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Factors affecting instant properties of powdered cocoa beverages

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Abstract

The increasing number of small and medium scale manufacturers of powder cocoa beverages (PCBs) in Nigeria requires relevant technical data useful in designing new and value added products from cocoa powder. This paper reports a preliminary study carried out to determine how some physical and chemical factors relate to the instant properties of some commercial samples of PCBs produced in Nigeria. The levels of chemical component like moisture, fat and sugar in the PCBs varied from 0.8% to 3.6%, 2.0% to 10.4% and 52.4% to 90.5%, respectively. Physical properties like the bulk density, angle of repose, average particle size and uniformity index of the products varied from 0.49 to 0.81 g/cm^3, 25.0° to 37.7°, 0.031 to 0.796 mm and 6.25 to 7.44, respectively. Instant properties such as wettability, dispersibility and solubility ranged from 10.7 to 21.7 s, 50.0% to 94.5% and 44.2% to 76.6%, respectively. These properties differed significantly ($p < 0.05$) among the 10 commercial samples of PCB studied. Sugar (sucrose) content of products had the most significant ($p < 0.05$) main effect on their instant properties followed by the fat content. Wetting time showed a significant ($p < 0.05$) negative linear correlation with sugar content. Agglomeration increased the average particle size, which correlated negatively with uniformity index. The instant properties of fine PCBs (average particle size <0.294 mm) were more predictable than the agglomerated samples.

Keywords: Powdered cocoa beverage; Instant properties; Multivariate analysis; Regression models; Wettability; Solubility; Dispersibility

1. Introduction

Instant foods are convenience products that require very little effort to reconstitute or cook prior to consumption. They range from liquids or semisolids to those that form porridge or stiff dough after due reconstitution. Powdered cocoa beverages (PCBs) are a class of instant foods that contain fine cocoa powder simply mixed with sugar and/or milk powder. PCBs originally are sources of high caloric intake and mineral nutrition. Some Nigerian PCB manufacturers also add certain ingredients such as egg powder, malt powder, fat and water-soluble micronutrients to increase the nutritive value of their products. A recent work by Daini, Ogunledun, Fagade, and Akinpelu (2003) that assessed the nutritional composition of currently sold in Nigerian market further confirmed this practice.

It is customary to add PCB into either cold or warm water and stir to dissolve prior to consumption. The entire process of dispersing or dissolving instant powdered food has been divided into four phases (Schubert, 1987). First, liquid penetrates into the pore system (otherwise known as wetting) before the particles sink below the liquid surface. Next, the particles disperse by low energy stirring. Finally, the particles go into solution provided they are soluble in the liquid other wise they remain suspended. It is also possible that the powdered food is first poured before the liquid. When the second sequence is followed, the role of wetting process thus becomes insignificant. The sequence followed in the food powder reconstitution also depends on the nature and the desired end use of the product. The ease with which each of these processes occurs is directly related to the end use quality of instant food. Thus, product attributes such as wettability, dispersibility and solubility have often been used to characterize instant powdered food (Picesky, 1986).

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Various physical and chemical methods have been used to improve the instant property of powdered food solids. Agglomeration is the most effective method to improve the rehydration characteristics of dried food powders (Barletta & Barbosa-Carnovas, 1993). It adjusts the particle size distribution, bulk density as well as enhancing wetting (or penetration of liquid into the porous system) due to faster capillary action. It provides mechanical stability and improves solubility (Schubert, 1980). The analysis of particle size distribution is an important method in evaluating the effect of agglomeration of agglomerated powdered foods. Methods and parameters used in the determination of particle size distribution are numerous. Some of these can be found in Chakkaravarthi, Math, Walde, and Rao (1993), Ortega-Rivas (2001) and Schubert (1987). Microparticulation is another method used to improve dispersibility of powdered foods like tea (Park, Imm, & Kij, 2001). Addition of surfactants (or emulsifiers) also aids in stabilizing the emulsion formed between the fat and water-soluble phases and as a result, affects both the rheology and sensory characteristics of reconstituted soluble food powders. Schubert (1980) presented a comprehensive review of various physical methods of agglomerating powdered solids as well as the laboratory methods of determining the instant properties.

There has been a tremendous increase in the number of small and cottage manufacturers of PCB brands offered for sale in the Nigerian food market. These products vary widely in price and consumption quality probably due to the difference in formulation and processing technology used. There is very little understanding of the relationship between the physical properties, chemical composition and the instant behavior of PCBs. Accurate prediction of the behavior of PCBs resulting from various formulations and manufacturing process is required to guide the development of new or value added food products (Singh, 1994). The developing tropical countries like Nigeria, Ghana, Trinidad and Tobago, etc., have a potential for making significant foreign earning from the cocoa beverage industry since they produce large quantity of cocoa bean, which is the major raw material for the industry. Incidentally, the powdered cocoa beverage manufacturing is one of the slowest growing beverage food industries worldwide and as such requires technical data from model studies on how ingredient combination and product formulation affects the quality of their products. Such information is at present generally scanty in the literatures.

This paper reports a preliminary study done to characterize some Nigerian made PCBs in terms of chemical composition and physical properties, and to establish how they influence the instant properties of PCBs.

2. Materials and methods

2.1. Materials

Ten brands of locally manufactured commercial samples of PCBs were purchased from some local retail markets in the southwest of Nigeria. The information provided by the retailers on the popularity of patronage and sales volume was also used to guide in sampling. The market prices of the PCBs varied widely. The coefficient of variation of the mean retail prices between brands was found to be about 45%. This could probably indicate a wide difference in their production cost and quality. The samples were picked in triplicate and finally mixed before use in the analyses.

2.2. Methods

2.2.1. Chemical analyses

Moisture of the PCBs was determined by air oven and fat content was determined by solvent extraction following AOAC (1984) method. For determining total sugar content, 0.2 g of the PCB sample was weighed into a centrifuge tube and a few drops of 80% ethanol were added to powder followed by 5 ml of distilled water and the mixture was stirred thoroughly. Twenty five millilitres of hot 80% ethanol was added, stirred and left to stand for 5 min before centrifuging at 2500 rpm for 10 min. The alcoholic supernatant was discarded. The extraction was repeated with 30 ml. Ten millilitres of 2 N sulfuric acid was added to the residue, while colored product formed was stabilized by addition of 5 ml stock phenol. The absorbance of the resultant colored complex at 490 nm. The sucrose content was determined using a calibration curve prepared with sucrose standard. All the chemicals used were of analytical grade supplied by BDH Chemicals, Loughborough, UK.

2.2.2. Physical properties

Bulk density of the samples was determined following the modified method of Okaka and Potter (1979). About 20 g of PCB sample was poured into a 100 ml measuring cylinder and tapped 10 times on a flat wooden platform. The volume occupied by the sample was recorded. However, it was observed that some of the PCBs were highly hygroscopic and absorbed moisture more rapidly. To avoid experimental error, the samples were poured directly from their containers into the measuring cylinder to minimize their exposure to air. The samples were filled up to 50 ml mark and tapped as indicated above. The mass of the empty and filled measuring cylinder, and the final volume occupied by each sample was noted. Analyses were done in triplicate.

The emptying angle of repose is an empirical method of estimating the flowability of particulate solids (Ortega-Rivas, 2001). Particulate solid with repose angle up to 35° is a free flowing material, 35–45° is fairly cohesive, and 45–55° is cohesive while >55° is very cohesive (Carr, 1976). In determining the emptying angle of repose of the PCBs, a 250 ml round mouth measuring cylinder was filled to a mark 200 ml with the powder. The fill was finally sealed with cotton wool. Care was taken to avoid compaction of the powder in the cylinder. The cylinder was then suspended on a retort stand in an inverted position making the mouth of the cylinder be approximately 20 cm above a flat surface. The cotton wool was suddenly removed to allow the powder flow freely under gravity to form a heap on the horizontal flat surface. The emptying angle of repose was calculated as the arc tangent of the ratio of height to the base radius of heap formed. Analyses were done in triplicate.

To determine the particle size distribution about 200 g of PCB sample were sieved through a set of seven standard sieves having between 0.05 and 1.8 mm (Ogawa Seiki Co. Ltd., Japan) for 5 min using a mechanical sieve shaker (S/N 13-10761, Endecotts, England). Weight of sample retained on each sieve were recorded and used in calculating mass fraction, defined as weight of sample retained on a sieve divided by the total sample weight.

Uniformity index was calculated as shown below:

$$\text{Uniformity index} = \left(\frac{\sum_{i=1}^{n} (X_i - X_m)^2}{n X_m^2} \right)^{0.5}, \qquad (1)$$

where X_m is the modal mass fraction; X_i is the mass fraction on the ith sieve, while n is the total number of sieves.

2.2.3. Instant properties

Dispersibility of the sample was determined by dissolving approximately 10 g of each sample in 100 ml of distilled water at 27 °C. The mixture was manually stirred continuously for 1 min and allowed to rest for 30 min for the suspended particles to settle down before the supernatant was carefully decanted. The density of the supernatant was then determined by filling an aliquot of the supernatant into a 50 ml density bottle. The mass of the filled bottle was noted. The weight of the dispersed solid was calculated as twice the difference in the mass of the supernatant and an equal volume (50 ml) of distilled water. All the weight determinations were done in duplicate using a digital balance (0.001 g accuracy).

Wettability (or wetting time) was determined as described by Schubert (1980). The wetting time was regarded as the time (in seconds) required for all the powder to become wetted and penetrate the surface of the distilled water at 27 °C. Analyses were done in triplicate.

Solubility was determined as described by Takashi and Seibi (1988). About 5 g of each sample were suspended in 50 ml of water at 30 °C in a centrifuge tube. The suspension was stirred intermittently for 30 min before it was finally centrifuged at 9500 rpm for 10 min. The supernatant was completely drained into an evaporating dish and dried to constant weight at 105 °C. The weight of the solids recovered after drying was used to calculate the water solubility (%). Analyses were done in triplicate.

2.2.4. Statistical analyses of data

Duncan Multiple Range Test (DMRT) was used to separate means of experimental data. Multivariate methods (cluster and principal component analyses) were used in determining product group and to understand variables important in the classification while multiple linear regression was performed to select independent variable required to predict the instant properties of the PCBs. The regression models that gave the least standard error of the estimate (SEM) were finally chosen. The statistical package for social scientists (SPSS) version 11.0 was used in the analysis.

3. Results and discussion

3.1. Chemical properties

The chemical composition of the PCBs is presented in the Table 1. The composition of the PCB samples differed significantly ($p < 0.05$). The moisture contents of the PCBs ranged between 0.8% and 3.6%. These values are similar with those reported by Daini et al. (2003) for some Nigerian PCBs. The very low moisture content must be maintained to extend the shelf life and maintaining acceptable consumption quality of these products.

The total sugar content varied widely ranging between 52% and 91%. Addition of sugar (sucrose) is done mainly to sweeten and further mask the residual astringency and bitterness of cocoa powder. Only 30% of the PCBs reported

Table 1
Physical, chemical and instant properties of the powdered cocoa beverages[a]

Parameter	Sample No.									
	1	2	3	4	5	6	7	8	9	10
Moisture content (%)	3.6h	1.8e	1.8e	2.2f	1.6d	1.0b	0.8a	1.2c	1.2c	3.4g
Fat content (%)	2.0a	2.4c	10.4h	3.2d	3.4e	8.8g	5.2f	2.2b	2.2b	3.2d
Sugar content (%)	89.5h	60.0c	58.8b	88.0g	52.4a	70.1e	59.0b	61.2d	78.9f	90.5i
Bulk density (g/cm^3)	0.53b	0.57c	0.57c	0.49a	0.69e	0.81g	0.58d	0.80g	0.73f	0.81g
Angle of repose (°)	25.0a	27.3b	37.7g	30.3c	32.7e	31.3d	31.3d	27.3b	35.0f	27.2b
Average particle size (mm)	0.764i	0.796j	0.031a	0.294h	0.088d	0.137g	0.117e	0.077c	0.055b	0.128f
Uniformity index	6.43b	6.25a	0.031a	6.47c	7.34f	7.24e	7.27e	7.37f	7.44g	7.28d
Wettability (s)	11.7c	13.3d	7.44g	11.0b	20.0i	18.3h	21.7j	16.7f	10.7a	15.0e
Dispersibility (%)	94.5j	86.0h	18.0g	55.5c	54.5b	50.0a	85.0g	91.0i	84.0f	79.5e
Solubility (%)	64.6e	65.6f	70.0h	67.2g	44.2a	76.2i	63.6d	49.8b	60.0c	76.6j

[a] Values followed by the same alphabet in the same row are not significantly different at $p < 0.05$.

in this study contain above the maximum of 85% sugar (sucrose) stipulated by the Standard Organization of Nigeria (SON, 1985). In support of the irregularity identified with the PCBs, Irefin and Ilori (1996) had earlier reported that about 22% of consumers interviewed experienced some irregularities in terms of cocoa based beverage produced in Nigeria. Due to the high sugar composition, they could absorb moisture rapidly when stored carelessly. This might contribute to reduced flowability, dispersibility and solubility as the particles get congealed after absorbing moisture.

The fat content is important as it contributes to overall energy value of foods. PCBs have caloric content ranging from 380 to 419 kcal/100g (Daini et al., 2003) and are particularly consumed by athletes and patient just recovering from an illness for energy boosting. The fat content of PCB samples studied ranged between 2% and 11%. Seventy percent of the PCB samples had fat contents less than the maximum of 3.7% stipulated by SON (1985). The variation in fat composition might be due to the varying level of sugar and the initial fat level of the original cocoa powder.

3.2. Physical properties

Particle size is the most important properties of food powders and it affects most product properties (Davies, 1984). The average particle size of the PCBs studied ranged between 0.055 and 0.796 mm (Table 1). Fig. 1 also shows the particle size distribution of the PCBs. Only three samples (samples 1, 2 and 4) could be classified as moderately coarse powder according to the British Pharmacopoeia since not more than 40% of their mass passed through 60 mesh sieve. Others could be classified as moderately fine and fine powders. The uniformity index (UI) is a secondary property derived from particle size distribution. As shown in Eq. (1), UI was used in this study as a measure of cumulative deviation from the modal mass fraction. The higher the UI value the more uniform the powder. From the results obtained, it could be stated that PCBs with the size

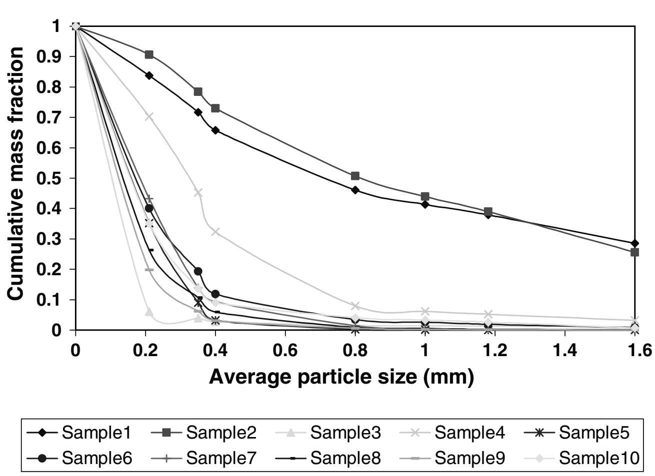

Fig. 1. Particle size distribution of the powdered cocoa beverage samples.

distribution that give UI value below 6.5 could be essentially classified as agglomerated products.

The bulk density (BD) is a measure of packing characteristics of particulate solids. The BD of the PCBs ranged between 0.49 and 0.81 g/cm^3. These values were significantly different ($p < 0.05$). Sample 4 had the least and samples 6 and 10 had the highest BD values. BD values correlated significantly ($p < 0.05$) with the uniformity index. In many of the previous studies, some significant linear correlations were reported between the BD and the moisture content of bulk particulate food materials. For some food grains, the BD increased with increasing moisture contents (Rameshbabu, Jayas, Muir, White, & Mill, 1996; Suthar & Das, 1996). Oje (1994) and Carman (1996), however, reported negative linear correlations. In a more related study, Shittu, Awonorin, Sanni, and Idowu (2002) reported a significant positive correlation between BD and moisture content for non-fermented cassava flour, whereas the correlation was not significant when a fermented cassava flour product was studied elsewhere Shittu, Lasekan, Sanni, and Oladosu (2001). In this study, the bulk density of all the CBs was weakly correlated with their moisture content ($r = -0.217$). These findings indicate that the influence of moisture content on the bulk density of particulate food material could vary widely depending the nature of the constituent particles and their interaction.

The angle of repose is an empirical measure of the relative flowability of particulate solids. Previous works (Duffy & Puri, 1996; Kamath, Puri, & Manbeck, 1994; Rennie, Chen, & Mackereth, 1998) have shown that this property is significantly influenced by factors like moisture content, particle size, storage time, etc., of a particulate solid. This property could be important to consumption quality of PCBs as they are prepared by pouring as heap onto a liquid surface. Powder flowability has also been explained in terms of inter particulate adhesion or stickiness. The inter-particulate stickiness in high sugar food is also affected by the glass transition of the amorphous sugars (Bhandari & Howes, 1999). During reconstitution with water for example, water molecules hydrate the particle surface (wetting) tending to reduce the inter particle cohesion thereby allowing faster water penetration of the bulk food capillary. Powders with higher repose angle are likely to sink with more difficulty when poured on liquid surface because of their inherent cohesion. The angle of repose of the PCB sample differed significantly ($p < 0.05$). It ranged between 25° and 38°. According to Carr (1976), particulate solid that have repose angle below 35° are free flowing. Therefore, most of the PCBs except sample 3 are free flowing solids. The relatively higher repose angle of sample 3 might be due to its higher fat content. Remarkably, the angle of repose, sugar and fat contents of samples 2, 8 and 9 were found to be similar, whereas the bulk density differed widely. These observations indicate that some interactive effects of the physical and chemical properties might be affecting the flowability of these products.

3.3. Instant properties

Before carrying out this study, a very clear-cut relationship between the physical, chemical and instant properties of powdered cocoa beverage was yet to be published. For example, Schubert (1980) reviewed some studies carried out in his laboratory on the influence of particle size distribution of some commercially available powdered products on their instant properties. In his paper, the influence of only the particle size on the dispersibility after some dispersion times and wetting time were presented graphically. Dispersibility showed more complex relationship with particle size than wetting time. It was specifically mentioned that for instantized sugar–cocoa mixtures, particle sizes <0.2 mm should be avoided for better wettability while sizes >0.4 mm were generally recommended for good instant properties.

In the current study, there were generally insignificant linear correlation between most of the measured physical, chemical properties and the instant properties measured at 27 °C, except sugar content that had significant negative correlation ($r = -0.76$, $p < 0.05$) with the wetting time (Table 2). This implies that the relationship between the instant properties on the physical and chemical variables is not linear and could involve some interactions of these properties. This agrees with the findings of Schubert (1980) mentioned earlier. The wetting time (wettability) of the PCBs ranged between 10 and 22 s (Table 1). This implies that higher sugar content causes shorter wetting time. Particle size and fat content also affect wettability of dried food powder (Ortega-Rivas, 2001). For the PCB sample studied, particle size and fat respectively showed positive and negative correlation with wetting time but the correlations were not significant. Remarkably, sample 9, with very small particle size had the least wetting time. Such product with average particle size of 0.055 mm is not likely to be an agglomerated powder. Its shortest wetting time indicates that instead of agglomeration probably some other means of instantizing, such as addition of surfactant like lecithin, could have been used in its formulation. The wetting times of the PCBs are within the range of 10–60 s reported for milk powder (Picesky, 1986) and about 3–10-fold shorter than those reported for green tea powder (Park et al., 2001) and instant kheer -an Indian dairy dessert (Jha, 2001).

Dispersibility is the ease with which the powder becomes distributed as single particle in the bulk liquid phase. During use, PCBs not consumed immediately after reconstitution i.e. allowed to stay a while between ingestion, has tendency to form sediments at the bottom of the container. This reduces the convenience in use, as it would require some intermittent stirring to ensure uniform mouth feel and probably the taste of the reconstituted food. However, when the constituent particles have different color and light dispersion characteristics, dispersibility may equally affect the product's appearance. Reconstituted foods that have low dispersibility often have high sedimentation volume, as both are opposite instant properties pertinent to instant powdered food (Park et al., 2001). The dispersibility of the PCBs ranged between 50% and 95%. These values are similar with about 50% to 95% reported for some sugar–cocoa mixtures (Schubert, 1980). This observation indicates that the PCBs sample studied would definitely have widely different consumption quality that could be best examined subjectively.

Solubility is another property relevant to the consumption characteristics of PCBs as it affects sensory attribute such as the taste perception. It should also be noted that particle dispersion in the aqueous phase is not the same as dissolution. With regards to PCBs, complete dissolution, as found in product fruit drink powders is not the target since cocoa powder itself contains some amount of insoluble solids. Instead, achieving complete dispersion of the insoluble particles is more relevant. This is technologically possible but may be more expensive depending on formulation. This is why measurement of dispersibility is a more important quality index than solubility for this type of products. The percent solubility of the PCBs ranged between 44% and 77%. The most important factor that is expected to affect solubility is the sugar content, since it is the major soluble component of the products. The amount of solubles in the original cocoa powder as well as those generated during the processing stages could also contribute to the solubility of PCBs. None of the physical and chemical

Table 2
Pearson correlation coefficient of the physical, chemical and instant properties of the powdered cocoa beverages

	M	F	SU	BD	RA	UI	PS	WT	DS	SO
Moisture content (M)	1.000									
Fat content (F)	−0.317	1.000								
Sugar content (SU)	0.702*	−0.333	1.000							
Bulk density (BD)	−0.217	0.024	−0.051	1.000						
Repose angle (RA)	−0.525	0.628	−0.397	−0.027	1.000					
Uniformity index (UI)	−0.452	0.399	−0.340	0.652*	−0.592	1.000				
Particle size (PS)	0.399	−0.386	0.176	−0.530	0.589	−0.914**	1.000			
Wetting time (WT)	−0.495	0.532	−0.776*	0.241	0.290	−0.469	0.563	1.000		
Dispersibility (DS)	0.241	−0.219	0.299	0.132	−0.127	−0.241	0.359	−0.043	1.000	
Solubility (SO)	0.314	0.453	0.505	−0.036	−0.038	0.072	−0.180	−0.183	−0.139	1.000

* Correlation significant at $p < 0.05$.
** Correlation significant at $p < 0.01$.

properties measured showed any significant linear correlation with solubility.

3.4. Multiple regression models for predicting instant properties

Multiple linear regression technique was used to search for the models relating the physical and chemical properties with the instant properties of all the PCBs. The resultant equations are shown in Table 3. The coefficient of determination (R^2) ranged between 64% and 75%. This represents a fair low predictability of the instant properties. It should be mentioned that efforts were made to generate interactions between the independent variables for them to be included in the regression process as a ploy to improve on the predictive power of the models. However, inclusion of more variable in the models did not give any significant improvement on their predictive power. Out of the three instant properties, wettability appeared to be the most complex to predict, as the resultant regression model was not significant though the coefficient of determination was fairly high. Such low predictability might be due to the complex nature of pore system in bulk powder that makes penetration behavior irregular (Picesky, 1986).

Fine powders are expected to have simpler bulk microstructure, since one of the effects of agglomeration in particulate system is creation of irregular particle geometry that could make prediction of liquid penetration difficult. Thus, an extra effort was made by separating the PCBs by multivariate statistical analysis. Principal component analysis was also performed using the both the correlation and covariance matrix scale. The use of correlation matrix enables one to understand the variables that could account for the grouping of the PCBs especially for cluster analysis. On this basis, the contribution (factor loading) of each variable to the first two principal component is shown in Table 4. Using the correlation matrix, the first two principal components (PCs) accounted for about 72.6% of the total variations. However, loadings of the physical properties were slightly higher than for the chemical properties. Uniformity index had the highest correlation with the first principal component (0.883) followed by the particle size (−0.877) and angle of repose (0.789). While in the PC2, bulk density had the highest correlation value of 0.785. Referring to Fig. 2, one can vividly observe by projecting the samples onto the PC1, that PC1 adequately distinguishes samples 1, 2 and 4 from the rest. Furthermore, it could also be deduced that out of all the properties, uniformity index is the most relevant factor that could be used for the purpose of classification. A variable–variable scatter plot (Fig. 3) between the dominant variables (uniformity index and bulk density) in the first two PCs could be used to show more vividly the separation of the PCBs into two distinct groups compared to Fig. 2. The fact that it is possible to further divide some PCB samples into more distinct groups as shown in the variable–variable plot (Fig. 3) is an indication it would be useful for handling larger number of sample. A peculiarity of samples 1, 2 and 4 that form a cluster is that they have lower wetting times and could be essentially classified as being truly agglomerated while the others could be

Table 4
Factor loading of the principal components using correlation and covariance matrix of variables

Variable	Principal components			
	Correlation matrix		Covariance matrix	
	1	2	1	2
Moisture content	−0.733	0.290	0.685	−0.203
Fat content	0.626	−0.355	−1.703	2.174
Sugar content	−0.593	0.477	14.636	0.566
Bulk density	0.455	0.785	−0.006	−0.004
Repose angle	0.789	−0.338	−1.699	3.389
Average particle size	−0.877	−0.318	0.078	−0.169
Uniformity index	0.883	0.395	−0.169	0.222
% Variance explained	51.3	21.3	91.1	6.94

Table 3
Multiple linear regression model predicting the instant properties of all the powdered cocoa beverages

Instant property	Independent variables	Coefficient	Sig. *P*	R^2
Solubility	Constant	48.12	0.143	0.75*
	Sugar	0.47	0.024	
	Fat	3.08	0.016	
	Angle of repose	−0.86	0.276	
Wettability	Constant	34.19	0.022	0.67**
	Sugar	−0.18	0.040	
	Fat	0.64	0.164	
	Angle of repose	−0.28	0.402	
Dispersibility	Constant	6.07	0.720	0.64*
	Sugar	−0.16	0.041	
	Fat	nd	nd	
	Angle of repose	nd	nd	
	Uniformity index	2.97	0.181	

nd, regression coefficients were not determined.
* Regression model significant at $p < 0.05$.
** Regression model is insignificant at $p = 0.05$.

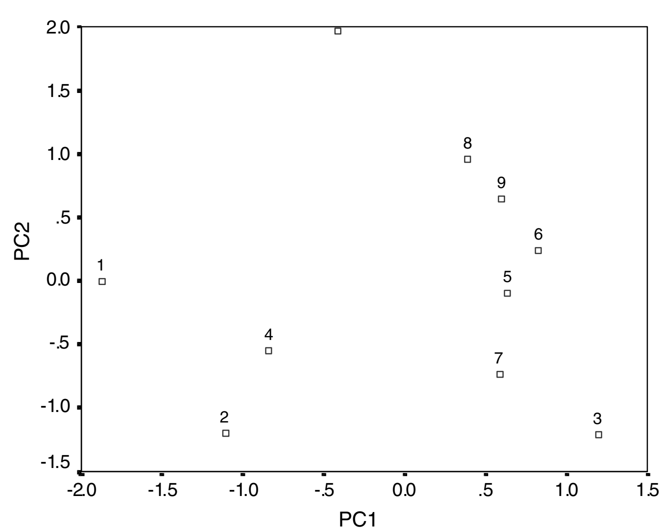

Fig. 2. Loading plot for the first two principal components of the variables (using correlation matrix).

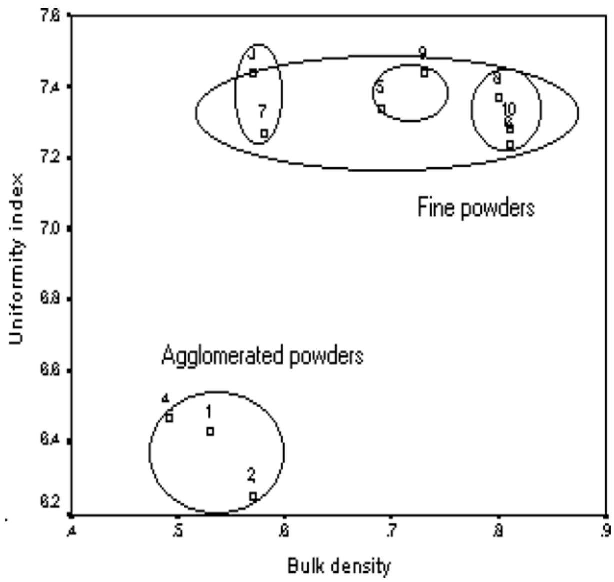

Fig. 3. Variable–variable scatter plot between bulk density and uniformity index.

classified as fine powders. This further corroborates that the physical properties are more important for classifying the PCB samples reported in this study than the chemical properties. Remarkably, sugar content is the property that accounts for the highest variability among the PCBs followed by the fat content and the angle of repose. These properties are, therefore, expected to contribute significantly to predict the instant behavior of the PCBs in this order as observed earlier (Table 3). In order to improve the predictive power of the regression equations, experimental data for sample 1, 2 and 4 were thus separated and the remaining data were used in another regression analysis.

The new set of regression equations predicting the instant properties of fine PCBs are as shown in Table 5.

Table 5
Multiple linear regression models predicting the instant properties of the fine powdered cocoa beverages

Instant property	Independent variables	Coefficient	Sig. P	R^2
Solubility	Constant	17.04	0.413	0.95*
	Fat	3.30	0.010	
	Sugar	0.72	0.011	
	Angle of repose	−0.61	0.312	
Wettability	Constant	187.85	0.021	0.99**
	Fat	0.24	0.120	
	Uniformity index	−20.48	0.031	
	Bulk density	−14.26	0.044	
	Sugar * Angle of repose	−5.36E−03	0.016	
Dispersibility	Constant	−1552.69	0.016	0.98*
	Fat	−220.19	0.014	
	Sugar	−4.32	0.018	
	Uniformity index	267.47	0.013	
	Sugar * Moisture	2.68	0.014	

* Regression model is significant at $p < 0.05$.
** Regression model is significant at $p < 0.01$.

Obviously, the predictive powers of the resultant equation were overwhelmingly improved for fine PCBs compared to the earlier results shown in Table 3 for the mixed consideration. This may imply that the instant behavior of the agglomerated is more complex than the fine PCBs. The solubility was shown to depend mainly on the chemical constituents (namely sugar and fat contents) of the PCBs ($r^2 = 0.95$, $p < 0.05$); the wetting time, however, was more significantly affected by the physical properties (bulk density and the uniformity index) while the interaction between the angle of repose and sugar also affected the wettability of the PCBs. It should be mentioned here that contrary to the expectation that particle size and fat content should have a direct influence on the wettability of powdered foods (Ortega-Rivas, 2001) secondary physical properties such as the bulk density and uniformity index replaced particle size. Fat composition did not have any significant effect on the wetting property. This might be due to the relatively low fat composition of the products. At higher fat composition, presence of free fat deposited on the particle surface may cause reduced wettability. The dispersibility of the fine PCBs was jointly determined by some physical (uniformity index) and chemical factors (sugar, fat and moisture content), which is in agreement with the postulations of Ortega-Rivas (2001).

From the foregoing, UI could be a more dependable physical property to distinguish the agglomerated from the non-agglomerated PCBs than the average particle size. The practical implication of this finding is that PCB manufacturers can develop methods that could give predictable UI given a combination of processing parameters used in instantization. It is also envisaged that formulations including additional functional and nutritional ingredients could present more complex instant behavior. To the best of our knowledge on experimental data on such formulations is yet to be published. Efforts are going on to generate more experimental data on this.

4. Conclusion

The following conclusions could be made from this study:

(1) The instant property of powdered cocoa beverages depends mainly on certain physical and chemical factors whose influence is further affected by the particle size distribution.
(2) A new statistical parameter known as uniformity index (UI), used to characterize the particle size distribution was found to be useful in modeling the instant behaviour of PCBs.
(3) The instant behavior of fine PCBs (average particle size <0.295 mm) could be more predictable than the agglomerated products.
(4) For the fine PCBs, the solubility depends mainly on the chemical factors (sugar and fat composition); their wetting property depends mainly on certain

physical factors such as uniformity index and bulk density; and their dispersibility depend on both the physical (UI) and chemical factors (sugar, fat and moisture content).

(5) The sugar content of the PCB formulations appeared to be the most influential factor affecting all the instant properties measured.

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