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Research Article

Physicochemical properties of banana peel flour as influenced by variety and stage of ripeness: multivariate statistical analysis

Abbas F. M. Alkarkhi, Saifullah bin Ramli, Yeoh Shin Yong and Azhar Mat Easa*

School of Industrial Technology, Universiti Sains Malaysia, 11800 Penang, Malaysia.

*Author to whom correspondence should be addressed, email: azhar@usm.my

Abstract

Physicochemical properties of banana peel flour (BPF) were studied in two varieties (Cavendish and Dream) and two stages of ripeness (green and ripe). BPF's were analyzed for pH, total soluble solids (TSS), water holding capacity (WHC) at 40, 60 and 80°C, oil holding capacity (OHC) at 40, 60 and 80°C, colour values L^*, a^* and b^*, back extrusion force and viscosity, and the data were analyzed using MANOVA, discriminant analysis and cluster analysis. All statistical analyses showed that physicochemical properties in variety and stage of ripeness were different from each other. Viscosity and WHC80 were recommended as testing methods to differentiate BPF between the two varieties, whilst TSS and viscosity were recommended for differentiation of BPF from green and ripe stages.

Keywords: food additives, banana peel flour, MANOVA, cluster analysis, discriminant analysis, Malaysia.

Introduction

Bananas are one of the most consumed fruits in tropical and subtropical regions. New economical strategy to increase utilization of banana includes the production of banana flour when the fruit is unripe and to incorporate the flour into various innovative products such as slowly digestible cookies [1], high-fibre bread [2] and edible films [3]. The peel of banana represents 40% of the total weight of the fruit [4], however has been underutilized. The production of banana peel flour has been reported previously by Ranzani *et al*, [5]. Banana peel flour can potentially offer new products with standardized composition for various industrial and domestic uses [6, 7, 8, 9]. Of particular interest is the findings that banana peel extract contained higher antioxidant compounds than that of the pulp [10], thus promising a more intense utilization of the peels in food and nutraceuticals. Potential applications of banana peel flour however depend on its chemical composition [11], as well as physicochemical and functional properties.

In its original form, it is relatively easy to differentiate between the peel of ripe and green banana, and with experience it is also possible to differentiate between varieties (skin colour, appearance, size and other dimensions). Once the peel is processed into flour, identification of the peel origin and stage of ripeness becomes a challenge. The aim of this study was to differentiate banana peel flour based on its physicochemical properties. As far as it is known, no study has been conducted on the physicochemical properties of banana peel flour with the intention of discriminating flour from different variety or stage of ripeness. Emaga *et al*, [12] investigated the effects of ripeness stage on the dietary fibre components and pectin of banana peels. The chemical composition of banana peel as influenced by the maturation stage and varieties have also been studied [11]. The physicochemical properties of the flour are expected to vary with varieties and stage of ripening as it is known that the composition of banana changes dramatically during ripening. In addition, the fruit of the banana trees are consumed at green, average ripe and ripe stages [11]. Therefore the amount of fruit waste from the peels is expected to increase with the development of processing industries that utilize the green and ripe banana. Thus it may be worthwhile to study the physiochemical characteristics of banana peel flour and devise methods to discriminate banana peel flour based on its physicochemical data. Statistical techniques that can be applied to perform this task include MANOVA, cluster analysis and discriminant analysis [13, 14, 15].

Two of the most popular varieties of banana are Cavendish (*Musa paradisiaca L, cv cavendshii*) and Dream (*Musa acuminata colla. AAA, cv 'Berangan'*). Cavendish banana is more expensive than the Dream banana. For the purpose of quality control in the small and medium industries with limited budgets and manpower, it may be easier to perform physicochemical measurements. The determination of chemical constituents of the flour such as sugar, starch, protein and dietary fibres is more labourious and time consuming. Therefore, the objective of this study was to firstly characterize selected physicochemical properties of green and ripe banana peel flour obtained from two varieties, secondly to use the data to discriminate between the flours and finally to single out the most appropriate physichemical methods that differentiate the flours.

Materials and Methods

Preparation of banana peel flour

Two of the most common banana varieties, namely Cavendish and Dream, were purchased from twelve markets around Penang, Malaysia. A total of 222-302 green (stage 1 of ripening: all green) and ripe (stage 6 of ripening: yellow with green tip) bananas of each variety were obtained from each market. The fruit were washed and separated into pulp and peel. To reduce enzymic browning, peels were then dipped in 0.5% (w/v) citric acid solution for 10 min, drained and dried in an oven (AFOS Mini Kiln, at 60^{o}C overnight). The dried peels were ground in a Retsch Mill Laboratory (Retsch AS200) to pass through 40 mesh screen to obtain banana peel flour (BPF). The yield of flour was calculated by dividing the amount of flour produced by the amount of fresh banana used, and the results were converted to g/Kg (g of flour/Kg of banana). Four types of BPF produced were ripe Cavendish BPF (CR), ripe Dream BPF (DR), green Cavendish BPF (CG) and green Dream

BPF (DG). All BPF's were stored in airtight plastic packs in cold storage (15±2°C) for further analyses.

pH, TSS and viscosity

The pH of the flour was measured using a Coming pH meter, model 10. Flour suspension (8% w/v) was stirred for 5 min, allowed to stand for 30 min, filtered and the pH of filtrate measured [16]. Total soluble solids (TSS) in the same flour slurries were measured using an Atago refractometer (Atago PAL-1, Co. Ltd., Tokyo, Japan) [17].

Viscosity was determined as described by Fagbemi, [18]. Flour was dispersed in water at 8% (w/v) concentration using a magnetic stirrer (1000 rpm) and heated from 30 to 95^{o}C in a shaking water-bath (Memmert, Gmbh-Germany) and kept at this temperature for 20 min. The slurry obtained was stirred constantly and cooled at room temperature. The viscosity was measured using a Vibro Viscometer (SV-10, A & D Japan).

Water (WHC) and oil holding capacity (OHC)

Twenty-five millilitres of distilled water or commercial olive oil were added to 1 g of dry sample, stirred and incubated at 40, 60 or 80^{o}C for 1 h. Tubes were centrifuged at 3000 x *g* for 20 min, the supernatant was decanted and the tubes were allowed to drain for 10 min at a 45^o angle. The residue was weighed and WHC and OHC calculated as g water or oil per g dry sample, respectively [19].

Colour

The instrumental measurement of banana peel flour colour was carried out with a Colorimeter Minolta CM-3500d (Minolta, Spectrophotometer, USA) and the results were expressed in accordance with the CIELAB system with reference to illuminant D65 and a visual angle of 10^o. The measurements were performed through a 6.4-mm-diameter diaphragm with an optical glass, placing the flour directly on the glass. The parameters determined were L^* (L^* = 0 [black] and L^* = 100 [white]), a^* ($-a^*$ = greenness and $+a^*$ = redness) and b^* ($-b^*$ = blueness and $+b^*$ = yellowness).

Back extrusion force of slurry

A TA-XT plus Texture Analyzer (Stable Micro Systems, Godalming, UK) was used to evaluate the texture of the banana peel flour slurry (8% w/v). Backward extrusion tests were conducted with the disc diameter 45 mm, setting the probe travel distance at 30 mm. Both tests were performed with a test speed of 2 mm/s, a trigger force of 5 × *g*, and force in compression mode. Force-time curves were recorded at a crosshead speed of 5 mm/s and recording speed was 5 mm/s to enable evaluation of back extrusion force (BEF) of the slurry [17].

Statistical analysis

Multivariate analysis of variance (MANOVA)

Multivariate analysis of variance is used where several dependent variables (p) are measured on each sampling unit instead of one variable. The objective of MANOVA is to compare the mean vectors of k groups for significant difference. Equality of the mean vectors implies that the k means are equal for each variable and if two means differ for just one variable then it can be concluded that the mean vectors of the k groups are different.

Discriminant analysis
Discriminant analysis is a multivariate technique used for two purposes, the first purpose is description of group separation in which linear functions of the several variables (discriminant functions (DFs)) are used to describe or elucidate the differences between two or more groups and identifying the relative contribution of all variables to separation of the groups. Second aspect is prediction or allocation of observations to groups in which linear or quadratic functions of the variable (classification functions (CFs)) are used to assign an observation to one of the groups [20, 21].

Cluster analysis
Cluster analysis (CA) is a multivariate technique, whose primary purpose is to classify the objects of the system into categories or clusters based on their similarities and the objective is to find an optimal grouping for which the observations or objects within each cluster are similar, but the clusters are dissimilar to each other. Hierarchical clustering is the most common approach in which clusters are formed sequentially. The most similar objects are first grouped and these initial groups are merged according to their similarities. Eventually as the similarity decreases all subgroups are fused into a single cluster. CA was applied to heavy metals in sediment data using a single linkage method. In the single linkage method, the distances or similarities between two clusters A and B is defined as the minimum distance between a point in A and a point in B:

$$D(A,B) = \min\{d(y_i, y_j), \text{for } y_i \text{ in A and } y_j \text{ in B}\} \quad (1)$$

Where $d(y_i, y_j)$ is the Euclidean distance in (1).
At each step the distance is found for every pair of clusters and the two clusters with smallest distance (largest similarity) are merged. After two clusters are merged the procedure is repeated for the next step: the distances between all pairs of clusters are calculated again and the pair with minimum distance is merged into a single cluster. The result of a hierarchical clustering procedure can be displayed graphically using a tree diagram, also known as a dendrogram, which shows all the steps in the hierarchical procedure [20, 21].

Results and Discussion

General descriptive statistics
The average length and diameter of Cavendish and Dream banana used for the study were 18.0 and 6.0, and 13.1 and 5.3 cm respectively. The average weight per fruit was 174 and 101 g for Cavendish and Dream banana, respectively. This indicates differences in the size and dimension of the two banana varieties. All BPF produced were brownish in colour and presented banana flavour. The average yield of CG, DG, CR and DR BPF were 38.5, 53.1, 48.6 and 48.7 g/Kg of fresh banana fruit respectively.

Table 1 summarizes descriptive statistics including the mean, standard deviation, maximum and minimum values for all physiochemical properties of BPF. The spread around the mean value (Standard deviation (Std)) was small and random in all BPF, indicating consistency of samples. The mean pH of BPF ranged between 4.80 to 6.20 with the order; DR > DG > CR > CG. The variation in pH might reflect differences in chemical components in BPF and that CR and CG contained more acidic compounds than DR and DG BPF. The mean TSS of BPF ranged between 1.51 to 3.46ºBrix with the order CR > DR > CG > DG. TSS indicates solid content of BPF and high TSS has been associated with high sucrose content in banana pulp [22]. Three types of soluble sugars, i.e. sucrose, glucose and fructose detected in banana peel may represent the TSS of BPF [12]. The lower TSS of green peel flour is acceptable since it is known that amylase, glycosidase, phosphorylase, sucrose synthase and invertase can act in the degradation of starch and the formation and accumulation of soluble sugars [12, 23, 24]. However, since TSS of CR was higher than DR, it can be concluded that CR had higher sugar content than DR BPF.

Table 1. Descriptive statistics for selected physiochemical properties of banana peel flour.

(a) Cavendish								
	Green (CG)				**Ripe (CR)**			
Parameter	Min	Max	Mean[c]	Std.	Min	Max	Mean[c]	Std
pH	4.30	5.33	4.80	0.42	4.86	5.69	5.47	0.24
TSS (°Brix)	1.53	1.90	1.73	0.12	3.20	3.63	3.46	0.14
L^*	34.83	48.73	40.88	4.46	32.43	41.08	37.62	3.07
a^*	3.79	6.42	5.20	0.78	4.77	6.34	5.55	0.39
b^*	21.01	27.07	23.27	1.94	11.02	14.01	12.47	0.88
WHC40[a]	4.14	5.20	4.91	0.36	5.39	6.55	6.10	0.33
WHC60[a]	4.81	5.85	5.23	0.33	5.59	6.72	6.34	0.33
WHC80[a]	5.15	6.50	5.88	0.34	6.65	9.26	8.19	0.68
OHC40[b]	0.69	0.85	0.76	0.04	0.78	1.06	0.93	0.08
OHC60[b]	0.68	0.80	0.76	0.03	0.92	1.05	0.98	0.04
OHC80[b]	0.95	1.17	1.03	0.06	1.07	1.39	1.28	0.08
Viscosity (mPa.s)	46.73	60.07	54.24	4.38	66.80	83.90	76.47	5.56
BEF (N)	32.70	40.91	37.29	2.53	35.94	63.24	50.68	8.73
(b) Dream								
	Green (DG)				**Ripe (DR)**			
pH	5.37	5.82	5.52	0.15	5.47	6.76	6.20	0.38
TSS (°Brix)	1.33	1.57	1.51	0.07	2.03	3.37	2.46	0.36
L^*	43.64	56.74	49.01	4.33	31.56	41.08	37.55	3.21
a^*	3.10	4.47	3.66	0.49	4.77	6.34	5.56	0.39
b^*	20.67	25.91	23.14	1.65	12.20	20.09	16.11	0.88
WHC40[a]	3.71	4.82	4.05	0.33	4.27	5.30	4.79	0.33
WHC60[a]	3.73	4.65	4.34	0.25	4.38	6.11	4.95	0.50
WHC80[a]	6.30	7.27	6.77	0.30	5.61	6.85	6.39	0.39
OHC40[b]	0.80	0.90	0.86	0.03	0.84	1.11	1.03	0.08
OHC60[b]	0.76	0.88	0.82	0.04	0.71	1.12	1.02	0.12
OHC80[b]	1.01	1.24	1.13	0.07	1.21	1.50	1.36	0.10
Viscosity (mPa.s)	10.93	19.60	15.84	2.77	18.47	28.40	23.85	3.68
BEF (N)	23.41	31.27	26.37	2.22	31.36	42.13	36.51	3.45

[a], g water/g dry sample, [b], g oil/g dry sample, [c] n=12

The mean L* value for all BPF ranged between 37.6 to 49.0 and DR and CR had the lowest L* value (~ 37.6). This indicates that a substantial level of colour change had occurred during drying that yielded dark brown powder, particularly in the ripe samples. As banana peel contains glucose, fructose and protein [12], an extension of Maillard reaction had occurred within BPF. In addition, certain enzymes such as polyphenol oxidase may be present in banana peel that could contribute a certain stage of enzymatic browning that took place during drying. In fresh banana, the colour changes of peel during storage as a result of ripening has been observed as a loss of greenness and an increase in reddish and yellowness tones [17], which correspond to an increase in the a* and b* values [25]. These took place as a result of the breakdown of the chlorophyll in the peel. There is some evidence that a* values of DR and CR BPF were higher than those of DG and CG. However, as a result of the browning reactions during drying, DG and CG exhibited higher b* values than DR and CR. This does not reflect the actual colour characteristics of green and ripe banana peel. No study could be found on the effect of drying on banana peel, but quality of banana paste as influenced by vacuum dehydration has been studied by Thipayarat [26]. It was found that banana paste dehydrated with vacuum dehydration had darker colour (lower L value) and more intense yellow colour (higher b value) as a result of condensation due to moisture loss, enzymatic and non-enzymatic browning [26].

In general, the mean WHC of all BPF increased with temperature and ranged between 4.1 to 8.2 g/g dry sample. These values are lower than those reported in mango dietary fibre (12 and 15 g water/g dry sample) and for mango peel dietary fibre (11 g/g) [27], but were higher than those of fibre-rich unripe banana flour (2.5 g/g) [19]. The mean WHC at all temperatures tested were the highest in CR BPF that ranged between 6.1 to 8.2 g/g dry sample. WHC could be related to the physical state of starch [28], dietary fibre and protein in the flour. According to Rodrı´guez-Ambriz *et al*, [19], amylose has the capacity to effectively bind water molecules, yielding a higher WHC. However, since starch was low in ripe banana peel [12], the high WHC noted in CR BPF could be attributed to the presence of dietary fibre and protein. Therefore, the increase in WHC at 80°C in all BPF was due partly to protein denaturation, the presence of dietary fibre such as hemicelluloses and pectin polysaccharides [29], and to a smaller extent, the gelatinization of starch in the flour that absorbs water into starch granules with concomitant swelling [19].

Another functional property of BPF is oil holding capacity (OHC). In general, the mean OHC of almost all BPF increased with temperature and ranged between 0.76 to 1.36 g/g dry sample. These values are lower than that reported in fibre-rich banana powder that could hold 2.2 g oil/g dry sample [19], but are similar to that of mango dietary fibre with OHC in the range 1.0 – 1.5 g oil/g [27]. Other products tested for OHC include mango peel dietary fibre (~ 4 g oil/g) [27], and citrus peel fibre (2.35 – 5.09 g oil/g) [30]. OHC relates to the hydrophilic character of starches present in the flour [19] that could be present in some quantity in BPF.

For all BPF the mean viscosity ranged between 15.8 to 76.5 mPa.s, and the mean BEF ranged between 26.4 to 50.7 N. The order of viscosity and BEF was similar; CR > CG > DR > DG. The functionality of starch is largely related to its gelatinization and pasting characteristics. When BPF is heated in water, starch granules swell at their gelatinization temperature and when amylose leaches out of the granules and swells, viscosity and textural changes result. In CG and DG, starch gelatinization may contribute to a certain extent to viscosity and texture. Since starch content is low in ripe banana peel [12], the viscosity and texture of BPF could have been attributed mostly by hemicelluloses and pectin polysaccharides. This explanation is acceptable since banana peel is known to contain a vast quantity of dietary fibre, mainly hemicelluloses and pectin polysaccharides [12, 29]. The total dietary fibre content of banana peel can be as high as 50% (based on dry basis) [12], while the hemicelluloses of banana peel constitute ~ 20% of peel and have solution properties [29]. Hemicelluloses of banana peel may even be further developed into gums or hydrocolloids [29]. The exceptionally high viscosity and BEF of CR BPF was also attributed to its high sugar content as indicated by TSS (Table 1). The differences in these functionalities may have implications in products incorporated with BPF.

Based on descriptive statistics of physicochemical characteristics of BPF, characteristics of samples could be summarized. CR can be characterized as high in TSS, viscosity and BEF but low in L* and b* values. DR was high in pH and a* value, but was low in viscosity, BEF and L* value. CG was high in b* value but was low in pH. DG was high in L* and b* values, but was low in TSS, viscosity, BEF and a* value. However, since colour changes occurred during drying, these colour values might not reflect the actual colour characteristics of banana peel.

Multivariate analysis

The results of MANOVA for physicochemical parameters are shown in Table 2. According to these results, the physicochemical properties in both varieties of banana and based of the stage of ripeness exhibited a strong significant difference in terms of selected parameters (P<0.0001). Variation in physicochemical properties was evaluated through DA. Only one DF was found to discriminate between the two varieties (Eq.2), and one DF to discriminate between the stage of ripeness (Eq.3). Wilk's Lambda test showed that DF is statistically significant, hence Wilk's lambda value (0.015) at (P<0.001) for the two varieties, and Wilk's lambda value (0.019) at (P<0.001) for the stage of ripeness. Furthermore 100 % of the total variance between the two varieties was explained by only one DF. The relative contribution for each parameter is given in Eq. 2.

$$Z_1 = -0.75\ pH + 0.08\ TSS - 1.19\ L^* - 0.23\ a^* + 2.44\ b^* + 0.81\ WHC40 + 0.04\ WHC60 - 1.12\ WHC80 - 0.42\ OHC40 - 0.04\ OHC60 + 0.33\ OHC80 + 2.58\ Viscosity + 0.14\ Texture \quad (2)$$

Also, 100% of the total variance between the two stages of ripeness was explained by only one DF. The relative contribution for each parameter is given in Eq. 3.

$$Z_2 = 0.65\ pH + 1.28\ TSS + 0.44\ L^* + 0.83\ a^* - 0.93\ b^* - 0.51\ WHC40 + 0.78\ WHC60 - 0.24\ WHC80 + 0.42\ OHC40 + 0.41\ OHC60 - 0.28\ OHC80 - 0.96\ Viscosity + 0.48\ Texture \quad (3)$$

Four physicochemical parameters (Viscosity, b^*, L^* and WHC80) exhibited strong contribution in discriminating the two varieties and account for most of the expected variations in physicochemical properties (Eq.2), while other parameters showed less contribution in explaining the variation between the BPF's.

The classification matrix for variety of banana (Table 3) showed that 100% of the cases were correctly classified to their respective groups. The results of classification also showed that significant differences existed between types of banana, which are expressed in terms of one DF (Eq.2). TSS exhibited the highest contribution in discriminating the stage of ripeness than viscosity and b^*value, while other parameters showed less contribution in distinguishing the BPF stage of ripeness.

Table 2. Multivariate test (MANOVA) for variety and stage of ripeness.

Effect	Test	Value	F	Sig.
Type of Banana	Pillai's Trace	0.99	164.64	<0.0001
	Wilks' Lambda	0.02	164.64	<0.0001
	Hotelling's Trace	66.89	164.64	<0.0001
	Roy's Largest Root	66.89	164.64	<0.0001
Stage of ripeness	Pillai's Trace	0.99	164.25	<0.0001
	Wilks' Lambda	0.02	164.25	<0.0001
	Hotelling's Trace	66.73	164.25	<0.0001
	Roy's Largest Root	66.73	164.25	<0.0001

Table 3. Classification results for discriminant analysis based on variety[a]

Variety	% correct	Predicted group membership	
		Cavendish	Dream
Cavendish	100	24	0
Dream	100	0	24

[a]100.0% of original grouped cases correctly classified.

The classification matrix for the stage of ripeness (Table 4) showed that 100 % of the cases were correctly classified to their respective groups. The results of classification also showed that significant differences existed between the stage of ripeness, which are expressed in terms of one DF (Eq.3).

Source identification

Relationship between the scores of DF and the samples studied (Fig.1) corresponded to the scores of DF for various samples. The sample Nos. 1-24 corresponded to the banana variety samples along 24 samples of each variety (Cavendish and Dream). It could be seen from Fig.1 that all Cavendish samples showed positive contribution to DF (Eq.2), whereas all Dream samples showed negative contribution. This contribution was mainly due to viscosity and b^* value and less to other positive parameters, whilst the negative contribution was mainly due to high value of L^* and WHC80.

Table 4. Classification results for discriminant analysis based on stage of ripeness[a]

Stage of ripeness	% correct	Predicted group membership	
		Green	Ripe
Green	100	24	0
Ripe	100	0	24

[a]100.0% of original grouped cases correctly classified.

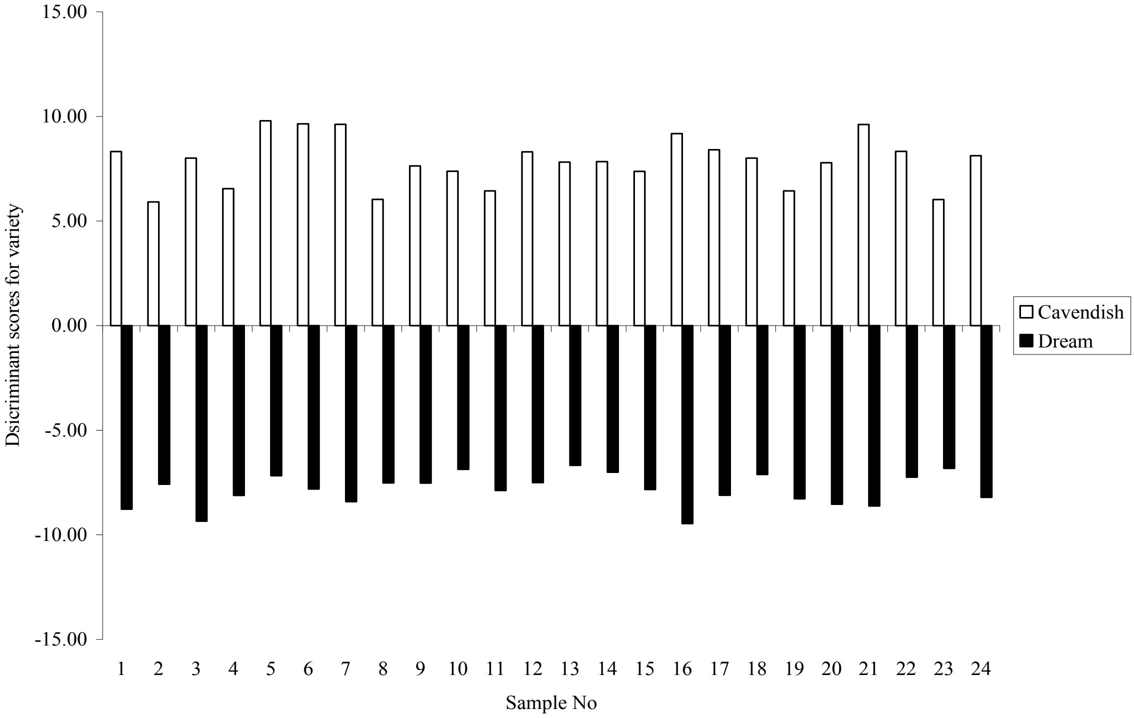

Figure 1. Scores for the discriminant function for both Cavendish and Dream banana peel flour.

Fig.2 shows the scores of DF for various samples based on the stage of ripeness. The samples Nos. 1-24 corresponded to the stage of ripeness samples along with 24 samples of each stage of ripeness (green and ripe). It can be seen that all green samples exhibited positive contribution to DF (Eq.3), whilst all ripe samples exhibited negative contribution. Positive contribution was mainly due to TSS content, while negative contribution was mainly due to viscosity. In general, it can be said that viscosity, L^* and b* value and WHC80 can be used to discriminate between BPF from the two varieties, whilst TSS, viscosity and b^* value can be used to discriminate between BPF from different stages of ripeness. However, since colour changes occurred during drying, only viscosity and WHC80 could be recommended as testing methods to differentiate BPF from the two varieties, whilst TSS and viscosity are recommended as discriminating methods of BPF from stage 1 and stage 6 of ripeness.

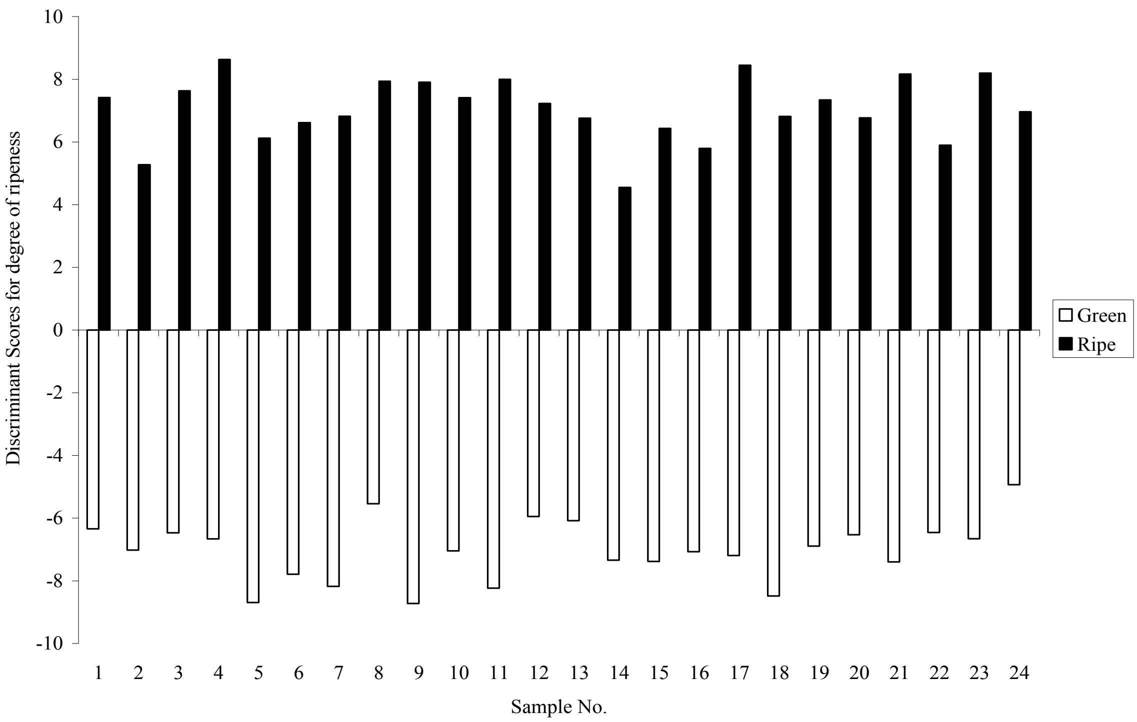

Figure 2. Scores for the discriminant function for stage of ripeness.

Cluster analysis

Cluster analysis (CA) was used to identify the similarity groups between the samples. CA rendered a dendrogram as shown in Fig.3, grouping all 48 samples into four statistically significant clusters. Cluster 1 (samples 1-12 for Cavendish Green (CG)), cluster 2 (samples 13-24 for Dream Green (DG)), cluster 3 (samples 25-36 Cavendish Ripe (CR)) and cluster 4 (37-48 for Dream Ripe (DR)). This result reveals that BPF from the two varieties and stage of ripeness had different characteristics in terms of physicochemical properties and indicates that each variety and the stage of ripeness are different based on the physicochemical properties. This supports the results of MANOVA and DA, since the same result was obtained by these two techniques. This grouping gives evidence that samples in each variety and stage of ripeness share with each other the sources of physicochemical properties. It implies that for rapid assessment and quality control of BPF using physicochemical properties, only one sample in each group will be sufficient to represent the whole variety or stage of ripeness.

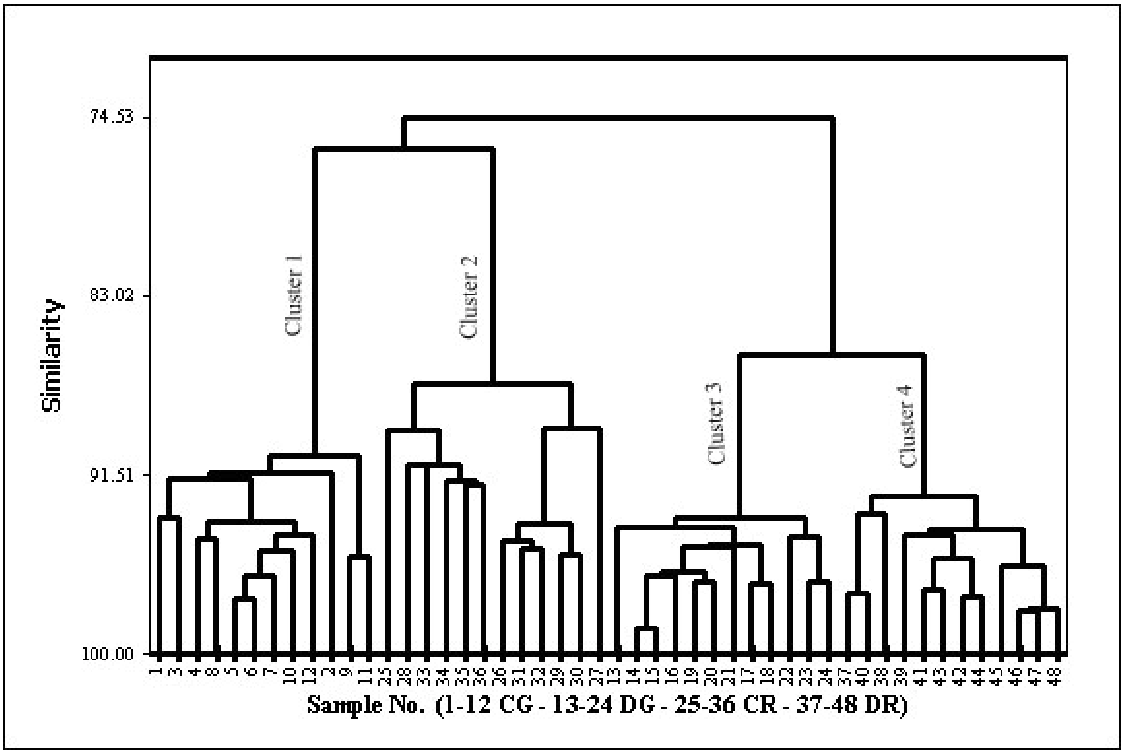

Figure 3. Dendrogram showing clustering of sampling sites based on physicochemical properties of banana peel flour produced using two different types of banana and different stages of ripeness.

Conclusion

Based on the physicochemical properties data and analysis, multivariate statistical techniques can help in discriminating between different varieties and the stage of ripeness of banana peel flour. For banana peel flour produced using hot-oven drying, viscosity and WHC80 could be recommended as quality control tests to differentiate between varieties, whilst TSS and viscosity are recommended as methods to discriminate flour produced from banana peel for stage 1 and stage 6 of ripeness. Future work should aim at studying similar techniques of differentiation of banana peel flour produced from all stages of ripeness. Improved drying methods to yield better quality flour should also be researched.

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References

1. Aparicio-Saguilan, A., Sayago-Ayerdi, Sonia G, Vargas-Torres, Apolonio, Tovar Juscelino, Ascencio-Otero, Tania, E. & Bello-Perez, Luis, A., (2007). Slowly digestible cookies prepared from resistant starch-rich lintnerized banana starch. **Journal of Food Composition and Analysis**, 20, 175-181.

2. Juarez-Garcia, E., Agama-Acevedo, E., Sayago-Ayerdi, S.G., Rodriguez-Ambriz, S.L. & Bello-Perez, L.A. (2006). Composition, digestibility and application in breadmaking of banana flour. **Plant Foods for Human Nutrition,** 61, 131-137.

3. Rungsinee, S. and Natcharee, P. (2007). Oxygen permeability and mechanical properties of banana films. **Food Research International,** 40, 365-370.

4. Tchobanoglous, G. Theisen, H. and Vigil, S. (1993). Integrated solid waste management: Engineering principles and management issues. McGraw-Hill, New York, 3-22.

5. Ranzani, T.D.C.M.R., Sturion, L.G. and Bicudo, H.M. (1996). Chemical and biological evaluation of ripe banana peel. **Archivos Latinoamericanos de Nutricion,** 46(4), 320-324.

6. Bardiya, N. and Somayaji, K. (1996). Biomethanation of banana peel and pineapple waste. **Bioresource Technology,** 58, 73-76.

7. Tewari, H.K., Marwaha, S.S. and Rupal, K. (1986). Ethanol from banana peels. **Agricultural Wastes,** 16, 135-146.

8. Annadurai, G., Juang, R.S. and Lee, D.J. (2002). Use of cellulose-based wastes for adsorption of dyes from aqueous solutions. **Journal of Hazardous Materials,** 92, 263-274.

9. Essien, J.P., Akpan, E.J. and Essien, E.P. (2005). Studies on mould growth and biomass production using waste banana peel. **Bioresource Technology,** 96, 1451-1455.

10. Someya, S., Yoshiki, Y. and Okubo, K. (2002). Antioxidant compounds from banana (*Musa* Cavendish). **Food Chemistry,** 79, 351-354.

11. Emaga, T.H., Andrianaivo, R.H., Wathelet, B., Tchango, J.T. and Paquot, M. (2007). Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. **Food Chemistry,** 103, 590-600,

12. Emaga, T.H., Robert, C., Ronkart, S.N., Wathelet, B. and Paquot, M. (2008). Dietary fiber components and pectin chemical features of peels during ripening in banana and plaintain varieties. **Bioresource Technology**, 99: 4346-43454.

13. Markus, P.F., Elena, R.R., Jacinto, D.M. and Carlos, D.R., (2002). Statistical differentiation of bananas according to their mineral composition. **Journal of Agricultural and Food Chemistry,** 50, 6130-6135.

14. Ricardo, C.R., Pablo, S.H., Elena, M.R.R., Jacinto, D.M. and Carlos D.R. (2003). Mineral concentration in cultivars of potatoes. **Food Chemistry,** 83, 247-253.

15. Suárez, M.H., RodrÍguez, E.M.R. and Romero, C.D. (2007). Mineral and trace element concentrations in cultivars of tomatoes. **Food Chemistry,** 104, 489-499.

16. Suntharalingam, S. & Ravindran, G. (1993). Physical and biochemical properties of green banana flour, **Plant Foods for Human Nutrition,** 43: 19-27.

17. Salvador, A, Sanz, T. and Fiszman, S.M. (2007). Changes in colour and texture and their relationship with eating quality during storage of two different dessert bananas. **Postharvest Biology and Technology,** 43: 319–325.

18. Fagbemi, T.N. (1999). Effect of blanching and ripening on functional properties of plantain (*Musa aab*) flour. **Plant Foods for Human Nutrition,** 54: 261–269.

19. Rodrı´guez-Ambriz, S.L., Islas-Herna´ndez, J.J., Agama-Acevedo, E., Tovar, J., & Bello-Pe´rez, L.A. (2008). Characterization of a fiber-rich powder prepared by liquefaction of unripe banana flour. **Food Chemistry,** 107: 1515–1521.

20. Richard A.J. & Dean W.W. (2002). Applied Multivariate Statistical Analysis. Prentice-Hall, London.

21. Alvin, C.R. (2002). Methods of Multivariate Analysis. John Wiley & Sons Inc. USA.

22. Bugaud, C., Chillet, M., Beaute, M.P. and Dubois, C. (2006). Physicochemical analysis of mountain bananas from the French West Indies. **Scientia Horticulturae,** 108, 167-172.

23. Terra, N.N., Garcia, E. and Lajolo, F.M. (1983). Starch-sugar transformation during banana ripening: the behavior of UDP glucose pyrophosphorylase, sucrose synthetase and invertase. **Journal of Food Science,** 48, 1097-1100.

24. Cordenunsi, B.R. and Lajolo, F.M. (1995). Starch breakdown during banana ripening: sucrose synthase and sucrose phosphate synthase. **Journal of Agricultural and Food Chemistry,** 43(2), pp 347-351.

25. Chen, C.R. and Ramaswamy, H.S. (2002). Colour and texture change kinetics in ripening bananas. **LWT – Food Technology,** 35, 415-419.

26. Thipayarat, A. (2007). Quality and physiochemical properties of banana paste under vacuum dehydration. **International Journal of Food Engineering,** 3(4), article 6.

27. Larrauri, J.A., Ruperez, P., Borroto, B. & Saura-Calixto, F., (1996). Mango peels as a new tropical fibre: Preparation and characterization. **LWT – Food Technology,** 29, 729-733.

28. Waliszewski, K.N., Aparicio, M.A., Bello, L.A. and Monroy, J.A. (2003). Changes of banana starch by chemical and physical modification. **Carbohydrate Polymers,** 52, 237-242.

29. Zhang, P., Whistler, R.L., BeMiller, J.N. and Hamaker, B.R. (2005). Banana starch: production, physicochemical properties and digestibility – a review. **Carbohydrate Polymers**, 59, 443-458.

30. Chau, C.F. and Huang, Y.L. (2003). Comparison of chemical composition and physicochemical properties of different fiber prepared from the peel of *Citrus sinensis* L. cv. Liucheng. **Journal of Agricultural and Food Chemistry,** 51, 2615-2618.