American Journal of Food Science and Technology, 2017, Vol. 5, No. 5, 210-219
Available online at http://pubs.sciepub.com/ajfst/5/5/7

DOI:10.12691/ajfst-5-5-7

Effect of Drum Drying on the Colour, Functional and Pasting Properties of Sweetpotato-based Complementary Food

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Abstract This study was conducted to understand the effect of drum drying on colour, functional and pasting properties of a sweetpotato-based complementary food. Four blends of complementary flours made up of Orange fleshed sweetpotato (OFSP), millet and soybean flours were formulated based on the nutrient strength of the individual flours. The functional, pasting properties and colour of the flour blends before and after drum drying was determined. Colour intensity (ΔE) and saturation (ΔC) of formulated products increased after drum drying. Water absorption capacity (WAC) of formulations ranged from 152.5 to 216.7%, swelling index (SI) from 6.65 to 7.73, bulk density (BD) from 0.787 to 0.827 g/ml and solubility from 17.78 to 20.32%. Drum drying conditions used reduced the WAC, SI, BD and solubility of the formulations. Though the drum drying conditions used did not reduce the pasting temperature, it was able to reduce the peak time and further reduce the peak viscosity, breakdown and setback viscosities. OFSP flour could be used to develop a complementary food with improved functional and pasting properties, when complemented with millet and soybean flours and processed through drum drying.

Keywords: *orange-fleshed sweetpotato, bulk density, water absorption capacity, colour, swelling power, solubility*

Cite This Article: Damian Laryea, Faustina D. Wireko-Manu, and Ibok Oduro, "Effect of Drum Drying on the Colour, Functional and Pasting Properties of Sweetpotato-based Complementary Food." *American Journal of Food Science and Technology*, vol. 5, no. 5 (2017): 210-219. doi: 10.12691/ajfst-5-5-7.

1. Introduction

The drum dyer is an old food processing equipment that was developed in the early 1900s. Its main purpose was for drying most liquid food materials until the invention of the spray dryer. It could dry slurries, liquid or dough materials into thin sheets which could then be made into flakes or powders [1]. Specifically, the drum dryer could be used to dry thick liquids, pulps, pastes or slurries, mashed potatoes, carrots, soups, baby cereals, etc. [2]. It has also been used to dry sweet whey, which is used as a sugar replacer in French-type bread and butter cookies with good sensorial and nutrient attributes [3].

There are two forms of the drum dryer: single drum dryer and double drum dryer. However another type exists which is similar to the double drum dryer, called the twin drum dryer. But the drums of the twin drum dryer moves in opposite directions to each other. The vacuum drum dryer is another type which is used to dry food materials sensitive to heat. All drum dryers have common parts such as the feeding system, a scraper, motor to rotate drums, pressure gauges, etc. Some may have an automated system included to control the screw speed and pressure of steam [1]. The temperature of steam for drum drying could be as high as 200°C, at which most of the moisture of the food material is removed.

Time for drying could take a few seconds or dozens of seconds to obtain moisture content of about 5% [1]. Energy consumption may range from 1.1 kg steam per kg of evaporated water to 1.6 kg steam per kg of evaporated water, corresponding to energy efficiencies of about 60-90%. Rate of production of products could be between 5 $kg/h/m^2$ and 50 $kg/h/m^2$. This depends on the initial moisture of feed, the final moisture content to be achieved, steam temperature, type of food, type of dryer, etc [1].

The drum dryer is easy to operate and maintain, flexible and appropriate for multiple but small quantity production. Products may have good porosity, hence good rehydration due to boiling evaporation. Drum drying may however affect flavour and colour of product due to direct contact with high dry heat [1].

The physico-chemical properties, macromolecule structure (starch granules) and other nutrients are affected by the process of drum drying. Colonna *et al*. [4] reported that drum drying degrades starch very slightly compared with extrusion cooking; which together with shear (due to the screws) degrades starches better to make them more soluble.

The drum drying process could improve the protein digestibility and make more amino acids available [5]. Desobry *et al*. [6] has reported that drum drying was able to stabilize carotenoids in pure β-carotene which was encapsulated in 25 Dextrose Equivalent maltodextrin, than spray and freeze-drying. It was also observed from their work that the higher the temperature, the lower the bulk density.

Pua *et al*. [7] also reported that the quality and acceptability of drum dried product is greatly and significantly affected by steam pressure and rotation speed of drums.

In another work by Majzoobi *et al*. [8], who sought to modify wheat starch, using the process of drum drying observed that the process destroyed native starch granules. It also degraded molecular structure and reduced the degree of crystallinity of starch. The pregelatinized starch was able to show cold water viscosity at 25 ºC unlike the native starch. Water absorption and swelling of the starch increased, but the intrinsic viscosity was greatly reduced by the drum drying process.

The drum dryer could therefore be used for the development of baby cereals or complementary food. Due to the various modifications it applies on the starches being drum dried, it could be used to produce instant complementary foods. It is also safe to use. As a result, its use in the processing of a Sweetpotato-based complementary food will produce an instant complementary food while improving on the quality of the food; in terms of digestibility, functionality and nutrient availability.

Pasting properties are an important index in determining the cooking and baking qualities of flours. The properties include peak viscosity, breakdown viscosity, setback viscosity, final viscosity, pasting temperature, peak time, etc. These help in determining the nature of flour and its use in the food industry. It also helps to ascertain the cooking properties of formulated flour blends which include complementary foods [9]. The Brabender or Rapid viscoamylograph could be used in determining these pasting properties.

Functional properties of flours have also been linked with some important qualities of products produced from these flours [10]. Some functional properties include; water absorption capacity, oil absorption capacity, least gelation concentration, bulk density, foaming properties (capacity and stability), swelling power/capacity, water solubility index, emulsifying capacity or emulsion activity/stability.

To promote the utilization of orange-fleshed sweetpotato (OFSP) towards reduction of vitamin A deficiency in Ghana, a sweetpotato-based complementary food was developed from OFSP flour, millet flour and soybean flour. The product was drum dried to improve upon nutrient quality and make it instant. Pasting and functional properties are important during the formulation of complementary foods [11,12]. Since the behaviour of individual flours used and the processing conditions have an effect on the pasting and functional properties of the formulated complementary food, this study is necessary.

2. Materials and Methods

The *Bohye* variety of Sweetpotato was obtained from the farms of the Crops Research Institute (CSIR-CRI), Fumesua. The Pearl millet and soybean were obtained from the open market in Accra.

2.1. Preparation of Flour from the Sweetpotato Millet and Soybean

Sweetpotatoes weighing 78.25 kg were sorted, peeled, chipped and dried in a hot air oven at 60°C for 12 h. Weight of chipped sweetpotatoes before drying was noted to be 49 kg. The dried sweetpotato chips were then milled in a hammer mill into flour. Millet weighing 27 kg was sorted, sieved, washed and dried at 60°C for 2 h and then milled into flour using the hammer mill. Soybean weighing 24 kg was also sorted and roasted for 15 min. It was then dehulled and milled into flour. All the flours were packed into high density polyethylene bags and stored in a cool dry room ready for formulation and analysis.

2.2. Formulation of Complementary Food

Based on the macronutrients of the individual flours with reference to the levels of macronutrients required of complementary foods as developed by CAC [13], material balance was used to estimate the minimum amount of each portion of flour to meet the standard. A range for the various proportions was therefore developed and mixture design (from the Statgraphics Centurion software) used to formulate the complementary food blend. The formulation is as shown in Table 1.

Table 1. Formulation for the complementary food blend

Runs	Flour compositions [%]			Other ingredients [% of total flour composition]		
	SP flour	Millet flour	Soybean flour	Sugar	Salt	Milk powder
1	60	10	30	5	0.5	5
2	60	15	25	5	0.5	5
3	50	15	35	5	0.5	5
4	55	10	35	5	0.5	5

SP – Sweetpotato
Formulations obtained from the statgraphics centurion from the range determined through material balance with reference to the CODEX, 2011 requirement for complementary foods.

2.3. Processing of the Complementary Food Blends

The flour blends produced from the formulations were drum dried. To 2.5 kg of flour blend, 2.37 L of water was added; therefore 95% of water per weight of flour blend was added to each of the samples and kneaded into dough. The dough was then introduced onto the drums. The pressure of steam used was 2.5 bar and temperature, 126.9°C while revolution of drums was at 0.1911 rev/min. Thin dry films were produced from the drum drying and these were then milled into flour and packaged for further analysis.

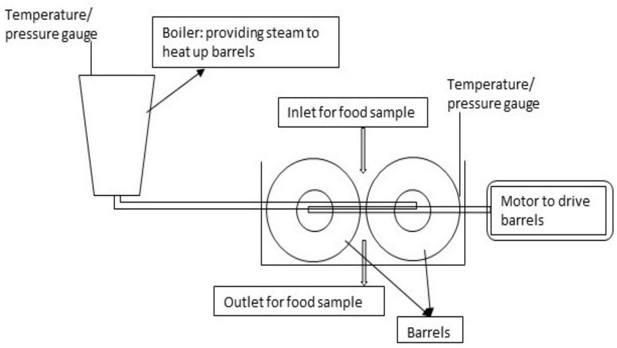

Figure 1. Schematic of double-barrel drum dryer used

2.4. Colour Determination of the Flour Samples

A hand-held chromameter CR-310 (Minolta Co. Ltd., Osaka, Japan) was used to determine the colour of flour samples. The chromameter was first calibrated with a white tile. The sample flour was poured to fill a petri dish and then covered. The lens of the chromameter was placed on the petri dish at three different parts. The colour measurements were then taken and recorded as *L*= darkness/lightness (0 = black, 100 = white), *a* (-*a* = greenness and +*a* = redness), and *b* (-*b* = blueness, +*b* = yellowness) [14]. ΔC and ΔE were also calculated as follows:

$$\Delta C = \sqrt{\Delta a^2 + \Delta b^2},\ \Delta E = \sqrt{\Delta a^2 + \Delta b^2 + \Delta L^2}$$

ΔC = Change in Chroma
ΔE = Change in Light intensity
$\Delta a = a_1 - a_0$, $\Delta b = b_1 - b_0$, $\Delta L = L_1 - L_0$
a_1, b_1 and L_1 = redness/greenness, yellowness/blueness and darkness/lightness value from samples
a_0, b_0 and L_0 = redness/greenness, yellowness/blueness and darkness/lightness value from the control used (sweetpotato flour).

2.5. Determination of Pasting and Functional Properties of the Flour Samples

2.5.1. Determination of the Pasting Properties of Flours

The pasting properties of the raw mixed flours and drum dried processed flours were determined using a Brabender viscoamylograph (Brabender, Duisberg Germany) which is equipped with 700-cmg sensitivity cartridge. 10% slurry (dry matter basis) of each of the flour samples was made with 500 mL distilled water and poured into the collection chamber. The equipment was then heated at a rate of 1.5°C per minute from room temperature to 95°C. This temperature was then held for 15 min and then cooled again to 55°C. The pasting temperature, peak viscosity, peak time, breakdown viscosity and setback viscosity were all deduced from the graph produced by the Brabender viscoamylograph [15].

2.5.2. Swelling Power and Solubility

A gram of sample flour was weighed and poured into a previously weighed 50 mL capacity centrifuge tube and 40 mL of distilled water added. The suspension obtained was uniformly and gently stirred using a stirring rod, avoiding excess force that might rupture the starch granules in the flour. It was then heated in a thermostatically controlled water bath at 85 ºC for 30 min, with constant stirring. The tubes were then cooled rapidly in ice cubes and then centrifuged at 2200 rpm for 15 min. The supernatant was poured into a weighed petri dish and evaporated to dryness in an oven at 105 ºC. The petri dish was then cooled in a desiccator and weighed in order to calculate the solubility while the swelling power was obtained through calculation when the sediment paste obtained after centrifugation was weighed [16].

2.5.3. Bulk Density

A calibrated centrifuge tube was weighed and filled with flour sample to the 5 mL mark, with constant tapping until there was no further change in volume. The tapped centrifuge tube was then weighed and the weight of the content noted. The bulk density of the sample was then calculated as the weight of sample noted per noted volume (5 mL) [17].

2.5.4. Water Absorption Capacity

Into a graduated centrifuge tube was weighed 1 g of sample. 10 mL of distilled water was added and tube shaken for 5 min to obtain dispersion. The resulting dispersion was then centrifuged at 3500 rpm for 30 min. The volume of supernatant was measured while the sediment and centrifuge tube weighed. The water absorption capacity of sample was then calculated per weight of initial dry sample [18].

2.6. Statistical Analysis

Data obtained was expressed as mean and standard deviation and One-way analysis of variance and Tukey's HSD test was used to ascertain any statistical differences at 95% confidence interval.

3. Results and Discussion

3.1. Functional Properties of the Formulations before Drum-drying

Water absorption capacity of samples ranged from 152.5 to 216.7 %. The first sample with 60% OFSP (Orange fleshed sweetpotato), 10% MF (millet flour) and 30% SBF [soybean flour] had the least water absorption capacity, while the sample with 55% OFSP, 10% MF and 35% SBF had the highest water absorption capacity (Table 2). A significant difference was observed between the first and fourth samples but not between the first and third, second and fourth samples, as well as between the second and third samples (Table 2). The water absorption capacity of samples was found to be higher than 150-180% reported by Olapade *et al.* [12], 124.67-165.33 reported by Adepeju *et al.* [11] and 95-133% reported by Ayo-Omogie and Ogunsakin [19] in their complementary blends. The variations and differences could be as a result of the various components of the complementary food blend. Drum drying the product may further improve upon this characteristic of the complementary food although not as much as an extruder would [4,8].

Swelling index was observed to be significantly higher ($p<0.05$) in samples with lower percentages of soybean compared with those with higher percentages. It ranged from 6.652 in sample 3 to 7.734 in sample 2 (Table 2). This implies that samples could swell up to about 7 times their original weight. The lower swelling power could be attributed to the soybean present. Soybean contains fats and this may interfere with water absorption by the starch granules by forming films around starch granules or competing with water that could have interacted readily with starch granules [20]. Although the percentage of fat in soybean flour is a little over 20% and amount of soybean flour used is small, there could have been significant interference. Moreover, the relatively higher sweetpotato flour contents in samples 1 and 2 could also be a contributing factor to the significantly higher swelling index. Considering complementary foods, the lower swelling index obtained seems to be an advantage, since lower swelling power is desirable. Complementary foods with lower swelling power are easily digestible by infants [21].

The swelling index was found to be higher than that reported by Ijarotimi and Oluwalana [22]. Their highest swelling index was reported in the control sample, Cerelac® to be 2.43%. Ayo-Omogie and Ogunsakin [19] reported a much higher swelling index (10.3-10.8 g/ml) in a fermented maize-cardaba banana complementary food. The difference between the swelling index of this study and that reported in literature may be attributed to the various food materials used in formulating the complementary food. The drum drying process is reported to improve upon this parameter by causing the gelatinization of starches in the sample [8,23,24].

The bulk densities of samples ranged from 0.787 to 0.827 (Table 2). Although sample 1 had the highest bulk density, there was no significant difference observed amongst samples. Bulk density is the mass of particles of the flours per total volume it occupies. It is influenced by the porosity of samples; thus, the spaces in-between flour particles and size of particles [25]. For complementary foods, lower bulk densities are desired [26], because products prepared are less bulky and easily digestible by infants while retaining the nutrients as compared with flours with high bulk densities which will require the addition of more water to make them less bulky and thereby reducing the nutrients; since infants only consume smaller amounts of food at a given time. Lower bulk densities were reported by Ikujenlola [27] (0.50–0.75 g/cm^3), Ijarotimi and Oluwalana [22] (0.66–0.73 g/cm^3) and Ayo-Omogie and Ogunsakin [19] (0.40–0.44 g/cm^3). Since their complementary foods were also unprocessed the difference in bulk density could be attributed to the different food ingredients used in the formulation of the complementary foods. Processing the formulated blends using the drum drying process is expected to reduce the bulk density of the Sweetpotato-based complementary foods being developed [7,8,24].

Solubility index (soluble solids) of samples were low, ranging from 17.78% in sample 1 to 20.32% in sample 4 (Table 2). It was observed that the higher the soybean content in the sample the higher the solubility. This could be attributed to the proteins present in soybean [28]. Proteins in the tertiary structure have hydrophobic regions which associate with non-polar solvents and hydrophilic regions which in turn associate with polar solvents, thus water. Soybean also contains oligosaccharides which are water soluble and may have contributed to the high solubility index in samples containing higher soybean flour. However, no significant differences were observed amongst samples. Solubility is further improved with processing methods such as drum drying and extrusion [1,23].

3.2. Pasting Properties of Formulations before Drum-drying

The pasting temperatures observed amongst the sample blends were high, ranging from 77.80°C in sample 1 to 78.40°C in sample 3 (Table 3). The highest pasting temperatures were observed in samples with reduced orange-fleshed sweetpotato flour (OFSPF) but increased levels of soybean. A significant difference was observed between samples 2 and 3 (Table 3). Considering the pasting temperatures in the individual ingredients, it can be observed that the ingredients complemented one another to result in the pasting temperatures observed. Therefore formulating complementary food is an important part as it may affect the resulting characteristics of the product. The pasting temperature of OFSP in this study was found to be lower than that reported by Jangchud *et al*. [29].

The pasting temperatures of all four samples reported in this study were however lower than that reported by Olapade *et al*. [12] and within range reported by Adebayo-Oyetoro *et al*. [30] but higher than that reported by Adepeju *et al*. [11]. Adebayo-Oyetoro *et al*. [30] developed a complementary food from fermented sorghum, walnut and ginger, while Adepeju *et al*. [11] produced theirs from breadfruit. Although all products are complementary foods the various components used are different, hence the difference in pasting temperature. Since pasting temperature corresponds to the amount of energy required to cook the food, lower pasting temperatures are more desirable.

Table 2. Functional properties of sample formulations before drum-drying

Samples	Functional properties			
	WAC [%]	Swelling Index [g/g]	Bulk Density [g/ml]	Solubility Index [%]
1[60:10:30]	152.5±5.00^{a}	7.297±0.22^{a}	0.827±0.05^{a}	17.78±0.81^{a}
2[60:15:25]	193.3±11.55^{bc}	7.734±0.04^{a}	0.815±0.02^{a}	18.74±0.76^{a}
3[50:15:35]	185.0±12.91^{ab}	6.652±0.10^{b}	0.807±0.00^{a}	18.78±1.15^{a}
4[55:10:35]	216.7±5.77^{c}	6.655±0.35^{b}	0.787±0.02^{a}	20.32±1.46^{a}

-WAC – Water Absorption Capacity
-Data is represented as mean ± standard deviation
-Sample ratios are represented as [Sweetpotato:millet:soybean]
-Values in same column with different superscripts are significantly different at 95% confidence level.

Table 3. Pasting properties of sample formulations before drum-drying

Samples	Pasting properties				
	Pasting temperature [°C]	Peak viscosity [BU]	Breakdown viscosity [BU]	Setback viscosity [BU]	Peak time [min]
1[60:10:30]	77.80±0.00^{ab}	128.0±2.83^{a}	14.00±1.41^{ab}	26.00±1.41^{a}	16.10±0.14ab
2[60:15:25]	77.75±0.07^{a}	142.0±2.83^{a}	18.00±0.00^{b}	31.50±0.71^{b}	15.20±0.00a
3[50:15:35]	78.40±0.28^{b}	90.50±4.95^{c}	8.00±1.41^{c}	23.00±0.00^{a}	15.75±0.42ab
4[55:10:35]	78.15±0.07^{ab}	109.0±2.83^{b}	12.50±0.71^{b}	22.00±1.41^{a}	16.20±0.07b
OFSPF	77.4	495	115	25	12.55
Millet flour	78.5	300	67	402	14.15
Soybean flour	50.2	8	3	3	0.00

-Data is represented as mean ± standard deviation
-Sample ratios are represented as [Sweetpotato:millet:soybean]
-Values in same column with different superscripts are significantly different at 95% confidence level.

Peak viscosity was observed to be highest in sample 1 (128.0 BU) and least in sample 3 (90.50 BU) (Table 3). Again, just like the swelling power in Table 2, the peak viscosity was observed to be highest for samples with lower soybean flour levels. Individually, the peak viscosities of millet and OFSP flours were higher compared to soybean which had a peak viscosity of 8 BU (Table 3). Given the wide difference in peak viscosities between soybean and millet or OFSP, soybean flour is therefore the main reason for the decreased peak viscosities. This is because soybean has negligible amount of starch [20]. Therefore products with more soybean content are more likely to be less viscous.

Breakdown viscosities of samples were observed to be as low as 8 BU in sample 3 to 18 BU for sample 2 (Table 3). It was observed that reducing OFSPF resulted in lower breakdown viscosities (Table 3). OFSPF had a relatively higher breakdown viscosity compared with millet and soybean (Table 3). Therefore samples with lower OFSPF may have reduced breakdown viscosities. There was however no significant differences observed between samples 1, 2 and 4 (Table 3). Breakdown viscosities reported in this study is much lower than that reported by Ayo-Omogie and Ogunsakin [19], who reported 11-326 BU in complementary food from fermented maize-cardaba banana blend. A lower breakdown viscosity indicates the product's ability to withstand higher cooking temperatures, which is also an indication of lower viscosities [21]. This will be a good characteristic for baby foods, because the product produced will be thin enough for easy digestion.

With respect to setback viscosity, sample 4 had the least setback viscosity (22.00 BU) while sample 2 had the highest (31.50 BU) (Table 3). There was however no significant differences between samples 1, 3 and 4 but between sample 2 and the other 3 samples (Table 3). Millet flour has a relatively high setback viscosity compared with the other flours. The flour blends had lower setbacks as expected because the proportion of millet (which has high setback) is low (10-15%) in the products. Therefore its reduced levels in the samples compared with the other flours resulted in the low setback viscosities obtained. Ayo-Omogie and Ogunsakin [19] reported much higher setback viscosities (38.5-174.58 BU) for their fermented maize-cardaba banana complementary food blend. This could be attributed to the difference in individual components of the complementary foods. Flours or starches with lower setback values have a lower tendency to retrograde [21]; thus the separation of paste formed from the water component of the mixture after a gel has been formed upon cooling.

Peak time is the amount of time needed to reach the peak viscosity. That is, the amount of time required to completely gelatinize the starches in the flour samples, thus, the cooking time. It was found to range between 15.20 to 16.20 min (Table 3). Formulation 4 had the highest time while formulation 2 had the least (Table 3). A significant difference ($p<0.05$) was observed between formulation 2 and 4. But none was observed between 1 and 3 (Table 3).

The peak times were found to be higher in the blends than the individual flours with soybean recording 0 min. The presence of high fat, protein and other food components in the soybean could have caused this effect. Chinma *et al.* [31] reported a peak time of 5.61 min for a full fat soybean sample. However, they extracted the starch from the soybean sample before conducting the analysis and the Rapid Viscoamylograph (RVA) was used in the analysis.

3.3. Colour of Sample Formulations before Drum-drying

Colour is an important parameter when it comes to food products as it has an influence on the purchasing and preference of the product. The colour of the samples was observed to be very light or whiter, given the very high L-values. L-values beyond 50 indicates relatively lighter or brighter colour while values below 50 represents darker colour [32]. The L-values ranged from 83.88 in sample 3 to 84.33 in sample 1 (Table 4). No significant differences ($p>0.05$) were observed amongst the samples. However, a significant difference ($p<0.05$) was observed between the samples and Orange-fleshed sweetpotato (OFSP) flour; and this may be due to the difference in flour compositions. The L-value for OFSP reported in this study (85.09) was observed to be lower than 87.70 reported by Jangchud *et al.* [29]. This could be attributed to the processing conditions involved in producing the sweetpotato flour.

The a-values of the samples were found to be in the range of -2.82 to -3.03 (Table 4). That of sweetpotato flour was -3.66. Given the interpretation of the a-value, the values can be found slightly in the green region of the a-scale [32]. The sweetpotato flour was found to be relatively more in the green region than the samples (Table 4) and this could be attributed to the flour compositions. The a-value reported in this study was however different from that reported by Jangchud *et al.* [29]. Their orange-fleshed sweetpotato was slightly in the red colour region [thus the positive, +a, region] compared to that reported in this study.

The b-value indicates the yellowness or blueness of the product [32]. Positive values indicate that the product is in the yellow region while negative values indicate vice versa. The samples were therefore in the yellow colour region. The b-value of the samples ranged from 16.19 to 17.23. That of the sweetpotato flour was found to be 17.36 (Table 4). Jangchud *et al.* [29] however reported a relatively higher b-value [25.8-30] for sweetpotato flour. There were significant differences between samples 1, 2 and 3, but not between 1 and 4 (Table 4).

Delta chrome (ΔC) represents the change in level of saturation of samples with respect to a standard sample while delta E (ΔE) represents the change in level of intensity of colour of a sample with reference to a standard sample [32]. Delta chrome (ΔC) of formulated samples with reference to the sweetpotato flour was found to be in the range of 0.66 to 1.44. That of the colour intensity (ΔE) was also in the range of 1.01 to 1.88. Significant differences were observed between samples 1, 2 and 3 but not 4, in terms of the delta chrome (ΔC). In the colour intensity (ΔE) a significant difference was only observed between sample 1 and 3 (Table 4). Smaller positive values obtained indicate that the difference in colour intensity and level of saturation of formulated blends and sweetpotato flour is very small. Therefore it could be inferred that the impact on the colour of sweetpotato flour by the other individual components (millet and soybean) was very small. The colour of sweetpotato flour hence dominated.

The relatively higher level of saturation and colour intensity values were obtained in sample 3 (Table 4). This sample also had the lowest values of L, *a* and *b* (Table 4). As a result, the difference between the colour of sweetpotato flour and that of the sample will be relatively wider. The formula for calculating delta chrome (ΔC) and colour intensity (ΔE) [32,33] confirms this explanation. Moreover, this sample, had the highest amounts of millet and soybean flours amongst all the samples, hence the reason for the result. Therefore the millet and soybean flours impacted on the flour colour although very small. An increase in millet and soybean flour could result in higher values hence change in colour.

3.4. Functional Properties of Drum-dried Complementary Food

The Water Absorption Capacity (WAC) of a food product is its ability to absorb moisture. It is defined as the amount of moisture taken up by the flour to achieve a desired consistency or optimal result. The WAC of the drum dried samples were in the range of 40 to 43.67% (Table 5). It was highest in sample 1 and least in sample 3 (Table 5). Also, samples with higher soybean content had lower WAC (Table 5). There was however no significant differences ($p>0.05$) among the samples.

Table 4. Colour of formulated blends before drum-drying

Samples	L	a	b	ΔC	ΔE
Sweetpotato flour	85.09±0.24^{a}	-3.66±0.01^{a}	17.36±0.09^{a}		
1[60:10:30]	84.33±0.10^{b}	-3.02±0.03^{b}	17.23±0.06^{ab}	0.66±0.02^{a}	1.01±0.21^{a}
2[60:15:25]	83.99±0.08^{b}	-2.90±0.03^{c}	16.54±0.03^{c}	1.12±0.08^{b}	1.57±0.19^{bc}
3[50:15:35]	83.88±0.19^{b}	-2.82±0.04^{c}	16.19±0.14^{d}	1.44±0.20^{c}	1.88±0.19^{c}
4[55:10:35]	84.27±0.24^{b}	-2.90±0.02^{c}	17.03±0.15^{b}	0.86±0.10^{ab}	1.19±0.07^{ab}

-Data is represented as mean ± standard deviation
-Sample ratios are represented as [Sweetpotato:millet:soybean]
-Values in same column with different superscripts are significantly different at 95% confidence level.

Table 5. Functional properties of drum-dried complementary food blend

Sample	Functional properties			
	WAC [%]	Swelling power [g/g]	Solubility [%]	Bulk density [g/ml]
1[60:10:30]	43.33±3.51^{a}	5.10±0.06^{a}	15.10±1.84^{a}	0.81±0.04^{ab}
2[60:15:25]	43.67±4.51^{a}	5.22±0.09^{a}	13.75±3.04^{ab}	0.76±0.02^{ab}
3[50:15:35]	40.00±5.29^{a}	5.10±0.09^{a}	18.20±0.14^{a}	0.77±0.03^{ab}
4[55:10:35]	41.00±4.24^{a}	5.17±0.63^{a}	15.80±1.27^{a}	0.75±0.04^{ab}
Weanimix	19.00±2.65^{b}	5.55±0.30^{a}	6.75±1.34^{b}	0.93±0.01^{c}
CCF	28.00±0.50^{c}	2.86±0.05^{b}	31.8±1.13^{c}	0.69±0.00^{a}

-Data is represented as mean ± standard deviation
-Sample ratios are represented as [Sweetpotato:millet:soybean]
-CCF – Commercial Complementary Food
-Values in same column with different superscripts are significantly different at 95% confidence level

Compared to results in Table 2, it can be observed that the drum drying process may have caused a decrease in the WAC. A flour or starch sample with higher water absorption capacity at low temperature is a suitable ingredient for quick preparations or instant food [34]. This may happen when there is a full or complete gelatinization of the starch granules. Compared to a local and common complementary food, weanimix, and a well-known commercial complementary food in Ghana, the OFSP-based complementary food had more soluble solids. The drum drying process was used in order to make the product instant, therefore based on what was reported by Pacheco-Delahaye *et al.* [34], the formulated complementary foods would be more readily soluble in water than the control samples. The interference of the various components, milk powder and sugar, can also not be ignored. Milk contains proteins and sugars which could dissolve in polar solvents.

Olapade *et al.* [12] reported a much higher water absorption capacity (150-180%) in plantain and cowpea complementary blends. Brou *et al.* [35], using maize, millet, beans and soybeans in the development of complementary foods also reported a range of 95 to 133%. In both cases the complementary food blends were not gelatinized. This implies that the higher WAC of the complementary food blends before drum-drying (Table 2) is within range, although the various components of the complementary flours are different.

Considering weanimix, the initial roasting process of the ingredients may have resulted in incomplete gelatinization of starches hence the low WAC. No significant differences ($p>0.05$) were observed amongst samples but between samples and the control samples (Table 5).

The swelling power of the drum-dried complementary foods was in the range of 5.1 to 5.22 g/g (Table 5). There was no significant difference ($p>0.05$) amongst test samples and weanimix but with the commercial complementary food. The commercial complementary food had the least swelling power (Table 5). This difference could be attributed to the different processing methods and ingredients used in the production of the various complementary foods.

Weanimix had a comparable swelling power to the orange-fleshed sweetpotato complementary foods due to the initial processing methods of roasting. This processing step may have reduced the swelling power of the starch granules. Okoli [36] reported that a moderate to high swelling power would enhance functionality of flours in foods such as baby foods and breakfast cereals.

The swelling power obtained by Ikujenlola [27] and Adepeju *et al.* [11] were relatively lower (1.10 – 1.50 g/g; 0.15 – 0.21 g/g, respectively) than all the complementary foods reported in this study. Ikujenlola [27] developed complementary food from a blend of malted and unmalted acha, soybean and defatted sesame while Adepeju *et al.* [11] developed a complementary food from a blend of bread fruit, groundnut and soybean. Ijarotimi and Oluwalana [22] also had a relatively lower swelling power (2.43 g/g) than that reported in this study (5.1 – 5.5 g/g). These variations could be attributed to the individual components used in the formulation of the complementary food. According to Majzoobi *et al.* [8], drum drying is able to increase the cold water viscosity of flours while the native flours are unable to do the same. Therefore the OFSP-based complementary food is able to form partial viscous solutions in cold water due to the process of drum drying; thereby making it a partial instant food. This was due to the chosen processing conditions (from trials conducted) of drum drying.

The solubility of samples ranged from 13.75 to 18.20% (Table 5). It was observed to be higher than weanimix but significantly ($p<0.05$) lower than the commercial complementary food. No significant differences ($p>0.05$) were observed amongst the samples (Table 5). Compared to the water solubility index of the samples before drum drying (Table 2), solubility of the drum dried complementary food is relatively low. This may be due to the incomplete gelatinization of the starch granules in the samples by the drum drying process.

A study to optimize the conditions in the drum drying process could result in the full gelatinization of starch granules thereby increasing the solubility of the complementary food. Another processing method, such as extrusion cooking could also be used, because it has been reported by Doublier *et al.* [23] to result in higher solubility than drum drying.

Solubility of sweetpotato flour could range from 1.5 to 9.6% [37]. This is often due to the sugars present in the sweetpoato. Therefore the water solubility index of the samples could be influenced by the other flour components and ingredients. Addis *et al.* [38] reported a solubility index of 1.1-3 g/g, while Adepeju *et al.* [11] reported 3.27 to 4.9 g/g. Brou *et al.* [35] also reported a solubility index between 0.02 and 0.20 g/g. The differences may be due to the various components used in the formulation.

Bulk density is the mass of particles of the flours per total volume it occupies. It is influenced by the porosity of samples, thus, the spaces in-between flour particles and size of particles. The packaging material and design for a product is dependent on its bulk density [25]. The bulk density of the OFSP-based complementary foods ranged from 0.75 to 0.81 g/ml (Table 5). No significant differences ($p>0.05$) were observed amongst samples. Compared to the local complementary food (weanimix) the OFSP-based complementary food had relatively lower bulk densities (Table 5). The commercial complementary food had the least. The product developed is therefore an improvement on the local complementary food but could be improved to compete with the commercial complementary food.

Lower bulk density is best for a complementary food [26,39]. Higher bulk density implies lesser spaces between particles of flours. This will end up increasing the viscosity of the flour. For complementary foods, high viscosities are not desired because consumption and digestion becomes difficult for babies.

This will result in the addition of more water by most mothers, hence reducing the nutrients of the food per serving to a baby. The bulk densities of OFSP-based complementary food were found to be higher than that reported by Ikujenlola [27], Ijarotimi and Oluwalana [22], Adepeju *et al.* [11] but comparable to complementary food developed by Ayo-Omogie and Ogunsakin [19]. The various components used in the formulation of the complementary foods were different.

3.5. Pasting Properties of Drum-dried Complementary Food

Pasting temperature represents the temperature required to gelatinize starches in a sample. It is an indication of the amount of energy required to cook the starch sample [40]. The pasting temperatures of the drum dried formulations ranged from 75.75°C to 86.95°C. There was a significant difference ($p<0.05$) observed between samples 1, 2 and 3, 4. However between samples 1 and 2, and 3 and 4 there were no significant differences ($p>0.05$) observed (Table 6). Samples 1 and 2 had the same sweetpotato flour content which differed in samples 3 and 4 and that may have resulted in the significant differences observed. Compared to the pasting temperatures before drum drying (Table 3), values were similar, however, the peak time (which is the time required to fully gelatinize the starches and also an indication of cooking time) reduced. Therefore, the drum drying process reduced the cooking time of the complementary food.

Compared to weanimix, the drum dried products had significantly ($p<0.05$) lower pasting temperatures and peak time. The commercial complementary food had the least pasting temperature (50.20 ºC) and required no time at all to reach maximum viscosity (Table 6). This implies that the starches in the commercial complementary food are probably fully gelatinized and therefore fully cooked making it an instant product [8] than the formulated products and weanimix. The drum drying process could be improved upon (by optimizing the temperature, time and moisture content of dough) to reduce pasting temperatures and peak times to a point where the starches in the product are fully gelatinized or the product is fully cooked.

Peak viscosity gives an indication of the viscous load or amount of energy required during mixing. It has been linked with the quality of products [41]. The peak viscosity ranged from 24.5 to 44 BU, which is significantly lower ($p<0.05$) than what was reported for the samples before drum drying (Table 3). There was no significant differences ($p>0.05$) between 1 and 2, and 3 and 4. Sample 4 had the least peak viscosity but was not significantly ($p>0.05$) different from sample 3. Differences could be attributed to the flour compositions in the formulations [42].

Peak viscosities were comparable with weanimix (Table 6) but higher than the commercial complementary food. The product developed is therefore very viscous in comparison with the commercial product. A significant difference ($p<0.05$) was observed between the commercial complementary food and the other complementary foods. With respect to complementary foods, lower viscosities are suitable [43].

Breakdown and Setback viscosities were also reduced after drum drying the samples. Breakdown viscosities were in the range of 1.50 to 5.50 BU while that of setback ranged from 9.50 to 17.50 BU (Table 6). Setback and Breakdown viscosities are an indication of the extent of retrogradation; that is, the separation of amylose from water in the gel formed upon cooling of a starch or flour paste. Low breakdown viscosities are an indication that the starches are stable and could withstand high temperatures [21]. This has an influence on peak viscosity, such that lower peak viscosities will be obtained [21], hence making the complementary food thin enough for easy digestion by infants and young children. Low setback viscosities of starches indicate that the products have a lower tendency to retrograde [44]. Therefore the complementary foods developed have the potential to form a stable paste hence the less likely the paste formed will separate upon cooling. As a result, when the complementary food is cooked and cooled, there will not be water formed at the surface of the paste; which is a desirable property for foods that need to cool before consumption. The commercial complementary food had the least of both Breakdown and Setback viscosities (Table 6). Breakdown and Setback viscosities are lower than that reported by Ayo-Omogie and Ogunsakin [19] but higher than that reported by Adepeju *et al.* [11].

3.6. Colour of Drum-dried Formulations for Complementary Food

L-values indicate the lightness/whiteness or darkness of the product. It is on a scale of 1 to 100; where 1-50 indicates the darker region and 50-100 indicates the lighter or whiter region [32]. Therefore given the L-values of the drum dried formulations, the colour of the product is light or in the whiter region. It ranged from 75.50 to 76.69. No significant differences ($p>0.05$) were observed amongst samples 1, 2 and 3. Drum drying relatively reduced the L-values from the initial samples (Table 4). This may have been as a result of Maillard reaction taking place between proteins and sugars present in the samples [45].

Table 6. Pasting properties of drum-dried formulation blend

Samples	Pasting properties				
	Pasting temperature [ºC]	Peak viscosity [BU]	Breakdown viscosity [BU]	Setback viscosity [BU]	Peak time [min]
1[60:10:30]	75.75±0.64^{a}	42.00±1.41^{a}	5.00±0.00^{ab}	12.50±0.71^{a}	14.78±0.53^{a}
2[60:15:25]	77.70±0.56^{a}	44.00±1.41^{a}	5.50±0.71^{b}	17.50±0.71^{b}	14.45±0.07^{a}
3[50:15:35]	86.95±1.63^{b}	26.00±2.83b	2.00±0.00^{ac}	12.00±1.41^{a}	15.40±0.14^{a}
4[55:10:35]	86.50±0.57^{b}	24.50±0.71b	1.50±0.71^{c}	9.50±0.71^{a}	15.20±0.21^{a}
Weanimix	92.50±1.98^{c}	27.00±4.24^{b}	1.00±0.05^{c}	12.50±0.71^{a}	25.88±1.87^{b}
CCF	50.20±0.00^{d}	11.00±1.41^{c}	3.00±0.04^{abc}	2.50±0.71^{c}	0.00±0.00^{c}

-Data is represented as mean ± standard deviation
-Sample ratios are represented as [Sweetpotato:millet:soyabean]
-CCF – Commercial Complementary Food
-Values in same column with different superscripts are significantly different at 95% confidence level

Table 7. Colour of drum-dried complementary food

Samples	L	a	b	ΔC	ΔE
Sweetpotato flour	85.09±0.24[a]	-3.66±0.01[a]	17.36±0.09[a]		
1[60:10:30]	76.02±0.08[bc]	-1.26±0.05[b]	22.00±0.19[b]	5.59±0.60[a]	10.66±0.32[a]
2[60:15:25]	76.69±0.05[c]	-1.15±0.01[b]	22.07±0.03[b]	5.77±0.69[a]	10.33±0.71[a]
3[50:15:35]	76.11±0.03[c]	-0.94±0.03[b]	21.72±0.01[b]	5.53±0.63[a]	10.40±0.22[a]
4[55:10:35]	75.50±0.03[b]	-0.81±0.01[b]	22.19±0.01[b]	6.02±0.66[a]	11.24±0.31[a]

-Data is represented as mean ± standard deviation
-Sample ratios are represented as [Sweetpotato:millet:soyabean]
-Values in same column with different superscripts are significantly different at 95% confidence level.

The a-values, just like L-values were reduced due to the drum drying, however the colour compared to that before drum drying remains in the green region of the a-b-colour-chart; based on the negative values obtained. The a-values ranged from -0.81 to -1.26 (Table 7). No significant differences (p>0.05) were observed amongst the samples. The b-value which represents the yellowness (positive values) or blueness (negative values) of a product, also increased compared with the samples before drum drying (Table 4). The b-values ranged from 21.72 to 22.19 and no significant differences were observed amongst samples.

In general, the drum drying process increased the redness (indicated by the reduction in a-values after drum drying) and yellowness (indicated by the increase in positive b-values) of the product (Table 7). The level of saturation (delta chrome, ΔC) and colour intensity (ΔE) increased compared to the samples before drum drying. ΔC ranged from 5.53 to 6.02 while ΔE ranged from 10.33 to 11.24. This increase in colour saturation and intensity could be as a result of browning which caused a decrease in the lightness or whiteness of the product [45].

4. Conclusion

The colour of the product was observed to be very light with high L-values [>80] while level of saturation (ΔC) and intensity (ΔE) of the colour compared with OFSP flour was low. The drum drying process however increased the level of saturation and intensity of the colour, with reference to OFSP. Water absorption capacity (WAC) of samples ranged from 152.5 to 216.7%, swelling index (SI) from 6.65 to 7.73, bulk density (BD) from 0.79 to 0.83 g/ml and solubility from 17.78 to 20.32%. Drum drying conditions used reduced the WAC, SI, BD and solubility. Pasting temperatures before and after drum drying were comparable but peak time, peak viscosity, breakdown and setback viscosities were reduced. OFSP flour could be used to develop a complementary food with improved functional and pasting properties, when complemented with millet and soybean flours and then processed through drum drying. This when adopted will help with vitamin A deficiency in Ghana and also increase the utilization of OFSP to help achieve food and nutrient security. Optimization of the drum drying process conditions (moisture content of dough, temperature and time for drum revolution) in the development of the OFSP-based complementary food could be studied.

Acknowledgements

This work was supported by the DANIDA Roots and Tuber Value Chain Project in Ghana. Also, many thanks to the International Potato Centre (CIP-Ghana), Fumesua for providing the *Bohye* variety of sweetpotato and Mr. John Barimah, Zeenatu S. Adams and Abena A. Boakye for their support.

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