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The effect of drying methods on the characteristics and functional properties of unripe banana (Musa spp.) flour: Air drying, freeze-drying and extrusion

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Abstract

The study aimed to investigate the properties of unripe banana flour (UBF) subjected to several drying processes, including air drying, freeze-drying and extrusion, consider as a source of nutrients and a functional ingredient. The result showed that air and freeze-drying did not alter morphology, crystallinity and properties of UBF as much as did extrusion. The UBF obtained through air and freeze-drying had a higher resistant starch (69 – 72%) when comparing with the extrusion. Air and freeze-drying increased the water holding capacity and viscosity of starch paste, but decreased its solubility, swelling capacity and browning. Extrusion induced a strong degradation of the starch molecules resulting in reduced granule crystallinity (0.14 – 0.34%), resistant starch (< 0.3%), final viscosity (49 – 82 cP) and setback values (32 – 46 cP). In contrast, increased swelling power, solubility and browning were obtained with the use of extrusion. The gelatinization temperatures (76 – 88°C) and enthalpy of gelatinization (16 – 17 J/g) of UBF after drying with air or freeze-drying while extrusion method exhibited the flour with lower gelatinization temperature (54 – 74°C) and enthalpy of gelatinization (0.3 J/g). The results of this study may be useful in considering the UBF as a functional ingredient and a feasible drying procedure. The UBF obtained by air drying was economically viable than that obtained by freeze-drying verify. Nevertheless, both procedures could provide the UBF as an ideal material to be used as functional thickening agent for starchy processed foods and also as resistant starch to lower digestion. Extruded UBF could be employed in a variety of instant drinks and processed foods aimed for consumption by children and elderly.

Keywords: Banana flour, thermal properties, X-ray diffraction, pasting, functional properties

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1. Introduction

Drying is a technique which significantly removes an amount of water from food in order to extend its shelf life. It has evolved from traditional sun drying to more advanced methods such as air drying, spray drying, sprout bed, drum dried, vacuum drying and freeze-drying [1]. Each method may induce differences in properties, microstructure and other characteristics of the final dried products. Among these techniques, freeze-drying involves the direct sublimation of frozen ice at low temperatures and pressures. It is widely regarded as the best because it reduces cell damage while simultaneously enhancing food bodies, porosity structure, appearance and nutritional content of the finished product. However, its drawbacks are high production costs and energy consumption [1, 2]. On the other hand, the traditional hot air drying appeared to be the preferred drying manufacture due to lower production costs and energy consumption [2, 3]. Unfortunately, the quality of dried products is limited due to the surface destruction and cell rupture of the original foodstuff [4]. Extrusion is another technique that has been proven to be an efficient method for altering the qualities of grain, flour and starch. Extrusion involves high heating, pressure and shear forces which cause changes in all physicochemical and functional properties of the final products [5], for example, damaging the starch morphology [6 – 9], promoting starch gelatinization and changing thermal properties [3, 4, 10], disrupting the structure of the amylose and amylopectin chains and decreasing resistant starch [11, 12].

Bananas (Musa spp) are abundant in tropical and subtropical regions and widely consumed with a global production rate of 3.2% and 4.6 million hectares of agricultural land in 2020 [13]. Kluai Namwa (Musa spp. ABB) is the most popular and widely grown in Thailand and ASEAN with the world gross exported increased from 25.6 thousand tons in 2009 to 38.7 thousand tons in 2018 [14]. Even though most bananas were marketed fresh, unripe bananas can still be used and turned into flour which has been found to have several nutritional and nutraceutical benefits. Previous research discovered that banana flour contained a high amount of dietary fiber, mineral elements and it is a source of resistant starch [7, 15, 16]. Several authors recently investigated the use of unripe banana flour (UBF) in a variety of foods as well as the substitution of the other flours such as potato, corn and wheat in the food industry [16, 17]. The possible method for producing unripe bananas into flour has been suggested. Several drying technologies can be used to produce banana flour including air drying [4], freeze-drying [12, 18], ultrasonic and spray drying [19], sprouted bed [3, 20], extrusion [8, 11, 12]. However, when banana flour was obtained under various drying conditions, the quality of the products

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varies significantly. The assumption of this work was based on the concept that each different method for producing UBF has their own set of drawbacks. The appropriate technique, therefore, could not only be considered to increase economic viability but also to provide a worthy natural functional ingredient for the food industry.

The objective of this study was to determine the impacts of drying processes affecting the physicochemical, functional and structural properties of the physical modified UBF. The results could be proposed a suitable drying means for producing processed banana flour desirable for the food application.

2. Materials and Methods

2.1 Materials

The unripe banana (Musa spp. ABB) was cultivated locally in the Western region of Thailand and harvested 110 days after anthesis. Banana with the first stage of ripening process (whole green color) was selected to use as raw material in this study. The unripe banana (UB) was manually washed under running tap water, skinned and sliced (1 mm). The enzymatic browning reaction was inhibited by immersing the sliced UB in a 0.1% (w/v) alum sulphate solution for 10 min and then drained.

2.2 Drying methods

The UB samples obtained from section 2.1 were subjected to dry with four different drying methods. The first method was adapted from Babu *et al*. [21], the UB slices were air dried (AD) using a tray drier (JSOF-600W, South Korea). The UB slices were dried for 8 hours at 55 °C to achieve a moisture level of 8 – 10%. The second method was freeze-drying (FD), the UB slices were frozen for 24 hours at −18°C in a chest freezer (Sanyo, SF-C1497, Thailand). After that, the frozen UB slices were freeze-dried at −50°C in a vacuum freeze dryer (Scanvac cool safe55, Denmark) until they attained an 8 – 10% moisture content. In both cases, the dried UB slices were kept at room temperature, milled into powder and sieved through 60 meshes. The third and fourth processes flours were the AD and FD flours which were subjected to extrusion with a twin-screw extruder (CTE-D22L32, China). The moisture content of UBF was adjusted to 12% by adding water during the extrusion. Screw speeds were 450 rpm with a feed rate of 25 Hz. The barrel temperature profile in the three barrel zones from the feeder to the dry zone were set constant at 40, 70 and 90 °C which was adapted from Pico *et al*. [12]. The samples obtained from air drying with extrusion (AD-ED) and freeze-drying with extrusion (FD-ED) were cooled to room temperature, milled and sieved with a 60 mesh. All 4 differently modified UBF samples were packed in plastic bags, kept in an airtight container and stored at room temperature (30 °C) until further analyses. The moisture content of UBF was controlled at 7 – 9% in AD and FD, while 4 – 7% in AD-ED and FD-ED samples.

2.3 Proximate, total starch, resistant starch, amylose and amylopectin measurement

Protein, fat, dietary fiber and ash of UBF were analyzed by the AOAC standard methods [22]. Total starch and resistant starch of the samples were measured by glucoamylase methods [23] and determined using Megazyme kits (Megazyme international Ireland, Ireland). Amylose and amylopectin content were determined according to ISO 6647-2:2007.

2.4 Water holding capacity measurement

The UBF samples (100 mg dry basis) were soaked in deionized water (10 ml). The solution was agitated at 25 °C for 6 hours before centrifugation at 14,000xg for 15 minutes. Prior to evaporation of the sample at 105 °C, the supernatant was carefully removed and weighed (g). Water holding capacity was calculated using a gram of adsorbed water per gram of dried material [24].

2.5 Solubility and swelling power measurement

The samples (0.4 g dry basis) were mixed with deionized water (40 ml) in a centrifuged tube and then heated for 30 minutes at a temperature range of 40-90 °C with an interval of 10 °C. The suspensions were then centrifuged for 10 minutes at 3000xg. The supernatant was decanted and the sediments were weighed before being dried at 105 °C. The swelling power was calculated as weight of wet sediment/weight of dried sample. The solubility was calculated as (weight of dissolved solids after evaporation/ weight of original sample) x100 [21].

2.6 Color and browning index

The color analysis was carried out with a colorimeter chroma meter (Minolta CR310, Japan) using the CIE standard (L*, a*, b*). The CIE values of L* represent the range of dark to light color, a* represent the range of green to red color, b* represent the range of blue to yellow color. The browning index (BI) was calculated as BI = [100(X−0.31)]/0.172 whereas X = (a*+1.75L*)/ (5.645L*+a*−3.012b*) [25]. The hue angle was determined as $\tan^{-1}$(b*/a*), whereas the chroma intensity was computed as (a*2+b*2)1/2 [26].

2.7 Pasting properties

Pasting properties of sample were analyzed using a Rapid Visco Analyser (Newport Scientific RVA-4, Australia). The samples of 3 g (dry basis) added with 25 ml distilled water were subjected to a heating-cooling cycle. They were heated to 50 °C for 1 minute, then increased to 95 °C with a heating rate of 12 °C/minutes, and maintained at 95 °C for 2 minutes, cooled down to 50 °C within 2 minutes. The data from 4 different treatments were recorded to compared for peak viscosity, breakdown, final viscosity and setback.

2.8 Thermal properties

The thermal properties of UBF was determined using a differential scanning calorimeter (Perkin Elmer, DSC 8000, USA) modified from the method of Teng *et al*. [27]. Three mg UBF (dry basis) was weighed in a stainless pan (40 μl) and added with distilled water (9 μl), sealed and left at room temperature for 1 hr before measurement. The samples were subjected to a heat range of 20 °C to 120 °C with a speed rate of 10 °C/minutes. The onset temperature (T_0), peak temperature (T_p), conclusion temperature (T_c) and enthalpy of gelatinization (ΔH_{gel}) were recorded. The analyzed pan of each samples was stored for 21 days at 4 °C for retrogradation monitoring. The

Table 1. Proximate, total starch, amylose, amylopectin, resistant starch (%dry basis) and water holding capacity of UBF obtained from air drying (AD), freeze-drying (FD), air drying and extrusion (AD-ED) and freeze-drying and extrusion (FD-ED).

Parameters	AD	FD	AD-ED	FD-ED
Crude protein^{ns}	2.67±0.08	2.54±0.11	2.50±0.12	2.49±0.17
Crude fat^{ns}	0.69±0.40	0.73±0.18	0.74±0.24	0.72±0.16
Dietary fiber^{ns}	7.46±0.46	7.53±0.28	7.63±0.24	7.59±0.22
Ash^{ns}	2.84±0.17	2.83±0.32	2.92±0.20	2.77±0.24
Total starch^{ns}	82.54±1.30	83.44±0.03	84.60±1.90	85.06±1.82
Amylose	28.12^{c}±0.02	33.93^{b}±0.01	36.33^{a}±0.01	36.87^{a}±0.02
Amylopectin	71.88^{a}±0.02	66.07^{b}±0.01	63.67^{c}±0.01	63.13^{c}±0.01
Resistant starch	69.01^{b}±0.78	72.10^{a}±0.34	0.23^{c}±0.25	0.27^{c}±0.38
Water holding capacity (g/g)	12.48^{b}±0.17	15.70^{a}±0.14	1.04^{d}±0.02	1.35^{c}±0.08

^{a,b,c,d} The mean values in the same row with different letters are significantly different ($p \leq 0.05$).

^{ns}not significantly.

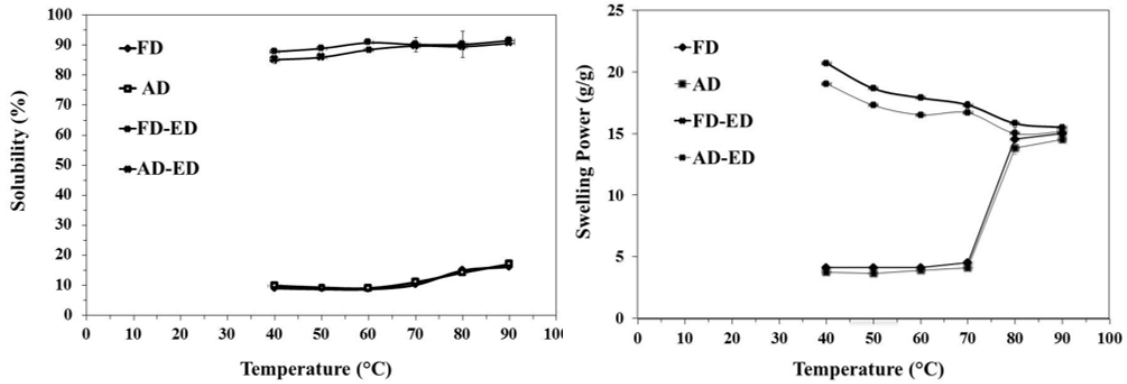

Figure 1: Solubility (left panel) and swelling power (right panel) of UBF obtained from air drying (AD), freeze-drying (FD), air drying and extrusion (AD-ED) and freeze-drying and extrusion (FD-ED) at different temperatures.

pan was rescanned using the similar temperature profile as previously mentioned. The enthalpy of rescanning was recorded as ΔH_{ret}.

2.9 X-ray diffractometry

The XRD diffractogram was constructed using a Bruker D8 Discover (Bruker AXS, Germany) with a voltage of 40 kV and 40mV with a step size of 0.02° at room temperature. The recording was made at a scanning speed of 1°/minutes and angle interval 2 to 45° (2theta). The ratio of the crystalline area with respect to the total area was used to compute crystallinity degree.

2.10 Microstructure

The UBF microstructure was obtained with a scanning electron microscopy (Tescan mira3, Czech Republic). The samples were sprinkled onto an adhesive tape attached to an aluminium stubs, covered with gold in a sputter coater prior to scanning. The microstructure was observed at the accelerated potential voltage of 15 kv and 350xmagnification were monitored.

2.11 Preparation of instant plant based soup

The plant base soup was prepared by mixing dried banana blossom powder 25%, as a major source of plant, coconut milk power 35%, pregelatinized starch 16% (control) and other ingredients 24%. The hot plant based soup was further processed by mixing these dried ingredients with hot water (80 °C) at a ratio of 1:6. The viscosity, browning index and resistant starch were determined using UBF from various drying methods with 100% substitution of pregelatinized starch.

2.12 Statistical analysis

All measurements were performed in triplicates. Data are presented as the mean ± standard deviation. The data analysis was performed with an ANOVA and the Duncan new multiple ranges test for mean differentiation at the 95% of significant confidence interval was carried out using the SPSS software version 23 (IBM, USA).

3. Results and Discussion

3.1 Proximate composition, total starch, resistant starch, amylose and amylopectin content

Drying methods had no effect on protein, fat, dietary fiber, ash and total starch content ($p>0.05$), but had a significant effect on amylose, amylopectin and resistant starches content ($p \leq 0.05$) as shown in Table 1. In this study, amylose content in UBF ranged from 28.12 to 36.87% similar to the finding of Bi *et al.* [7] and Nimsung *et al.* [28] who reported on the amylose

Table 2. CIE Color, browning index and water holding capacity of UBF obtained from air drying (AD), freeze-drying (FD), air drying and extrusion (AD-ED) and freeze-drying and extrusion (FD-ED).

Parameters		AD	FD	AD-ED	FD-ED
CIEColor	L*	79.24^{b}±0.06	81.78^{a}±0.27	56.58^{c}±0.36	57.70^{c}±0.81
	a*	2.54^{b}±0.08	2.00^{c}±0.03	7.48^{a}±0.12	7.38^{a}±0.20
	b*	11.63^{c}±0.01	10.26^{d}±0.18	16.72^{a}±0.51	15.95^{b}±0.47
Browning index		18.11^{b}±0.07	14.74^{c}±0.31	43.69^{a}±1.69	41.47^{a}±1.02
Hue		103.56^{b}±2.01	116.07^{a}±1.00	50.59^{c}±0.75	48.88^{c}±1.01
Chroma		11.90^{c}±0.83	10.46^{d}±0.19	18.31^{a}±0.52	17.57^{b}±0.87

^{a,b,c,d} The mean values in the same row with different letters are significantly different ($p \leq 0.05$).

Table 3. Pasting properties and thermal properties of UBF obtained from air drying (AD), freeze-drying (FD), air drying and extrusion (AD-ED) and freeze-drying and extrusion (FD-ED).

	AD	FD	AD-ED	FD-ED
Peak viscosity(cP)	3,984.16^{b}±184.37	6,921.33^{a}±110.45	545.00^{d}±45.31	871.28^{c}±71.43
Breakdown(cP)	643.28^{c}±66.43	1,535.00^{a}±180.03	469.33^{d}±49.66	1,243.79^{b}±56.20
Final viscosity(cP)	5,189.30^{b}±285.67	8,251.67^{a}±102.10	49.33^{d}±1.15	81.67^{c}±6.50
Setback(cP)	1,874.18^{b}±115.91	2,865.33^{a}±287.00	31.67^{d}±2.08	45.77^{c}±1.39

^{a,b,c,d} The mean values in the same row with different letters are significantly different ($p \leq 0.05$).

content in banana flour to be 26.10 – 32.05%. The amount of amylose of AD and FD samples (28.12 – 33.93%) were lower than the AD-ED and FD-ED samples (36.33 – 36.87%). The higher amylose content in flour after extrusion could be due to the fact that extrusion at a high temperature under shearing released more short chain starch, resulting in higher amylose content [11]. As a result, the components of amylopectin differ from those of amylose in a reciprocal manner. The UBF samples had high total starch content, with nearly 80% of starch, more than half of which was resistant starch with content values similar to those reported by Bezerra *et al*. [20]. UBF from AD had significantly lower resistant starch content (69.01%) than that of FD (72.10%). This could be due to the fact that the temperature (55 °C) during air drying was lower than the UBF gelatinization and transition temperatures (76 – 85°C). On the other hand, the freeze-drying technique may result in disorganized and chain rigidity in the starch structure [29], therefore, could promote the development of resistant starch to different extent from the air drying sample [4, 12]. The extrusion reduced the resistant starch by about 90% in AD-ED and FD-ED samples (0.23−0.27%). This phenomenon could be due to the high shear stress and temperature during extrusion, which destroyed the granules and the crystalline structures preventing the forming of more amorphous region [6]. This result was consistent with the finding of Sarawong *et al*. [11] who discovered that all extruded banana flour had a very low RS level with a drop of 91.5−98.1% compared to the native flour.

3.2 Water holding capacity

The water holding capacity (Table 1) of the AD sample (12.48 g/g) was significantly lower than that of the FD sample (15.70 g/g) ($p \leq 0.05$). This might be due to the difference in the surface of the starch particles. In case of FD, the UBF was dried under sublimation of ice crystal, resulting in a porous structure. The water then could be able to interact well with the starch chains, this increasing the water holding capacity [18]. The result agreed with those of Ahmed *et al*. [4] who reported green banana flour processed by tray drying and air oven drying had lower water holding ability than green banana flour processed by freeze-drying. The AD-ED and FD-ED samples had the lowest in water holding capacity (1.04 – 1.35 g/g) comparing with AD and FD samples. This result conformed to that of Sarawong *et al*. [11] who found that the extrusion of banana flour processed under high temperature (80 – 130°C) and low moisture content (20%) decreased water holding capacity of the flour from 2.44 g/g to 1.47 – 1.95 g/g.

3.3 Solubility and swelling power

The solubility is an indicator for the amount of soluble molecules leach out from the starch granule [17]. As illustrated in Figure 1, The AD and FD samples (8 – 19%) had lower solubility compared with those of AD-ED and FE-ED samples (84 – 90%). This could be the results of the dextrinization process during extrusion which caused degradation and fragmentation of the starch granules, leading to the formation of significantly more water-soluble products [8]. It was in accordance with the report of Sarawong *et al*. [11], in which the solubility of extruded banana flour was increased 77.45% from 7.60% in native flour.

The swelling power of starch is a measurement of the starch granules ability to bind water during temperature range of 40 °C to 90 °C (Figure 1). The AD and FD samples had swelling power substantially lower than those of the AD-ED and FD-ED samples. This was owing to the pregelatinization occurred under extrusion process. When the temperature was elevated to 80 – 90°C, the swelling power of the AD and FD samples grew dramatically. This peculiar behavior might cause by the varied gelatinization temperatures of the UBF, which were found to be between 76 – 88.40°C for a group of AD and FD and 53.9 – 73.80°C for a group of extrusion (AD-ED and FD-

Table 4. Thermal properties of UBF obtained from air drying (AD), freeze-drying (FD), air drying and extrusion (AD-ED) and freeze-drying and extrusion (FD-ED).

	AD	FD	AD-ED	FD-ED
Gelatinization				
T_0 (°C)	76.10^{b}±0.02	78.99^{a}±0.03	53.9^{d}±0.25	54.10^{c}±0.16
T_p (°C)	79.00^{b}±0.14	83.30^{a}±0.05	62.16^{d}±0.35	65.09^{c}±0.26
T_c (°C)	85.02^{b}±0.25	88.40^{a}±0.31	72.87^{d}±0.16	73.80^{c}±0.17
ΔH_{gel}(J/g)	16.06^{b}±0.09	17.39^{a}±0.09	0.29^{d}±0.01	0.31^{c}±0.01
Retrogradation				
T_0 (°C)	74.98^{b}±0.23	79.00^{a}±0.06	33.64^{d}±0.54	34.66^{c}±0.19
T_p (°C)	79.00^{a}±0.06	83.28^{a}±0.07	59.53^{c}±0.77	59.79^{c}±0.13
T_c (°C)	93.25^{b}±0.33	94.28^{a}±0.44	73.53^{d}±0.14	74.50^{c}±0.09
ΔH_{ret}(J/g)	13.93^{b}±0.11	14.77^{a}±0.15	8.24^{d}±0.14	8.54^{c}±0.17

^{a,b,c,d} The mean values in the same row with different letters are significantly different ($p \leq 0.05$).

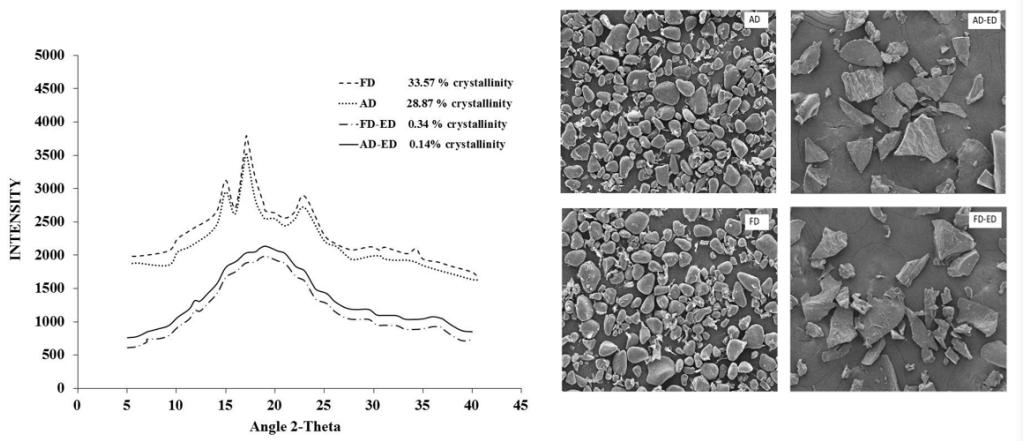

Figure 2: X-ray diffractograms and microstructure (350x) of UBF obtained from air drying (AD), freeze-drying (FD), air drying and extrusion (AD-ED) and freeze-drying and extrusion (FD-ED).

ED). The result was consistent with that of Agama-Acevedo *et al*. [16] who reported the banana flour from four varities (Macho, Enano, Valery and Morado varities) was soluble and more swelling when heated to gelatinized temperature (approximately 70 − 80°C). The studied of Zheng *et al*. [30] had a similar pattern of the swelling of the native banana flour and extruded samples.

3.4 Color and browning index

The AD sample had lower lightness (L*), but higher redness (a*) and yellowness (b*) values than those measured in FD sample as shown in Table 2. The difference in color could be seen clearly using hue, chroma and browning indicating that AD samples had lower hue (104), higher in chroma (11.90) and in browning index (18.11) than FD samples where relevant values were 116.07, 10.46 and 14.74, respectively. This browning phenomenon was hypothesized to be the result of Maillard reaction which occurred more strongly during the heat transfer of the air drying process than during freeze-drying [4, 18, 31]. The AD-ED and FD-ED had the highest redness (a*) and yellowness (b*) values, while the lightness (L*) values were the lowest. The hue, chroma, and browning index results showed a corresponding change, which resulted in more melanoidin formation and a darker browning color during the extrusion process [6].

3.5 Pasting properties

The pasting properties of UBF as function of various drying conditions are presented in Table 3. The results revealed that the peak viscosity, breakdown, final viscosity and setback values of the AD sample were significantly lower than those of the FD sample. This was due to the lower amylose content of AD sample that may be less capable of binding water and re-associated in starch chain. As a result, UBF dried by air drying had greater stability but less retrogradation than UBF dried by freeze-drying [3, 32]. The AD-ED and FD-ED samples had significantly lower in pasting properties than AD and FD samples (Table 3). It could be attributed to the greater degree of gelatinization, shear fragmentation and the degradation occurring during extrusion. Sarawong *et al*. [11] reported a similar reduction trend of the pasting properties in extruded green banana flour, with peak viscosity reducing from 1,293 to 114 cP, breakdown value reducing from 543 to 101 cP, final viscosity reducing from 1,064 to 39 cP and setback value resulting from 314 to 26 cP. This observed phenomenon clearly indicated that the extrusion improved the properties of banana flour in terms of reducing both viscosity and retrogradation, increasing the solubility and the swelling power at already low temperature which may be suitable for instant drinks and processed foods aimed for consumption by children or elderly.

Table 5. The viscosity, resistant starch, fiber, protein and browning index of plant based soup mixed with UBF obtained from air drying (AD), freeze-drying (FD), air drying and extrusion (AD-ED) and freeze-drying and extrusion (FD-ED).

Parameters	Control	AD	FD	AD-ED	FD-ED
Viscosity (cps)	5182^{b}±212	5382^{b}±112	$5{,}512^{a}$±198	$2{,}865^{c}$±371	$2{,}745^{c}$±267
Resistant starch(% dry basis)	0.01^{b}±0.13	9.13^{a}±0.33	9.21^{a}±0.68	0.02^{b}±0.02	0.03^{b}±0.17
Browning index	36.41^{b}±0.13	36.71^{b}±0.13	35.88^{c}±0.27	39.32^{a}±0.21	38.91^{a}±0.87

^{a,b,c} The mean values in the same row with different letters are significantly different ($p \leq 0.05$).

3.6 Thermal properties

The thermal properties were employed to quantify the gelatinization and retrogradation phenomena as shown in Table 4. The gelatinization temperatures (T_0, T_p and T_c) in the AD sample ranged from 76 to 85 °C were lower than those in FD sample (79 – 88°C). ΔH_{gel} of the AD sample was also significantly lower (16.06 J/g). It indicated that AD sample required less energy to gelatinize and melt the ordered structure. FD sample was dried under sublimation mechanism might cause internal rigidity structure that resisted the gelatinization, so inducing higher resistant starch and amylose contents [4]. The results agreed with those of Ahmed *et al.* [4] who reported the gelatinized temperature and ΔH_{gel} of green banana flour obtained from air drying to be lower than that obtained from freeze-drying. The AD-ED and FD-ED samples had lower transition temperatures and ΔH_{gel} than AD and FD samples. The extrusion caused degradation and fragmentation of the starch granules, thus lower temperature was required to melt the ordered structure within starch granules.

In order to monitor the retrogradation behavior of UBF, the gelatinized samples were stored at 4 °C for 21 days. The results showed a similar trend to those of the gelatinization process, revealing much higher ΔH_{ret} (13.93 – 14.77 J/g) found in AD and FD flour in comparison with the AD-ED and FD-ED samples (ΔH_{ret} 8.24 – 8.54 J/g). This behavior indicated a certain effect of the extrusion on amylose and amylopectin which might lose their ability to retrograde and could result in the low setback value of the extruded UBF as mentioned previously [8].

3.7 X-ray diffractometry

X-ray diffractometry (XRD) is a method to analyse the amorphous and crystalline zone of the polymer. It is used to determine the structure of carbohydrate in flour or starch. The crystallization characteristics of the starch granules of the UBF obtained for the different drying means were in Figure 2. One can clearly notice that the XRD pattern of the AD and FD samples exhibited similarity pattern with a region of three prominent peaks. The highest peak located at 2θ of 17° and two minor peaks located at 2θ of 14° and 22° respectively, with a high degree of starch crystallinity of 28.87 – 33.57%. This diffraction pattern is consistent with a β type conforming to the findings of previous studies [4, 7, 33 – 35]. The extrusion affected the XRD pattern of the starch of AD-FD and FD-ED by eliminating the organized starch crystalline structure (crystallinity 0.14 – 0.34%), the diffractogram formed a high pattern of an amorphous state nearly 99%. This is possibly caused by the mechanisms of the extrusion process which damaged the starch granules and the crystallinity. These results were in agreement with those of Giraldo-Gomes *et al.* [8] and Pico *et al.* [12] who also reported the altered XRD starch pattern of the extruded banana flour compared with those of the native drying.

3.8 Microstructure

SEM images of the UBF showed further that the surface morphology was also affected by drying process (Figure 2). The particles obtain from AD and FD had similar and mostly irregular shapes and sizes, tending to exhibit oval shape and spheroid forms, wherefore some small particles were round. [4, 7, 17, 20, 21, 28]. Bi *et al.* [7] argued that banana flour particles were most often long and oval in shape with small and larger surface areas, which tended to be more susceptible to enzymatic digestion with a higher digestion rate. On the other hand, the SEM picture of the AD-ED and FD-ED samples showed evidence of more irregular shape of the flour particles. This morphology was due to the gelatinization of the UBF and degradation phenomenon when subjected to high shear and temperature [6, 8, 9].

3.9 Instant plant base soup properties

Instant plant base soup was prepared by using pregelatinized starch as a thickener (control sample) and the properties of the samples prepared by using 100% substitution of pregelatinized with UBF from several drying methods were shown in Table 5.

The viscosity and browning index of the soup with the UBF derived from AD and FD samples did not differ, in same case, from the control sample ($p>0.05$). As expected, the soups added with AD and FD samples had higher levels of resistant starch than the control. The soups prepared with AD-ED and FE-ED samples were not significantly different from the control ($p>0.05$), having a lower viscosity and a darker color. The findings suggested that the modified UBF acquired through air and freeze-drying should preferably be used as a functional thickening agent in soup, whereas those samples obtained through extrusion could be used as instant drinks which need less viscosity property.

4. Conclusions

Overall, the physically modified UBF properties were influenced by drying technique. The UBF dried by air drying had significantly darker and negative characteristics as considered by the content of resistant starch, amylose, pasting and thermal properties as compared to the freeze-drying process. In terms of flour qualities and economic feasibility, air drying was found to be the suitable method to generate the modified UBF because it used less energy during processing than the freeze-drying. Nevertheless, both techniques produced the modified UBF samples with high resistant starch content indicating that they could

be employed as a functional thickening ingredient in the food industry and these two drying means may be appropriate for altering the UBF properties to expect for the slow digestibility and result in low glycemic index of the product such as soups. The combined extrusion with air and freeze-drying exhibited destructured starch granules and resulted in a darker color and lower content of resistant starch. The strong degradation of the starch structure and morphology of the extruded UBF caused lower paste viscosity and a lower energy requirement for gelatinization, resulting in higher solubility and swelling power at a lower temperature. Consequently, the extruded UBF became more soluble in water allowing it to be used for instant drinks and food products aimed for consumption by the elderly and children.

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