, which was located at the top of the chamber. The lecithin solution acts as a binder during the drying process as recommended for fluidization process by Dhanalakshmi et al. [13]. The solution droplets fell down on the creamer powders, while the filtrated hot air from the bottom of the chamber flowed throughout the chamber to reduce the moisture content and dustiness of particles. The atomization of the feed solution was stopped for 5 min every 10 min during fluidization, and the gas flow rate was increased steadily to ensure the proper flow pattern of the solids, and the balance between the coating and agglomeration mechanisms (layering and particle coalescence) could be reached. This helps to compensate the moisture and prevent further stickiness in the drying chamber. Vanilla (5% w/w) was added at the final drying stage because of thermal sensitivity of aromatic compounds. Additional flavors could be added to enhance the overall flavor of the reduced-fat products [53].

3. Analytical tests

3.1. Water activity (a$_w$)

Water activity (a$_w$) of all regular and instant creamers was measured in triplicate by using an AquaLab water activity metre (Series 3TE, Decagon Devices Inc., Pullman, WA, USA) with ±0.001 sensitivity at 21°C.

3.2. Average particle size

Average particle size (D[$_{4,3}$]) was determined by measuring the volume-weighted mean diameter (de Brouckere mean diameter, D$_{4,3}$) in triplicate for each sample. The experiments was performed by means of a particle size analyzer with powder feeder unit (Model 2000 hydro S, Malvern Instrument, Worcestershire, UK) equipped with a Mastersizer software 2000 (Version 5.13). The volume-weighted mean diameter is estimated by the following equation:

$$D\,[4,\,3] = \Sigma n_i D_i^4 / \Sigma n_i D_i^3$$

where n$_i$ is the number of particles with diameter D$_i$[15].

3.3. Wettability determination

The wettability of creamers was determined according to the method described by Gong et al. [19] with minor modification. In this experiment, 100-mL hot distilled water (70 ± 5°C) was poured into a 250-mL glass beaker; then 10 g of creamer powder was poured into the beaker. The time required for the powder to completely become wet was recorded as wetting time. This measurement was carried out in triplicate for each sample.

3.4. Apparent viscosity measurement

The apparent viscosity of all creamers was measured with a rheometer (RheolabQC Rheometer, Anton Paar Co, Österreich, Austria) at room temperature (25 ± 1°C). The experiment was conducted by reconstituting 20-g creamer with100-mL hot distilled water (70 ± 5°C). Then, 25 ml of prepared solution (20%, w/w) was shaken prior to analysis. Prior to shearing test, all samples were left 5 min to reach the equilibrium condition. Apparent viscosity was measured in triplicate for each sample.

3.5. Color evaluation

The color intensity of all creamers was measured by a Hunter Lab colorimeter (Model A60–1012-402, Fairfax County, VA, USA). The color intensity was expressed in the CIELAB space as L* (lightness; 0 = black, 100 = white) and b* (+b = yellowness, −b = blueness) values [24]. For color measurement, 10 mg of sample was placed in a transparent polypropylene bag for analysis. The color measurement was done in triplicate for each sample.

3.6. Yield determination

The drying yield was measured according to the method described by Koocheki et al. [31]. The averages of three individual measurements were considered for each sample:

$$Y = 100 \times \left(M_1 / M_2 \right)$$

M_1 = mass of initial ingredients (g); M2 = mass of final powders (g).

3.7. Experimental design and statistical analysis

A full factorial design technique was considered to prepare different samples (**Table 2**). One-way analysis of variance (ANOVA) and Fisher's multiple comparison tests were used to find out the significant ($p < 0.05$) or insignificant ($p > 0.05$) difference among all samples. Then, the data were subjected to two-way analysis of variance (ANOVA) to determine the main and interaction effects of inulin and maltodextrin on the creamer characteristics. The degree of significance of all independent variables could be determined with F-ratio. The factor or independent variable with higher F-ratio represents the factor with more significant powerful effect and vice versa [38]. Also, the t-test was applied to analyze the significant ($p < 0.05$) difference among mean values of samples before and after agglomeration process. Minitab

Components	Formulations															
	CS	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Maltodextrin (%)	0	0	0	0	15	15	15	15	20	20	20	20	25	25	25	25
Inulin (%)	0	2.5	5.0	7.5	0	2.5	5.0	7.5	0	2.5	5.0	7.5	0	2.5	5.0	7.5
HPKO (%)	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Sodium caseinate (%)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Skim milk powder (%)	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
DPHP (%)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Silicon dioxide (%)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lecithin (%)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Solid corn (%)	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Vanilla (%)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

HPKO, hydrogenated palm kernel oil; DPHP, dipotassium hydrogen phosphate; final volume was adjusted up to 100 ml by distilled water.

Table 2. The compositions of different reduced-fat creamer slurries.

version 16 (Minitab Inc., State College, PA, USA) was used to run the statistical analysis. All formulated creamers were compared with control and two commercial creamers (A and B) to investigate the impact of different fat replacers and drying techniques.

4. Results and dissociation

4.1. Effect of different fat replacers and drying techniques on water activity

Figure 2 shows that the water activity (a_w) of the formulated creamers was significantly ($p < 0.05$) affected by the type and content of fat replacer as well as drying technique. As shown in **Figure 2**a, water activity of regular creamers significantly decreased from 0.36 to
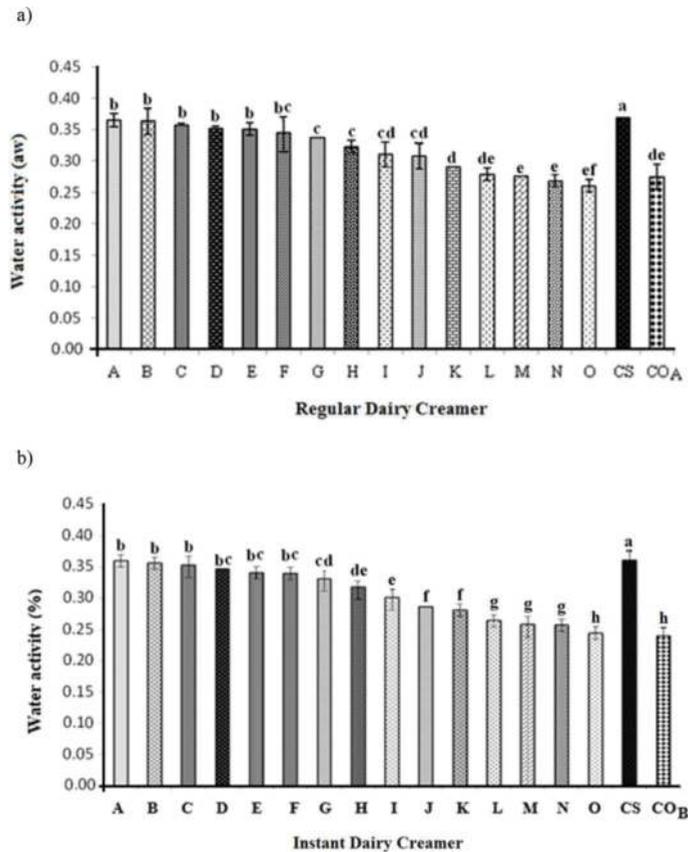

Figure 2. Water activity of differently formulated regular creamers (a) and instant creamers (b) as compared to the control (CS) and two regular and instant commercial creamers (CO) (a and B). [a–m] Significant differences at the confidence level of $p \leq 0.05$ (mean ± SD, n = 3); A–C: Creamers with 0% maltodextrin and 2.5, 5.0 and 7.5% inulin, respectively. D–G: Creamers with 15% maltodextrin and 0, 2.5, 5.0 and 7.5% inulin, respectively. H–K: Creamers with 20% maltodextrin and 0, 2.5, 5.0 and 7.5% inulin, respectively. L–O: Creamers with 25% maltodextrin and 0, 2.5, 5.0 and 7.5% inulin, respectively.

0.26 with increase in maltodextrin and inulin contents. The samples containing higher malto-dextrin and inulin contents had lower water activity, while control sample (CS) had the high-est water activity among all formulated creamers (**Figure 2**a). The control sample is probably more hygroscopic than the other formulated creamers. The result showed that the control creamer adsorbed more water than other formulated creamers. It had the highest stickiness and very poor reconstitution properties as well. In this case, Kumar and Mishra [32] explained that the proper water activity of powder should be between 0.20 and 0.25. Water activity (a_w) of instant spray-dried samples also varied from 0.36 to 0.24 (**Figure 2**b). It was concluded that the single and interaction effects of inulin and maltodextrin significantly ($p < 0.05$) affected the water activity of regular and instant spray-dried creamers (**Table 3**). Maltodextrin has highly hygroscopic effect with the extensive ability to capture the free moisture, so aw reduction can be due to such maltodextrin function.

Table 4 also shows that the water activity of the creamer was significantly influenced by fluid-ized-bed drying. This difference was analyzed by comparing the water activity of the regular and instant creamer before and after fluidized-bed drying, respectively. Maltodextrin showed more significant ($p < 0.05$) effects than inulin as indicated by its higher F-ratio. It was observed that the agglomeration induced by fluidized-bed drying significantly ($p < 0.05$) decreased the water activity of instant creamers. This might be attributed to long residence time (about '30 min) and hot air (50°C) injected throughout fluidized-bed the dryer. The hot air caused

Creamer	Creamer characteristics	Linear effect				Interaction effect		R²
		Inulin		Maltodextrin		Inulin* Maltodextrin		
		p-value	F-ratio	p-value	F-ratio	p-value	F-ratio	
Regular	Water activity	0.000	52	0.000	793	0.000	1	0.971
	particle size	0.000	14	0.000	1744	0.000	74	0.994
	Apparent viscosity	0.000	48	0.000	1442	0.278[a]	1	0.990
	Wettability	0.000	22	0.000	832	0.006	4	0.988
	Lightness (L*)	0.000	158	0.000	5181	0.000	40	0.997
	Yellowness (b*)	0.000	134	0.000	8691	0.000	22	0.999
	Yield	0.367[a]	1	0.002	8	0.477[a]	1	0.690
Instant	Water activity	0.000	585	0.000	1389	0.000	12	0.998
	particle size	0.000	108	0.000	2259	0.001	7	0.995
	Apparent viscosity	0.000	859	0.000	38,957	0.000	95	0.999
	Wettability	0.000	550	0.000	800	0.000	5	0.988
	Lightness (L*)	0.000	7609	0.000	265,995	0.000	206	0.999
	Yellowness (b*)	0.000	474	0.000	15,137	0.000	32	0.997
	Yield	0.000	23	0.000	4009	0.000	12	0.998

[a]Non-significant ($p > 0.05$).

Table 3. Two-way ANOVA showing the single main effect and interaction effect of inulin and maltodextrin on characteristics of regular and instant reduced-fat dairy creamers.

Creamers	Mean	p-value	T-value	Test
RSRC	0.33	0.000	5.87	Water activity (a$_w$)
ISRC	0.29			
RSRC	58.68	0.000	29.55	Wettability
ISRC	37.97			
RSRC	5.66	0.000	−12.84	Apparent viscosity
ISRC	6.30			
RSRC	66.05	0.000	−9.96	Particle size
ISRC	120.15			
RSRC	84.33	0.000	12.61	Lightness (L*)
ISRC	81.01			
RSRC	13.79	0.000	−14.99	Yellowness (b*)
ISRC	15.70			
RSRC	64.40	0.360[a]	−0.92	Yield
ISRC	66.59			

RSRC: Regular spray-dried reduced-fat creamer.
ISRC: Instant spray-dried reduced-fat creamer.
[a]Insignificant at $p > 0.05$.

Table 4. Student *t*-test for significant comparison of the regular and instant reduced-fat dairy creamers.

more water evaporation from the surface of the particles, thus providing less stickiness (wall deposition). The results showed that the regular creamers had higher water activity than the instant creamers, indicating a higher amount of freely available water for the undesirable biological reactions and consequently inducing shorter shelf life.

4.2. Effect of different fat replacers and drying techniques on wettability and apparent viscosity

Table 5 shows the wettability and apparent viscosity of different reduced-fat dairy creamer as compared to two commercial creamers and control. The wettability and viscosity of the regular and instant dairy creamer were significantly ($p < 0.05$) affected by the different compositions and drying techniques. Wettability is an important instant property of powder, and it is defined as the ability of particles to overcome the surface tension between the liquid (solvent) and themselves [14]. It is also directly affected by the interactions between two phases [9]. In general, wettability is considered to be the rate-controlling step of the reconstitution process [29] with the surface content strongly affecting the wettability [16]. In the current study, the regular (75 s) and instant (63 s) control creamers showed the longest wetting time among all formulated creamers (**Table 5**). This might be explained by the effects of fat replacer and total solid contents on the wettability of the reduced-fat creamer (**Table 6**). The presence of free fat on the particle surface could reduce wettability of control sample due to its hydrophobicity, making it difficult for water to penetrate into the powder.

Sample	Regular creamers			Instant creamers		
	Wettability (s)	Apparent viscosity (mPa.s)	Yield (%)	Wettability (s)	Apparent viscosity (mPa.s)	Yield (%)
Control*	75.00 ± 0.82^a	4.75 ± 0.19^a	43.00 ± 1.83^l	63.00 ± 0.00^a	4.85 ± 0.01^n	43.30 ± 1.20^l
MA0%, IN2.5%	75.50 ± 0.70^a	4.88 ± 0.02^{ab}	43.55 ± 0.62^l	61.00 ± 1.4^a	4.84 ± 0.01^n	43.55 ± 0.62^l
MA 0%, IN 5%	75.50 ± 0.70^a	5.04 ± 0.06^b	47.00 ± 0.00^k	56.50 ± 0.70^b	5.21 ± 0.01^m	47.00 ± 0.31^k
MA0%, IN7.5%	76.00 ± 0.93^a	5.06 ± 0.05^b	47.77 ± 0.31^k	55.50 ± 0.70^b	5.29 ± 0.01^l	47.77 ± 0.31^k
MA15%, IN0%	69.00 ± 0.97^b	5.32 ± 0.02^b	53.35 ± 0.50^j	54.00 ± 1.41^b	6.03 ± 0.02^k	53.35 ± 0.50^j
MA15%, IN2.5%	66.50 ± 0.70^{bc}	5.37 ± 0.02^b	55.03 ± 0.04^i	44.00 ± 2.12^c	6.01 ± 0.01^k	55.03 ± 0.04^i
MA15%, IN 5%	64.00 ± 1.06^{cd}	5.46 ± 0.02^b	60.55 ± 0.78^h	40.00 ± 0.00^d	6.21 ± 0.01^i	60.55 ± 0.78^h
MA15%, IN7.5%	61.50 ± 0.83^d	5.54 ± 0.01^{bc}	61.45 ± 0.63^h	39.50 ± 3.53^d	6.18 ± 0.01^j	61.45 ± 0.63^h
MA20%, IN0%	58.50 ± 0.70^e	5.76 ± 0.02^{cd}	65.80 ± 1.13^g	35.00 ± 3.53^{ef}	6.49 ± 0.01^h	65.80 ± 1.13^g
MA20%, IN2.5%	58.50 ± 0.75^e	5.81 ± 0.02^{cd}	66.00 ± 1.41^g	36.00 ± 1.41^e	6.56 ± 0.02^f	66.00 ± 1.41^g
MA20%, IN 5%	54.00 ± 1.21^f	5.89 ± 0.01^{cd}	70.60 ± 0.55^f	32.50 ± 0.70^{fg}	6.52 ± 0.00^g	70.60 ± 0.55^f
MA20%, IN7.5%	50.50 ± 0.65^g	6.04 ± 0.03^d	75.66 ± 0.48^e	30.00 ± 0.00^g	6.75 ± 0.02^e	75.66 ± 0.48^e
MA25%, IN0%	45.50 ± 2.05^h	6.29 ± 0.00^d	79.77 ± 0.48^d	24.00 ± 1.41^h	7.09 ± 0.01^d	79.77 ± 0.48^d
MA25%, IN2.5%	44.00 ± 1.40^h	6.35 ± 0.01^d	85.06 ± 0.09^c	24.00 ± 0.73^h	7.12 ± 0.01^c	85.06 ± 0.09^c
MA25%, IN 5%	40.00 ± 0.09^j	6.41 ± 0.01^d	89.45 ± 0.77^b	19.00 ± 1.40^i	7.35 ± 0.01^a	89.45 ± 0.77^b
MA25%, IN7.5%	40.50 ± 0.77^{ij}	6.53 ± 0.03^d	94.60 ± 0.56^a	13.00 ± 1.40^j	7.32 ± 0.01^b	94.60 ± 0.56^a
Commercial creamers	43.00 ± 1.41^{hi}	5.82 ± 0.02^d	—	17.00 ± 0.00^i	7.29 ± 0.00^b	—

*Control (0% inulin and maltodextrin); mean values ± standard deviation with different lowercase letters in the same column indicating significant difference ($P < 0.05$); control (0%MA & 0%IN); MA, maltodextrin; IN, inulin.

Table 5. Significant differences ($p < 0.05$) among different regular and instant reduced-fat dairy creamers as compared to two regular and instant commercial creamers in terms of wettability, apparent viscosity and yield.

As shown in **Table 5**, the regular spray-dried creamers exhibited different levels of wettability (40–75.50 s), while the instant spray-dried creamers lower faster wettability (13–61 s) than regular creamers with similar formulations. This was comparable with the wettability of the regular commercial creamer A (43 s) and instant commercial creamer B (17 s), respectively. The results showed that the wetting time of regular and instant creamers was decreased by increasing the particle size and decreasing the water activity of creamers. Jakubczyk et al. [26] reported that the wettability of the apple puree powder was improved from '45 to '33 (s) by increasing maltodextrin from 6 to 15% (w/w). The amount of wall materials significantly affected the wettability of the final powder. The results showed that there was a reverse relationship between wetting time and the content of wall materials (i.e. inulin and maltodextrin).

Characteristics		Inulin	Maltodextrin	Total solid content	Wettability	Viscosity
Viscosity	r-correlation	0.180	0.938	0.950	−0.988	—
	p-value	0.506	0.000*	0.000*	0.000*	
Wettability	r-correlation	−0.156	−0.925	−0.931	—	—
	p-value	0.564	0.000*	0.000*		
Particle size	r-correlation	0.656	0.907	0.924	−0.903	0.941
	p-value	0.045*	0.000*	0.000*	0.001*	0.000*

r = r Pearson correlation; significant at $p < 0.05$; r > 0.9 represents positive strong correlation, while and r > −0.9 represents negative strong correlation.

Table 6. Correlation analysis between total solid content, inulin and maltodextrin contents and creamer characteristics.
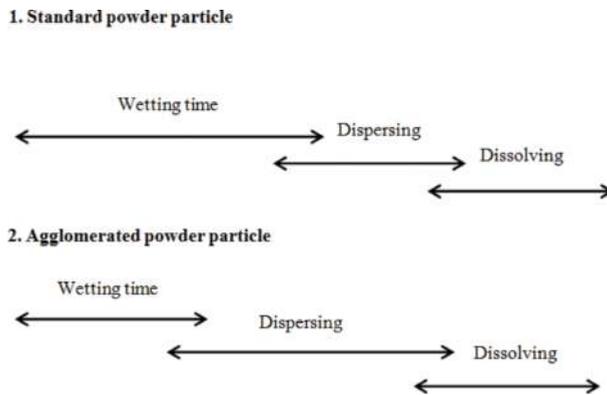
Figure 3. Dissolution timeline for regular and agglomerated (instant) powder showing the overlaps between different phases with time [14].

The creamer containing the highest maltodextrin (25%) and inulin (7.5%) showed the shortest wetting time among all formulated creamers (**Table 5**).

The instant creamer exhibited significantly higher wettability (shorter wettability) than the regular creamer (**Table 5**) due to large particles exhibiting more empty spaces among themselves, resulting in easier penetration by the liquid (i.e. water) [15]. Lecithin can modify the flowability and wettability of dried powders due to its potential surface active properties with higher porosity and better wettability [13]. **Figure 3** clearly shows the schematic of dissolution timeline for standard and agglomerated powder [14] by correlation between the wettability, dispersibility and solubility in the regular (non-agglomerated) and instant creamers.

As shown in **Table 5**, the apparent viscosity of regular spray-dried creamers varied from 4.88 to 6.53 (mPa.s) as compared to the control (4.75 mPa.s) and regular commercial creamer A (5.82 mPa.s). In addition, the viscosity of the instant spray-dried creamers varied from 4.84 to 7.35 (mPa.s) compared to the commercial instant creamer B (7.29 mPa.s) and control sample (4.85 mPa.s) (**Table 5**). The result showed that the apparent viscosity of regular and instant

creamers was significantly ($p < 0.05$) increased by increasing the concentration of maltodextrin and inulin in the creamer formulation. This could be due to increasing the total solids of samples and positive effect of inulin and maltodextrin on the formation of a stable particle gel with tridimensional network in the present of aqueous phase which led to enhance the viscosity of creamer. Debon et al. [10] also reported the similar observation. They reported that the addition of 5% inulin to the formulation significantly increased the apparent viscosity of low-fat fermented milk. It might be due to several different factors such as (i) the interaction between inulin and milk protein (i.e. sodium caseinate) leading to enhance the viscosity, (ii) the high inulin capacity to retain water [46] and (iii) the capacity to retain water by formation of small aggregates of inulin microcrystal [20]. This might be due to the increase in the amount of soluble materials and reduction in the moisture content.

The apparent viscosity of the spray-dried creamers was greatly enhanced after agglomeration via fluidized-bed drying (**Table 5**). This could be explained by the significant ($p < 0.05$) effects of the agglomeration on the intermolecular interactions among creamer particles which resulted in higher viscosity. In addition, the lower moisture content and higher total solid content can be also responsible for the higher viscosity of the instant creamers. Water acts as a mobility enhancer, resulting in a larger free volume and a reduction in the viscosity [48].

4.3. Effect of different fat replacers and drying techniques on average particle size

In the current study, the average particle size of different creamers was determined by measuring the volume-weighted mean. The particle size of the powder can significantly affect its appearance, flowability, wettability and dispensability [43]. **Figure 4** showed a significantly increase in the particle size of different formulated creamers. The results showed that the creamer O containing 25% maltodextrin and 7.5% inulin exhibited the largest particle size (101.45 μm), while the control sample had the smallest particle size among all regular spray-dried dairy creamers, respectively (**Figure 4a**). As stated by Master [36], the particle size is highly influenced by the viscosity of the feed. Similar observations were previously reported by Jinapong et al. [27] wherein increasing the solids content of instant spray-dried soymilk powders from 5.2 to 13.0% significantly resulted in enlargement of the particle size from 14.54 to 23.59 (μm).

Figure 4b shows that agglomeration process by fluidized-bed drying technique significantly ($p < 0.05$) increased the volume-weighted mean ($D_{4, 3}$) or particle size of the instant spray creamers compared to the regular creamers. As stated by Chen and Özkan [8], agglomeration results in larger particles, bigger particle clusters and better flow characteristics than one-stage drying. The instant spray-dried creamers exhibited different particle size, ranging from 46.45 to 193.26 μm compared to control creamer (47.35 μm) and the commercial instant creamer B (190.94 μm) (**Figure 4b**). As stated by Carić [7], the most suitable particle size for rapid dispersion is around 150–200 μm. Binder in the wet agglomeration process leads to the enlargement of particle size, thereby improving the flowability of the final powder [3, 44]. Jinapong et al. [27] reported that the particle size of the instant spray-dried soymilk was increased from 25 to 260 μm after subjecting the sample to fluidized-bed drying. This finding was also reported also by Machado et al. [35] wherein agglomerated soy protein had much larger particles than non-agglomerated regular creamer. In addition, it was found that the agglomeration through fluidized-bed drying also caused stickiness reduction and flowability
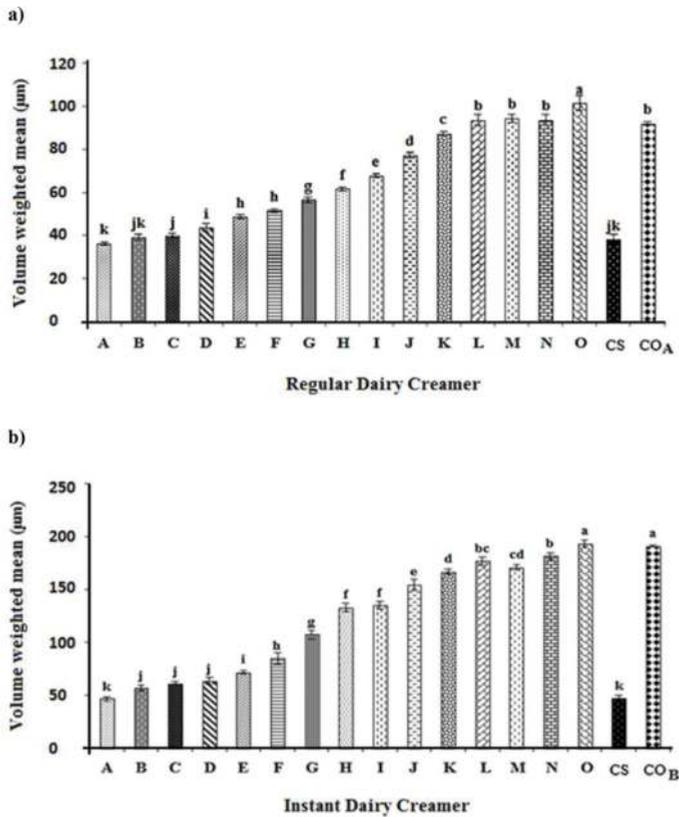
Figure 4. Volume-weighted mean (or average particle size) of differently formulated regular creamers (a) and instant creamers (b) as compared to the control (CS) and two regular and instant commercial creamers (CO) (a and B). [a-m] Significant differences at the confidence level of $p \le 0.05$ (mean ± SD, n = 3); A–C: Creamers with 0% maltodextrin and 2.5, 5.0 and 7.5% inulin, respectively. D–G: Creamers with 15% maltodextrin and 0, 2.5, 5.0 and 7.5% inulin, respectively. H–K: Creamers with 20% maltodextrin and 0, 2.5, 5.0 and 7.5% inulin, respectively. L–O: Creamers with 25% maltodextrin and 0, 2.5, 5.0 and 7.5% inulin, respectively.

improvement in the creamer. As the particle size increases, the adhesive forces decrease due to the attractive forces (i.e. van der Waals) among creamer particles [54]. However, the application of the spray drying process followed by the agglomeration process resulted in a significant ($p < 0.05$) better flowability and reconstitution properties than the spray drying alone. Dhanalakshmi et al. [13] indicated that the powder flowability and reconstitution are highly affected by the particle size, shape and distribution, the particle surface properties as well as the geometry of the system. As shown in **Table 3**, the linear and interaction effects of the inulin and maltodextrin had significant ($p < 0.05$) effect on the volume-weighed mean (or particle size) of spray-dried creamers.

4.4. Effect of different fat replacers and drying techniques on yield

Table 5 shows the yield of regular and instant dairy creamers compared to the control sample. The control sample had remarkably lower yield (43%) than other regular spray-dried creamers.

The low yield was observed for the control. This could be due to the stickiness of this sample to the spray drying chamber and cyclone wall. This might be because the control did not contain inulin and very low percentage of maltodextrin as a drying aid. Stickiness is one of the main technological issues in the production of powders such as coffee creamer because it results in a reduction of the yield and stability. The result showed significant improvement in the production yield by increasing the maltodextrin and inulin content in the formulation (**Table 5**). This was in agreement with the previous finding reported by Shrestha et al. [45] for spray-dried tomato pulp. In fact, the addition of drying aids such as maltodextrin with high glass transition temperature (>145°C) to the premix is one of the most suitable ways to increase the stability, decrease the stickiness and improve the yield [21, 45]. In addition, maltodextrin can help to shorten the drying time, thus reducing the input energy required for spray drying process. According to Adhikari et al. [1], the improvement of yield (recovery) might be due to the formation of a thin protein-rich membrane at the particle-air interface. The high glass transition temperature of this surface layer causes the conversion of this thin membrane into a glassy state, which prevents particles from sticking to each other and to the walls of the dryer which resulted in the decrease of the wall deposition during drying and increase of the yield. As shown in **Table 3**, maltodextrin with higher F-ratio had higher significant effects than inulin on the yield. There was no significant ($p > 0.05$) difference between the yields of single- or double-step drying processes for regular and instant creamer, respectively.

Figure 5. The appearance of regular commercial creamer (a) as compared to the control creamer (b) and regular formulated-reduced-fat creamer containing 25% maltodextrin and 7.5% inulin.

It means that there was not any material loss or stickiness to the wall during fluidized-bed dying process. This could be attributed to the high efficiency of such drying technique.

4.5. Effect of different fat replacers and drying techniques on color

Figure 5 shows the appearance of the regular creamer as compared to the control and commercial creamer. The results indicated that differently formulated creamers, control and commercial creamer had significant ($p < 0.05$) different color intensity in terms of L* and b* (**Table 7**). In general, the lightness (L*) of all formulated regular and instant creamers was enhanced by increasing maltodextrin and inulin concentrations in the creamer formulation. The result indicated that the addition of maltodextrin and inulin to the creamer formulation led to decrease the stickiness and increase the lightness of samples. Similar observation was reported by Shrestha et al. [45] on spray-dried orange juice. The regular and instant creamer with 25% maltodextrin and 7.5% inulin had the highest L*, while the control showed the lowest L*among all samples due to the caramelization reaction (**Table 7**). The regular creamer containing the highest maltodextrin content (25%) exhibited almost similar color to the regular commercial

	Regular creamers		Instant creamers	
Sample	L*	b*	L*	b*
Control*	71.07 ± 0.05[l]	22.49 ± 0.21[a]	70.73 ± 0.21[o]	24.57 ± 0.05[a]
MA0%, IN2.5%	73.28 ± 0.33[k]	22.04 ± 0.06[b]	71.20 ± 0.11[n]	23.71 ± 0.21[b]
MA0%, IN5%	72.67 ± 0.27[k]	21.09 ± 0.13[c]	72.23 ± 0.00[m]	23.62 ± 0.11[b]
MA0%, IN7.5%	71.48 ± 0.55[l]	20.14 ± 0.04[d]	70.46 ± 0.02[p]	22.50 ± 0.47[c]
MA15%, IN0%	78.91 ± 0.07[j]	18.37 ± 0.36[e]	74.05 ± 0.00[l]	20.69 ± 0.09[d]
MA15%, IN2.5%	82.30 ± 1.47[i]	18.09 ± 0.07[e]	76.38 ± 0.03[k]	20.42 ± 0.17[d]
MA15%, IN 5%	84.63 ± 0.21[h]	17.46 ± 0.53[f]	79.13 ± 0.02[j]	17.47 ± 0.00[e]
MA15%, IN7.5%	85.57 ± 0.19[g]	15.15 ± 0.00[g]	80.48 ± 0.01[i]	17.44 ± 0.00[e]
MA20%, IN0%	87.46 ± 0.24[f]	11.63 ± 0.02[h]	82.11 ± 0.00[h]	13.92 ± 0.00[f]
MA20%, IN2.5%	87.12 ± 0.01[f]	11.03 ± 0.02[i]	84.05 ± 0.11[g]	13.32 ± 0.00[g]
MA20%, IN 5%	89.28 ± 0.17[e]	10.28 ± 0.01[j]	84.30 ± 0.02[f]	12.61 ± 0.02[h]
MA20%, IN7.5%	89.80 ± 0.00[de]	10.83 ± 0.08[i]	86.73 ± 0.02[e]	11.76 ± 0.03[i]
MA25%, IN0%	90.90 ± 0.50[c]	7.73 ± 0.00[k]	88.73 ± 0.02[c]	10.79 ± 0.11[j]
MA25%, IN2.5%	90.51 ± 0.00[cd]	7.22 ± 0.30[l]	88.71 ± 0.01[c]	9.21 ± 0.00[k]
MA25%, IN 5%	92.56 ± 0.57[b]	6.99 ± 0.00[l]	89.17 ± 0.19[b]	8.56 ± 0.01[l]
MA25%, IN7.5%	95.32 ± 0.00[a]	6.85 ± 0.07[l]	90.15 ± 0.01[a]	8.08 ± 0.07[m]
Commercial creamers (Regular and instant)	95.44 ± 0.40[a]	7.00 ± 0.07[l]	88.59 ± 0.00[d]	8.20 ± 0.02[m]

*Control (0% inulin and maltodextrin); mean values ± standard deviations with different lowercase letters in the same column indicating significant difference ($P < 0.05$); MA, maltodextrin; IN, inulin.

Table 7. Significant different ($p < 0.05$) color intensity of different regular and instant reduced-fat dairy creamers as compared to two regular and instant commercial creamers.

creamer A (**Table 7**). According to Roland et al. (1999), reduced-fat ice cream made by only maltodextrin exhibited similar whiteness to 10% fat ice cream. Moreover, the control and creamer containing 0% maltodextrin and 2.5% inulin had the highest b*among all samples. On the other hand, the regular and instant samples containing 25% maltodextrin exhibited similar yellowness (b*) as compared to regular and instant commercial samples (A and B). The instant commercial creamer B and the formulated creamer containing 25% maltodextrin and 7.5% inulin had the lowest b* among all instant creamers (**Table 7**). The lightness (L*) and yellowness (b*) of the instant creamers were slightly decreased after applying the agglomeration process. This might be attributed to the effects of binder solution and Maillard reaction on the lightness of the instant creamer. Szulc and Lenart [49] also reported similar findings for the agglomerated dairy powders. They explained that Maillard reaction was responsible for the color changes during agglomeration (i.e. fluidize-bed drying). Color can change during the drying process due to several chemical reactions. Most of the time, enzymatic activity is not desirable, because it affects the amount of nutrients in food (e.g. hydrolysis of lecithin by phospholipase) or the color of the products. The yellowish color of regular and instant creamer is mainly due to the non-enzymatic reaction, either by caramelization or by Maillard reactions. The caramelization process is a complex series of chemical reactions promoted by the direct heating of sugars [6].

5. Conclusions

The present work describes the possibility of producing regular and instant reduced-fat dairy creamers by spray and fluid-bed drying and the changes in some of the physical, chemical and powder properties of the creamer powders depending on the maltodextrin and inulin levels. A significant effect of the type and concentration of the fat replacers (wall materials) on the process yield, wettability, viscosity, solubility, color, water activity and particle size was found. The results showed that the process has some difficulties for drying of control samples. The use of wall materials (maltodextrin and inulin) significantly improved the drying process and leads to improve the physicochemical properties of reduced-fat dairy creamer functionality. The highest wettability, viscosity, solubility, yield and lightness and lowest water activities were obtained from the samples containing the highest contents of maltodextrin (25% w/w) and inulin (7.5%). As a result, the current study also revealed that the instant formulated-reduced-fat creamers from two-stage drying (spray drying followed by fluidized-bed drying) showed significantly ($p < 0.05$) better quality than regular creamer from one-stage drying (spray dying only). The current study suggests optimizing the fluidized-bed drying condition for preparation and commercialization of instant reduced-fat dairy creamer.

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