Physico-chemical properties and extrusion behaviour of selected common bean varieties

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PHYSICOCHEMICAL PROPERTIES AND EXTRUSION BEHAVIOUR OF SELECTED COMMON BEAN VARIETIES

Running Title: Properties and extrusion behaviour of common beans

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Abstract

BACKGROUND: Extrusion processing offers the possibility of processing common beans industrially into highly nutritious and functional products. However, there is limited information on properties of extrudates from different beans varieties and their association with raw material characteristics and extrusion conditions. In this study, physicochemical properties of raw and extruded Bishaz, K131, NABE19, Roba1 and RWR2245 common beans were determined. The relationships between bean characteristics and extrusion conditions on the extrudate properties were analyzed.

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RESULTS: Extrudate physicochemical and pasting properties varied significantly ($P < 0.05$) among bean varieties. Expansion ratio and water solubility decreased, while bulk density, water absorption, peak and breakdown viscosities increased as feed moisture increased. Protein exhibited significant positive correlation ($P < 0.05$) with water solubility index, and negative correlations ($P < 0.05$) with water absorption, bulk density and pasting viscosities. Dietary fibre, and iron showed positive correlation while total ash exhibited negative correlation with peak viscosity, final viscosity and setback. Similar trends were observed in principal component analysis.

CONCLUSION: Extrudate physicochemical properties were found to be associated with beans protein, starch, iron, zinc and fibre contents. Therefore, bean chemical composition may serve as an indicator for beans extrusion behavior and could be useful in selection of beans for extrusion.

Key words: Common beans; extrusion; pasting; physicochemical properties, water solubility

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.*)* contributes to the nutrition, economic and social well-being of many people in developing countries.[1,2]Beans not only provide proteins, energy and dietary fibre, but are also rich sources of micronutrients such as iron, zinc, B-vitamins and health promoting bioactive compounds like polyphenols.[3–5] Based on their soluble fibre, low fat content and antioxidant activity, beans have been identified as important for the control of degenerative diseases such as cancer and coronary heart diseases.[3] Despite their relevance in nutrition and health, use of beans as raw material in the food industry is still constrained by the limited knowledge on bean behavioral and functional characteristics in food processing. Moreover, the consumption of beans worldwide is still low, estimated at 4 to 66 kg/capita per year for different countries.[5] Low consumption is partly attributed to the limited industrial utilization, lengthy energy-consuming preparation methods and the presence of antinutritional factors (ANF).[3,6,7] Antinutrient substances including condensed tannins, lectins, phytates and trypsin inhibitors) and the flatus causing oligosaccharides affect physiological and biochemical processes such as nutrient digestibility and bioavailability.[3,6]

Antinutritional factors (ANF) however can readily be reduced through processes like extrusion, germination, fermentation, boiling, and roasting.[7–9] Among these processes, extrusion has been singled out as the most promising technique which can transform beans into highly nutritious and palatable food. Extrusion, a high temperature-short time process has been used for processing many foods, and it effectively changes their nutritional, sensory, and physicochemical properties.[7,8,10,11] Additionally, extrusion precooks food causing protein denaturation, starch expansion, gelatinization and plasticization which improve the texture and alter viscosity of the food.[12,13]

Recent studies have shown that bean extrusion results in numerous desirable changes.[4,7,13]A study by Anton *et al* [3] reported significant decreases in phytic acid and trypsin inhibitors in beans following extrusion. Similarly, Nyombaire *et al*[7] reported significant reduction in phytohemagglutinin activity in red kidney beans. Beany flavor in bean products was significantly reduced to almost non-detectable levels by extrusion cooking (Nyombaire et al, 2011)[7]. Increased protein and starch digestibility due to protein denaturation and modification of the starch crystalline structure, respectively, have also been reported. [8,14]

By improving palatability, reducing ANF and the cooking time, extrusion provides a practical solution that can be explored to improve consumption of beans around the globe. However, alteration of the physicochemical and functional properties of food during processing could sometimes lead to undesirable changes.[15] Factors affecting extrudate physicochemical properties and extrusion behavior have been studied majorly in cereals and only to a limited extent in grain legumes.[11,16] The objective of the current study was to determine extruded bean physicochemical properties and how these relate to bean chemical composition, physical properties and processing conditions.

EXPERIMENTAL

Bean material preparation

Five breeder-certified dry bean varieties Roba1, RWR2245, K131, NABE19 and Bishaz were collected from farmers in Rakai and Wakiso districts of Uganda. Roba1 is a cream-white plain coloured bean enriched with iron and zinc through biofortification. K131 and NABE19 are red mottled beans, resistant to weevil damage and have tendency to develop hard-to-cook phenomena during storage. RWR2245 is a large red mottled high-iron and fast-cooking bean. Bishaz, is a climbing sugar bean, which is fairly resistant to weevils and widely liked by consumers.

Beans were sifted and sorted on a wire mesh to remove chuff, broken and shriveled grain. Clean sorted beans were washed twice with potable tap water and dried in a hot air oven (55 °C, 14 - 16 h) to about 10% moisture content. For mineral determination, beans were washed thrice in distilled deionized water to remove all dust contaminants, dried in a hot air oven, and milled using a porcelain mortar and pestle in a dust-free environment. Bean flour was stored in plastic bags at room temperature (23 – 27 °C) until analysis. Prior to extrusion, the dried bean grains were milled using a commercial mill (Yize, Model YZMF, Shuliy Henan, China), to pass through a 1.5 mm sieve.

Bean chemical composition

Moisture content, crude protein, ash, crude fibre and dietary fibre were respectively determined using dry oven, Kjeldahl with quantification of total nitrogen ($N \times 6.25$), dry ashing at 550 °C, neutral detergent and acid detergent fibre methods as described by Shimelis *et al*[17,] and Gouveia *et al*.[18] The starch and amylose content were determined spectrophotometrically using methods described by Chow *et al*[19] and Bartkiene *et* al,[20] respectively. Mineral extraction was done using concentrated nitric acid-hydrogen peroxide mixture (5:1, v/v) following the method described by Wheal *et al*.[21] Fe and Zn were then quantified by AAS.[22]

Bean grain physical characteristics

Hydration capacity and hydration index

Hydration capacity (HC) and hydration index (HI) were determined according to Tripathi *et al*[23] with modifications. Fifty (50) undamaged whole clean seeds picked randomly in triplicate from each bean variety were weighed and transferred into 1000-ml plastic measuring cylinders, and to each 100 ml of distilled deionized water was added. After keeping for 16 hours, the hydrated grains were wiped using dry soft absorbent tissue to remove any extra water. The weight of beans after soaking was recorded and HC and HI calculated using equations 1 and 2:

$$HC, (g/seed) = \frac{(weight\ of\ 50\ seeds\ after\ soaking - weight\ of\ 50\ seeds\ before\ soaking}{Number\ of\ seeds\ (50)} \quad (1)$$

$$HI = \frac{Hydration\ capacity}{original\ weight\ per\ seed} \quad (2)$$

Swelling capacity (SC) and swelling index (SI)

The SC and SI were determined according to Tripathi et al[23] with modifications., Briefly, after soaking for 16 hours as in the method for HC and HI above, the beans were placed into clean 250 ml dry measuring cylinders and 100 ml of distilled deionized water were added. The new volume occupied by the 50 beans after soaking was recorded and grain SC and SI calculated using equations 3 and 4:

$$SC,(ml/seed) = \frac{Volume\ of\ beans\ after\ soaking - Volume\ before\ soaking}{Number\ of\ seeds\ (50)} \quad (3)$$

$$SI = \frac{(SC)}{Volume(ml)\ per\ seed} \quad (4)$$

Cooking time

Cooking time was determined for soaked and unsoaked beans using methods described by Wang *et al*,[24] with modifications. Twenty five (25) clean whole seeds were soaked in distilled deionized water in triplicate at a ratio of 1:4 for 14 hours and then the water was drained. The beans were placed on a rack of a Canadian Grain Commission automated Mattson cooker with plungers on each grain, and boiled on a hot plate (Model, Stuart SD162) at temperatures ~ 95°C. The cooking time for each bean was automatically recorded using '*Udoo*' software and average cooking time taken as the time when plungers had pierced through 80% of the beans. The cooking time for clean unsoaked beans was also determined as above.

Pasting properties

Pasting characteristics for raw bean flour (approximately 12% moisture content) were determined using the general pasting profile of a Rapid Visco Analyzer (RVA), Model RVA 4500, Perten Instruments, Australia. Briefly, 3.5 g of bean flour were weighed into clean dry canisters in triplicate. Distilled deionized water (25 ml) was added to the sample and stirred to disperse all flour in the water. The RVA set at configuration 50 °C initial temperature, holding at 50 °C for 1 minute, was heated to 95 °C within 3.7 minutes. The sample was held at 95 °C for 2.5

minutes, then cooled down to 50 °C within 3.8 minutes. Viscosity and temperature changes were automatically recorded using the Thermocline software, TCW3, of the RVA.

Extrusion cooking

Bean flour moisture was adjusted to 15, 17.5 and 20.0% by adding pre-calculated volumes of distilled deionized water, based on flour moisture content and quantity. The water was added while continuously mixing in a stainless steel mixer for homogenization. Samples were kept in clean polyethylene bags (gauge 30 microns) at ambient temperature (24 - 27°C) to prevent moisture loss and extruded within 2 hours after mixing.

Pre-conditioned raw bean flour was extruded at barrel temperatures 60/110/150 °C, in a Twin Screw Extruder (Model DP 70-III, Jinan, China), with motor power 37 kW and mass flow rate 150 kg/hr. The screw speed (210 rpm) and feed flow rate (180 rpm) were kept constant for all samples. The die diameter, flighted length of screw, screw diameter (d), outer screw diameter (D) and length to diameter of extruder were, 5 mm, 124 mm, 27 mm, 41 mm and ~18:1, respectively. The screw speed and feed flow rate conditions were kept constant for all samples.

Resultant extrudates were cooled to room temperature, and milled using a Stainless Steel mill (Model Y132M1-6 Rongchen, China) to pass through a 1.5 mm pore size sieve.

Bean extrudate physicochemical analysis

Expansion ratio, ER

Extrudate expansion ratio (*ER*) was determined according to Maskus *et al*.[10] Ten (10) cylindrical pieces of cut extrudate (chunks) were picked in replicate from a single run, their diameter determined at three random points using a Vernier caliper (Model RK, New Delhi, India), and the average was computed. The internal diameter of the extruder die (5 mm) was also recorded. The *ER* was calculated using equation (5):

$$ER = \frac{Mean\ diameter\ of\ extrudates\ (mm)}{Extruder\ die\ diamter\ (mm)} \quad (5)$$

Bulk density, BD

Ten (10) randomly selected cylindrical pieces from the extrusion run were weighed on an analytical weighing scale (accuracy, 0.0001 g). The diameter and height for cylindrical extrudates were also determined using a Vernier caliper. The volume of the cylindrical pieces was calculated as:

$$Volume = \pi(\frac{d}{2})^2\ h \quad (6)$$

The Bulk density (BD) was expressed as:

$$Bulk\ density = \frac{Extrudate\ mass\ (g)}{Extrudate\ volume\ (ml)} \quad (7)$$

Water absorption (WAI) and water solubility index (WSI)

The method applied by Nyombaire *et al*[7] was used for determining WAI and WSI with modifications. Approximately 0.50 g of pure bean flour was weighed into a dry 15 ml-centrifuge tube, and 10 ml of cool distilled deionized water (temperature, 24 - 27°C) were added. The sample-water mixture was homogenized by shaking for one minute at room temperature and then centrifuged at 3000 x g for 10 minutes. The supernatant was carefully poured into a dried and weighed evaporating dish. The weight of the gel was determined and WAI calculated using equation (8):

$$WAI = \frac{Weight\ of\ gel\ (g)}{Original\ weight\ of\ solids\ (g)} \quad (8)$$

The supernatant was evaporated overnight at 110 °C. The weight of the dry solids was determined. WSI was calculated using equation (9):

$$WSI = \frac{Weight\ of\ solids\ recovered\ from\ supernatant\ (g)}{Original\ weight\ of\ solids\ (g)} \quad (9)$$

Extruded flour pasting properties

Pasting properties for extruded flour were determined using extrusion profile on a RVA, Model RVA 4500, (Perten Instruments, Australia). Briefly, 3.5 g of bean flour (approximately 12% m.c.) was weighed into clean dry canisters in triplicate. Distilled deionized water (25 ml) was added to the sample and stirred to disperse all flour in water. The RVA was originally set at 31 °C initial temperature, holding at 31 °C for 2 minutes, heated to 95 °C within 5 minutes, held at that temperature for 3 minutes, and then cooled to 31 °C within 5 minutes. Viscosity and temperature changes were automatically recorded using operating Thermocline software, TCW3, of the RVA.

Statistical analysis

Means and standard errors of means for experimental data were computed using Minitab version 16.0 (Minitab Inc. State College PA, USA). Mean comparison was done using ANOVA and Tukey's family error rate test. Linear correlation analysis between properties of raw beans and extrudates, and principal component analysis (PCA) were done using Statistica, 7.1 (StatSoft Inc., Tulsa, USA).

RESULTS AND DISCUSSION

Bean chemical composition

Bean varieties did not vary significantly in chemical composition ($P > 0.05$), except the protein, amylose, ash and iron (Fe) content (Table 1). The composition of the beans was comparable to previously reported values (protein, 200 – 316 g/kg; Fe, 41.1 - 87.2 mg/Kg; Zn, 22.02 – 50 mg/kg; ash, 41.0 –53.4 g/kg, crude fibre, 47.0 – 60 g/kg).[4,17,18] Starch, protein, and fibre, which were main components of the bean varieties have been shown to affect gelatinization and consequently the viscosity characteristics of food.[10,25]

Bean physical properties

Hydration and swelling indices

Results for hydration capacity (HC), hydration index (HI), swelling capacity (SC) and swelling index (SI) are presented in Table 2. Hydration index determines the ability of the dry bean to imbibe water and is an important attribute indicating the processing behavior of beans.[25] The HC, HI and SC were significantly different ($P < 0.05$) among bean varieties, but no significant differences ($P > 0.05$) were recorded for SI. Beans with high hydration capacity also exhibited high HI and SC (Table 2). Differences in hydration capacity (HC) were possibly due to differences in composition and compactness of the grain cells, the cell wall structure and seed coat permeability.[23]

Cooking time

Cooking time differed significantly ($P < 0.05$) among varieties both for soaked and unsoaked beans (Table 3). As expected, there was reduction in bean cooking time following soaking. Soaking reduced the cooking time of beans by 30.2% to 61.7%. Reduction in cooking time after soaking was more pronounced for Bishaz, Roba1 and RWR2245, which may be attributed to the high water hydration capacity and consequently the quick gelatinization of starch in presence of sufficient moisture.[29]

The HI and SI (Table 2) and cooking time (Table 3) show patterns similar to those recorded by Shimelis and Rakshit[17] and in agreement with suggestions that high hydration capacity leads to better cooking quality (less cooking time and soft texture).

Raw bean flour pasting properties

Pasting characteristics play an important role in the selection of variety for use in the food industry as thickener, binder or other uses which are dependent on paste viscosity.[26] Peak viscosity (PK), final viscosity (FV) and setback viscosity (SB) were significantly different ($P < 0.05$) among bean varieties (Table 4), though K131, Bishaz and Roba1 showed nearly similar patterns (Fig.1). The similarities in pasting behavior (Fig.1 and Table 4) could be related to the molecular structure and chemical composition of beans.[13,27]

Beans with high amylose contents (Bishaz, K131 and Roba1) exhibited low pasting viscosity. This was in agreement with Wang and Ratnayake[27] who observed that the presence of high levels of amylose restricts granule swelling during pasting, resulting in low peak viscosity. High peak viscosities observed for NABE19 and RWR2245 were possibly associated with the low amylose content and the large starch granule sizes, that could develop high peak viscosities compared to smaller starch granules.[15,27,28]

Pasting temperatures observed were in agreement with values (83.2 to 95.6°C) reported elsewhere.[12,29] High pasting temperatures observed for Bishaz, were possibly an indication of high resistance to swelling and rupture of starch granules,[26,29] due to starch granule size, structure and the presence of other components such as proteins, fibres and lipids.[15,29] Peak time was not significantly different (P > 0.05) among bean varieties. Bean varieties displaying high pasting peak viscosities (NABE19 and RWR2245) could be a good choice for thickening application[15].

Bean extrudate properties

Water absorption index, WAI, and water solubility index, WSI

For Bishaz, NABE19 and Roba1, WAI increased with increase in feed moisture (Fig. 2). This was not the case with K131 and RWR2245. The increase in WAI at high feed moisture was probably due to the tendency of water to act as a plasticizer, hence limiting the mechanical disruption and fragmentation of starch granules.[30–32] Low WAI at low feed moisture was possibly due to the high shear degradation of starch causing crystal melting of amylopectin molecules and dextrinization.[32,33] For products extruded at high feed moisture, protein denaturation, starch gelatinization and swelling of fibre could be responsible for the increased WAI.[32]

The WSI is associated with the degradation undergone by starch granules during heat processing.[33] It is the integration of effects of melting, gelatinization, dextrinization, and the consequent solubilization of starch.[11,31,33,34] Decrease in WSI as feed moisture increased (Fig. 2b), could be due to the low degree of starch transformation, the reduced shear degradation of starch granules and the low tendency to dextrinization since high feed moisture acts as a plasticizer in the extruder.[7,11,35] Beans with high starch and amylose content (Bishaz and K131) exhibited large increments in WAI as feed moisture increased. Beans with longer cooking time both for soaked and unsoaked beans and high swelling index (NABE19 and K131) showed low water absorption index and high water solubility index upon extrusion (Tables 2 and 3), which might be associated with the starch structure and the protein-starch interactions.[12,15,27] Pearson's correlation showed negative relationship between crude fibre and WSI, and positive correlation between protein and WSI. The low WAI and high WSI displayed by Bishaz, NABE19 and K131 at low feed moisture (Fig. 2) possibly suggest them as suitable candidates for soups and gruels. High WSI for RWR2245, Bishaz, and NABE19 and 15% feed moisture, and NABE19 and K131 at 17.5% feed moisture possibly suggested a higher degree of starch disintergration and dextrinization, thus increasing the number of molecules solubilized.[31,33]

Bulk density and expansion ratio

Product bulk density is directly related to the extent of extrudate expansion and is very important in the production of expanded and formed food products[32] Bulk density (BD) varied significantly ($P < 0.05$) among bean varieties (Fig. 2c) and increased as feed moisture increased, except for Roba1 and RWR2245. Results for this study agree with previous authors [30,36] who observed similar patterns on bulk density. High BD at high feed moisture could be explained by the lubricating and plasticizing effect of moisture, which lowers the mechanical shear effects and disruption of starch in the extruder.[32,37] It could be an effect of fibre contained in the dough rupturing starch cell walls before full expansion of the gas bubbles or the low feed moisture hindering starch gelatinization.[32] Increase in feed moisture lowers melt viscosity and this causes bubbles formed in starch to collapse after maximum expansion resulting in low expansion and increased bulk density.[32] Notable however, the effect moisture content on bulk density is dependent on the composition of the extrudates.[31]

Extrudates with low BD showed high WSI, a characteristic indicative of extent of gelatinization of the heated food.[36,38] Beans with higher dietary fibre and starch content (Bishaz, K131, NABE19, RWR2245) had high WSI and low bulk density. High WSI would be necessary for permitting incorporation of large amounts of flour in instant soups or gruels.[26] Low BD would be desirable for the crunchiness of snack products [10].

The degree of expansion affects product density, fragility, tenderness and texture,[15] which are important attributes in snack products. In this study, a low degree of expansion resulted in dense extrudates (Fig. 2d). High degree of expansion resulted in higher water solubility and low water absorption index in beans, which agreed with related studies.[12,15,36] High degree of expansion is important in extruded products to achieve high water solubility. [29] Thus, extrudates of RWR2245 processed at 15% feed moisture and Bishaz, K131 and NABE19 (processed 15 and 17.5% feed moisture) with high expansion and water solubility properties, may be suitable for instant flour products.[12,35] Pearson's correlation coefficients (Table 6) showed no correlation between ER and the composition of beans, implying that extrudate expansion was possibly associated with processing conditions as explained by Maskus et al[10] and Wani et al.[15] Bean varieties Bishaz, NABE19 and RWR2245, which exhibited high expansion at low feed moisture would be suitable for snack manufacture.[10]

Extruded bean flour pasting properties

Extruded bean flour showed fairly stable viscosity characteristics when subjected to heating and shear (Table 5). Notable differences in extruded bean flour peak viscosities and final viscosities were observed at different feed moisture levels (Table 5, Fig. 3).

High final viscosity (FV) was observed for varieties RWR2245 and K131 at 15% and 20% feed moisture (Fig.3a and 3c), respectively. In general, bean extrudates with high FV values also had high cold peak viscosity (CPk), an indication of solubility of starch in water at cold temperature.[29] High peak viscosities observed for bean variety RWR2245 at 15% feed moisture could possibly be explained by the low degree of starch gelatinization due to low moisture during extrusion; and the gelatinization resistance caused by fibre- and protein-starch interactions.[29,30,32] Low peak viscosities (Table 5) for extruded flour compared to raw bean flour (Table 4) is attributable to rupture and pre-gelatinization of starch during extrusion cooking, protein denaturation, as well as the starch-protein interactions.[7,13,30,37] Protein denaturation as well as the starch-protein interactions results in structures with low capacity for interaction with water.[31,38]

The relatively high final viscosity in all extrudates compared to cold or raw peak viscosities could be explained by the re-association of amylose molecules upon cooling for processed foods, which gives a tendency to retrogradation.[29,38] Relative similarities between setback viscosity (SB) and FV were observed for Bishaz, K131 and Roba 1 at 15% feed moisture, indicative of low tendency to retrogradation and syneresis and ability to form more stable gruels.[30]. Bean extrudates which featured with high setback viscosity (RWR2245 and Bishaz) possibly indicated high tendency to syneresis[26] and would be less suitable for gruels. FV and SB were positively moderately correlated to dietary fibre, iron and ash content. Studies on fibre-enriched baked energy bars reported that fibre increased viscosity of extrudate.[39] Low breakdown viscosity for Roba1 across treatments could be suggestive of the greatest resistance to starch gelatinization and the lowest retrogradation tendency.[4,26]

Hold viscosity (HV) differed significantly among treatments for Bishaz and RWR2245 and tended to increase with increase in ingredient FM content, except for RWR2245, NABE19 and Roba1. HV characteristics may be associated with the rate of amylose exudation, granule swelling, and amylose-lipid complex formation.[26] No significant correlations were observed between pasting viscosities and starch or amylose content (Table 6). PCA however revealed that starch was an important factor affecting bean extrudate properties (Fig. 4b).

Differences in pasting properties for raw and extruded beans were consistent with Wang *et al*[27]who explained that pre-gelatinized starch granules when heated with water show less expansion. Such behavior is very important for reduction of bulk density and water absorption of gruels[30]. Negative correlations observed (Table 6) between protein with raw peak viscosity (RPk), protein with FV, and protein with setback (SB) concurred with Berrios *et al*,[13] indicating that high protein composition and protein-starch interactions reduce viscosities of extrudates.

Correlation and principal component analysis (PCA)

Significant correlations were observed between bean composition and extrudate properties (Table 6). There was strong negative correlation between the beans crude fibre content and extrudate WSI. Crude fibre content was positively correlated with flour bulk density (BD) and final viscosity. Protein content had fairly strong positive correlation with WSI (R = 0.602), but negative correlation with WAI, BD, raw peak and final viscosity. The positive correlation of protein with WSI was possibly associated with the increased hydrophilicity for water by the disintegrated proteins.[40]Similarly, negative correlation observed between ash with raw peak, hold, final and setback viscosities suggested that increased ash content reduced viscosity of extrudates. Peak, breakdown, hold, final and setback viscosities were significantly positively correlated to dietary fibre and iron content, a relationship also observed in PCA (Fig. 4a). Correlation relationships (Table 6) suggested that bean with high protein and ash content produce extrudate with high WSI, and low BD, Peak, breakdown, hold, final and setback viscosities.

Results of PCA (Fig. 4a and 4b) were in agreement with the correlation analysis (Table 6) which showed significant relationships between chemical components of beans and extrudate physicochemical properties. The first four principal components generated based on percentage of explained variability accounted for, Kaiser's criterion of eigen values >1, or even Catell's scree graph spot of abrupt level out,[41] accounted for 76.52% of total variance, and these were retained. Factor 1 pertained to iron and pasting properties, factor 2 to water solubility-water absorption-bulk density-and protein content, factor 3 pertained to expansion ratio, and factor 4 to starch content. On the basis of eigen vector loadings, the first factor with an eigen value of 4.14 explained 27.6% of the total variation, while the second factor (eigen value 3.71) explained 24.8% of the variation. The third factor with an eigen value of 2.18 explained 14.5% variation and the fourth with eigen value of 1.40 explained 9.4 % of total variance.

PCA revealed that the greatest variance in extrudate properties could be explained by the protein, iron and fibre contents of the beans (Fig. 4a and 4b). Secondary variances were attributable to amylose, zinc and starch contents. Variances in flour bulk density (BD) and WAI were possibly associated with the crude fibre and amylose content, while changes in cold peak (CPk), hold, setback (SB) and final viscosities (FV) could be explained by the dietary fibre and iron, zinc and amylose contents. Changes in WSI and ER could be explained by the protein and starch contents. Accordingly, protein, fibre, starch, amylose, and iron content seem to be the main bean chemical components affecting bean extrudate properties, findings which are related to other authors except for iron.[32,39]

CONCLUSION

Results of this study revealed that bean extrudate physicochemical properties and extrusion behavior is affected by the bean chemical composition, notably protein, fibre, starch, iron and zinc, and the feed moisture content. Pasting properties were associated with starch, fibre and iron content, while extrudate expansion, water absorption and solubility properties were related protein, starch and crude fibre. Based on their high expansion and water solubility at low feed moisture ≤17.5%, Bishaz, K131, NABE19 and RWR2245 could be recommended for flour to make pastes or gruels. Bishaz, NABE19 and RWR2245 which exhibited high expansion at low feed moisture could be recommended for snacks. The low expansion and water solubility as well as high bulk density water absorption at 20% feed moisture, reflecting incomplete gelatinization and rupture of starch, suggest that extrusion of common beans should preferably be done at feed moistures ≤17.5%. Extrusion of beans at relatively low feed moisture is important to produce extrudate with high water solubility, which would be an important application in processing of flour for soups and gruels.

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Table 1. Chemical composition of dry common bean varieties

	Chemical composition of dry common beans (*dry basis*)							
	Crude protein	**Crude fibre**	**Dietary fibre**	**Total ash**	**Starch**	**Amylose (g/100 g starch)**	**Fe (mg/kg)**	**Zn (mg/kg)**
	g/kg							
Bishaz	217.50±8.78^{b}	48.45±1.38^{a}	71.38±2.45^{ab}	43.87±0.36^{c}	390.94±13.90^{a}	33.01±1.34^{a}	64.86±9.18^{a}	28.03±0.13^{a}
K131	273.05±1.73^{a}	44.41±2.29^{a}	81.55±2.90^{a}	53.44±0.58^{a}	408.83±18.30^{a}	33.09±0.41^{a}	72.80±3.24^{a}	28.53±0.47^{a}
NABE19	260.16±1.09^{a}	40.86±0.59^{a}	64.44±4.85^{b}	51.60±0.15^{a}	407.02±7.30^{a}	29.35±0.50^{b}	37.85±1.90^{b}	26.56±0.27^{a}
Roba1	259.61±1.14^{a}	54.68±10.70^{a}	62.63±1.63^{b}	47.12±0.18^{b}	388.23±24.40^{a}	32.63±0.76^{ab}	66.70±13.90^{a}	27.55±1.51^{a}
RWR2245	251.97±7.64^{a}	40.71±2.63^{a}	72.21±3.18^{ab}	42.89±0.57^{c}	405.62±12.10^{a}	31.05±0.24^{ab}	75.95±3.79^{a}	28.02±1.11^{a}

Values are means of three replicates and their standard error values. Means with the same superscript letter are not significantly different (P < 0.05).

Table 2. Mean values for dry common bean hydration and swelling properties

Bean variety	**Swelling capacity (mL/seed)**	**Hydration capacity (g water/seed)**	**Swelling index**	**Hydration index**
Bishaz	0.51±0.03^{a}	0.47±0.01^{a}	1.28±0.08^{a}	0.93±0.00^{c}
K131	0.22±0.01^{b}	0.20±0.00^{c}	1.42±0.12^{a}	0.99±0.01^{b}
NABE19	0.46±0.00^{a}	0.46±0.00^{a}	1.33±0.03^{a}	1.08±0.01^{a}
Roba1	0.19±0.01^{b}	0.18±0.00^{c}	1.27±0.01^{a}	0.93±0.00^{c}
RWR2245	0.39±0.02^{a}	0.40±0.02^{b}	1.13±0.06^{a}	1.00±0.02^{b}

*Values are means of three replicates and the standard errors of values. Means followed by same superscript letters in each column are not significantly different (*P *< 0.05)*

Table 3. Cooking time of dry common bean varieties with and without soaking

Bean variety	Average cooking time (min)	
	Un-soaked beans	**Soaked beans**
Bishaz	133.60±2.54[a]	51.20±1.77[c]
K131	115.2±2.52[b]	80.40±4.65[a]
NABE19	134.2±5.00[a]	77.20±2.20[ab]
Roba1	83.80±3.48[c]	49.20±5.51[c]
RWR2245	114.60±2.98[b]	64.60±5.80[b]

Values are means of three replicates and their standard errors of means. Means followed by same superscript letters in each column are not significantly different (P < 0.05)

Table 4. Raw bean flour pasting properties, [*12% moisture content*]

Bean variety	Peak viscosity (cP)	Final viscosity (cP)	Peak time (min)	Pasting temperature (°C)	Breakdown viscosity (cP)	Setback viscosity (cP)
Bishaz	502.50 ± 18.60 [c]	1083.25±16.71[b]	7.00 ± 0.00 [a]	92.45± 0.68[a]	88.00 ± 2.16[a]	669.75±6.26[b]
K131	519.50 ± 18.19[c]	1214.25±13.83[b]	7.00 ± 0.00 [a]	88.28± 0.52[b]	59.50 ± 5.45[ab]	754.75±9.88[b]
NABE19	1155.75 ± 32.68 [a]	2383.50±92.98[a]	6.93 ± 0.05 [a]	81.71± 0.42[c]	20.75 ± 2.78[b]	1293.50±109.41 [a]
ROBA1	530.00 ± 15.62 [c]	1058.25±21.79[b]	7.00 ± 0.00 [a]	85.31± 0.38[b]	90.00 ± 17.89[a]	618.25±18.79[b]
RWR2245	981.75 ± 67.56 [b]	2020.25±123.61 [a]	6.92 ± 0.08 [a]	81.71± 0.85[c]	85.25 ± 16.70[a]	1123.75±72.47[a]

Values are means of three replicates and those followed by the same superscript are not significantly different at P <0.05

Table 5. Pasting properties for bean flour extruded at die temperature 150°C

Bean variety	Ingredient moisture content (%)	Cold Peak viscosity (cP)	Raw Peak viscosity (cP)	Holding viscosity (cP)	Breakdown Viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)
Bishaz	15	278.33±21.90^{bcd}	244.00±18.51^{bc}	12.33±0.33^{h}	224.31±19.23^{abc}	123.67±5.46^{fg}	109.33±4.91^{fg}
K131		260.00±1.00^{cd}	224.00±2.08^{bcde}	19.33±0.88^{gh}	204.67±1.20^{abcde}	114.33±033^{g}	95.33±1.20^{g}
NABE19		236.00±15.20^{cde}	195.33±4.41^{cdef}	51.33±0.88^{bcde}	144.00±4.04^{bcd}	262.67±8.19^{bc}	211.33±8.09^{bc}
ROBA1		174.33±2.33^{e}	155.33±3.28^{ef}	38.00±3.00^{ef}	117.33±3.84^{de}	218.67±9.60^{cd}	180.67±7.42^{bcd}
RWR2245		363.00±20.6^{a}	339.3±16.22^{a}	96.33±5.93^{a}	243.00±10.34^{ab}	461.33±18.90^{a}	364.99±13.10^{a}
Bishaz	17.5	276.32±1.67^{bcd}	247.33±4.06^{bc}	52.67±2.33^{cde}	193.67±1.76^{bcdef}	296.67±2.60^{bc}	243.30±0.33^{b}
K131		354.67±3.48^{ab}	289.33±5.24^{ab}	23.67±2.33^{fgh}	272.33±1.76^{a}	127.67±2.03^{fg}	109.00±3.21^{fg}
NABE19		242.00±1.73^{cde}	163.33±8.65^{def}	42.67±2.19^{de}	120.67±6.69^{fg}	212.70±15.40^{de}	170.00±13.36^{de}
ROBA1		201.67±31.53^{de}	162.33±15.50^{def}	52.00±2.00^{cde}	110.33±13.54^{g}	229.50±11.50^{cde}	177.50±9.50^{cde}
RWR2245		253.00±5.20^{cde}	216.67±8.84^{bc}	56.33±3.67^{bcd}	160.33±5.17^{cdefg}	268.70±16.00^{bcd}	212.30±12.5^{bcd}
Bishaz	20	251.04±1.15^{cde}	230.00±0.58^{bcd}	60.67±2.03^{bcd}	168.67±2.60^{cdefg}	268.67±5.49^{bcd}	206.33±3.84^{bcd}
K131		317.71±49.13^{abc}	291.03±45.18^{ab}	73.67±8.17^{b}	217.33±47.61^{abcd}	329.33±29.60^{b}	255.67±21.82^{b}
NABE19		253.33±2.19^{cde}	195.33±8.95^{cdef}	53.33±3.76^{cde}	139.33±7.88^{efg}	257.67±16.80^{cd}	204.30±14.50^{bc}
ROBA1		228.67±1.20^{de}	142.67±3.18^{f}	35.67±0.88^{efg}	107.00±2.31^{g}	185.00±8.54^{ef}	149.33±7.75^{d}
RWR 2245		266.67±3.76^{cd}	235.00±3.21^{bcd}	61.33±4.33^{b}	173.67±1.33^{b}	287.00±14.50^{bc}	225.70±11.03^{b}

Values are means of three replicates. Means followed by the same superscript are not significantly different at P <0.05

Table 6. Correlation coefficients of bean extrudate physicochemical properties against chemical composition

Variable	WAI	WSI	ER	BD	CPk	RPk	HV	BdV	FV	SB
Starch (g)	-0.231	0.293	0.048	-0.208	0.061	-0.061	0.067	0.235	0.031	0.045
Amylose (g)	0.023	-0.226	-0.110	0.325	0.248	0.152	0.315	0.197	0.319	0.255
Crude fibre (g)	0.226	**-0.530***	-0.248	**0.592***	0.123	0.226	0.326	0.068	**0.400***	0.279
Dietary fibre (g)	-0.153	0.167	0.008	-0.065	**0.630***	**0.550***	**0.679***	**0.592***	**0.524***	**0.475***
Fe (mg)	0.026	-0.133	-0.006	0.180	**0.444***	**0.432***	**0.530***	**0.501***	**0.561***	**0.523***
Zn (mg)	-0.100	-0.043	-0.167	0.113	0.188	0.276	0.395	0.352	0.363	0.324
Protein (g)	**-0.480***	**0.602***	-0.074	**-0.476***	0.293	**-0.432***	-0.303	-0.003	**-0.491***	-0.383
Ash (g)	-0.281	0.339	-0.102	-0.295	0.209	**-0.655***	**-0.603***	-0.395	**-0.688***	**-0.615***

Values in bold and followed by an asterisk are significant at P < 0.05.
Where, WAI =water absorption index; WSI = water solubility index; BD = flour bulk density; HV = hold viscosity; CPk = Cold peak viscosity RPk = raw peak viscosity; BdV = breakdown viscosity; FV = final viscosity; and SB = Setback viscosity.

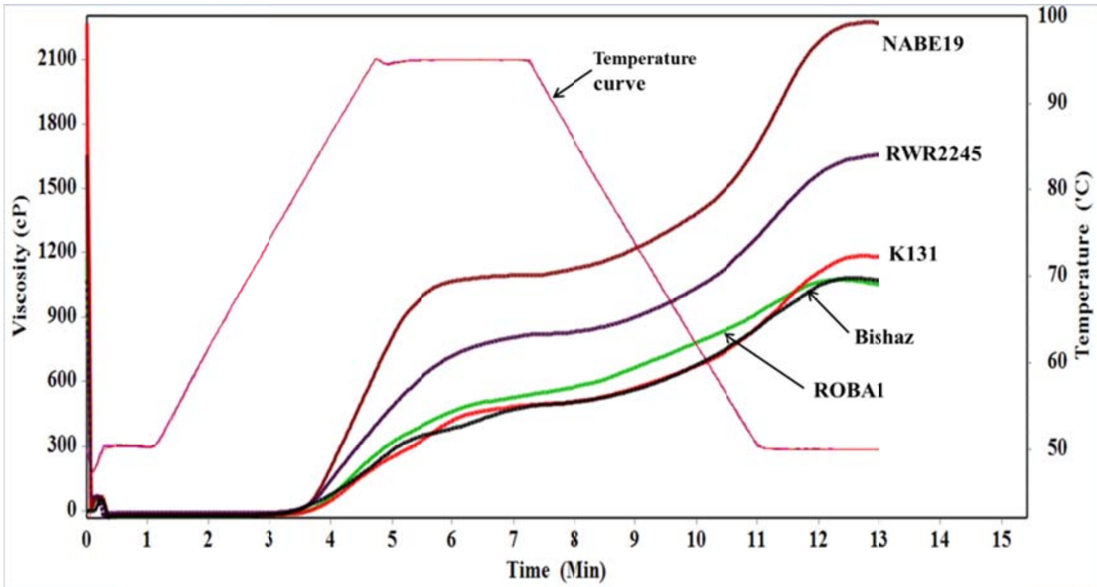

Figure 1. Raw bean flour pasting viscographs

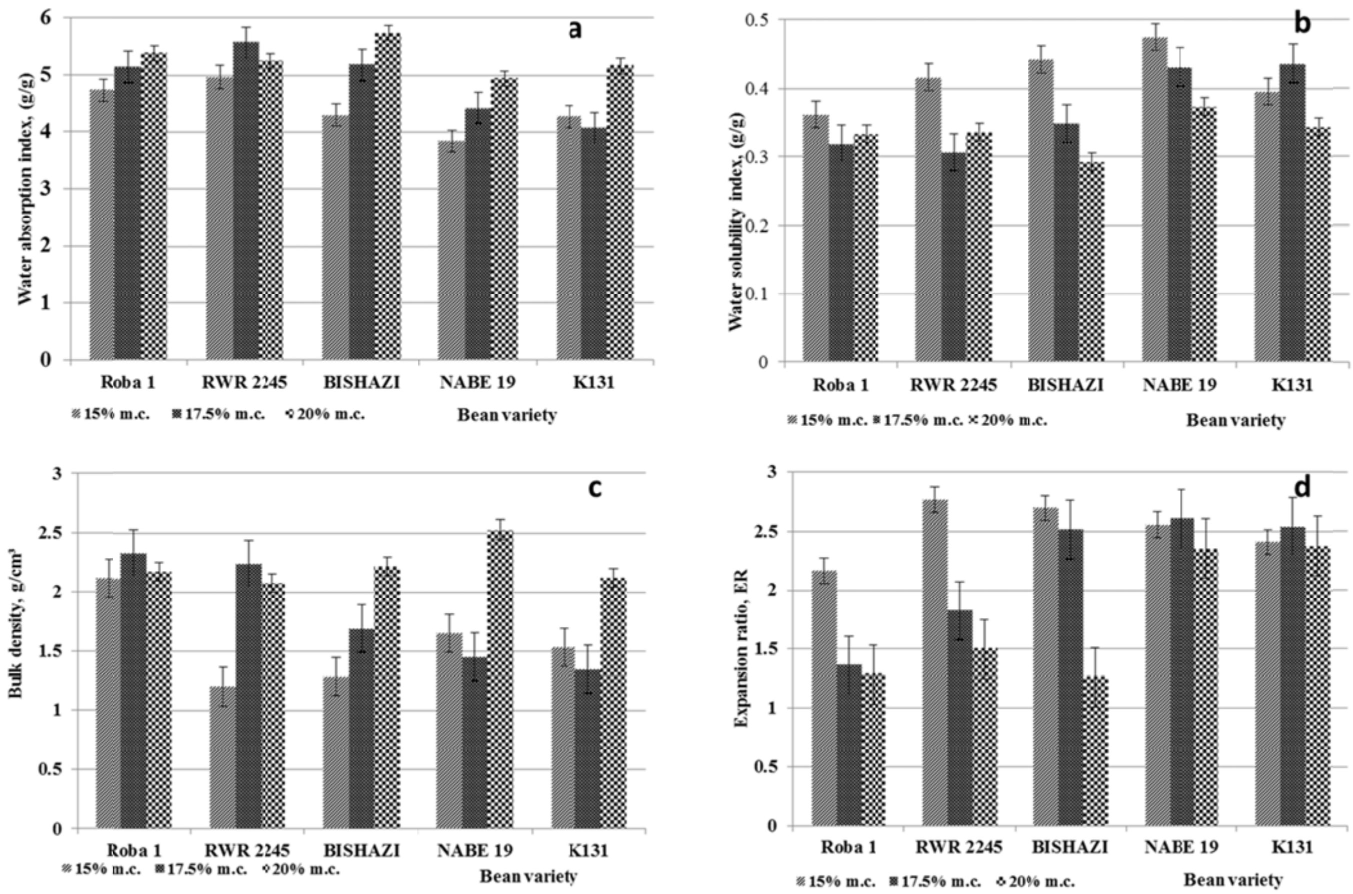

Figure 2. Bean extrudate water absorption index (a), water solubility index (b), bulk density (g/cm^3) (c), and expansion (d) properties
Extrusion feed moistures were 15%, 17.5% and 20% m.c., respectively.
Values are means of three replicates.

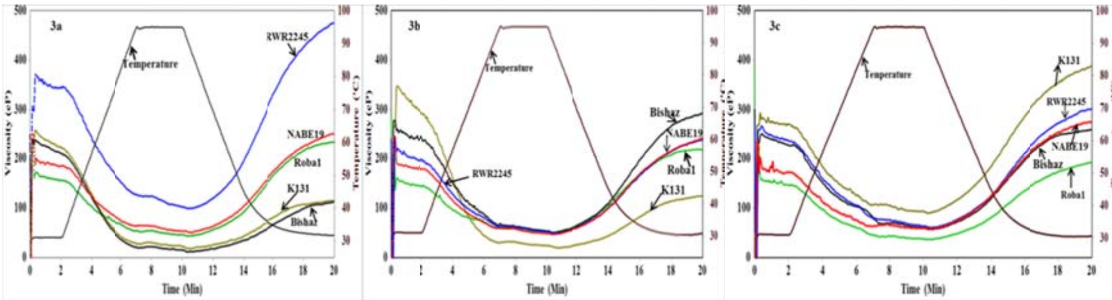

Figure 3. Extruded bean flour pasting viscographs: ***3a***, *viscographs at 15% FM;* ***3b***, *viscographs at 17.5% FM; and* ***3c***, *viscographs at 20% FM*

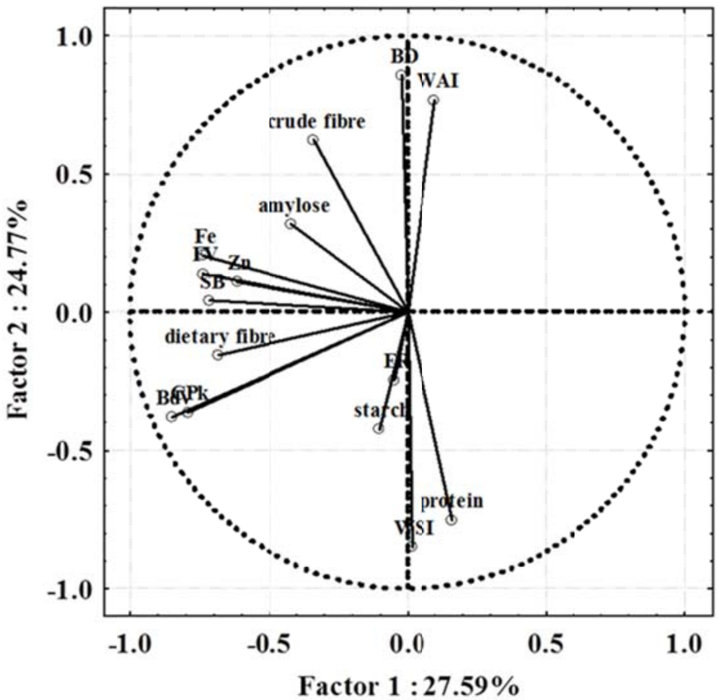

Figure 4a. Analysis of principal components for the physicochemical properties of bean extrudates based on Factor 1 and Factor 2

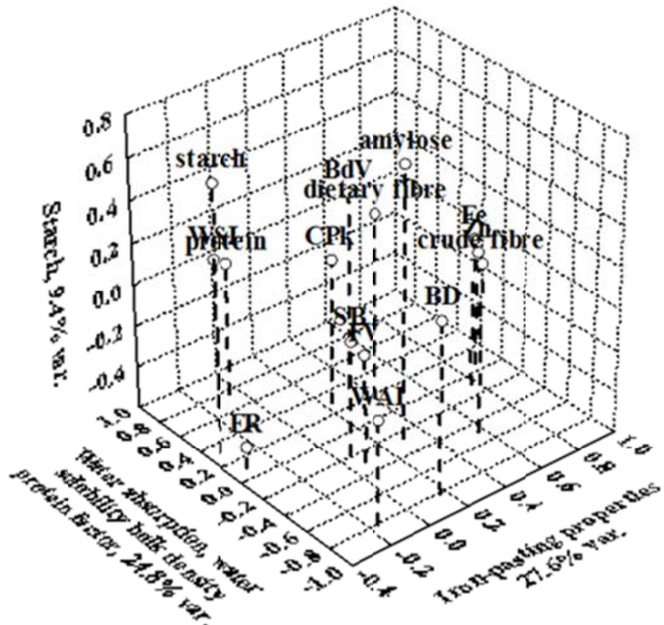

Figure 4b. Analysis of principal components for the physicochemical properties of bean extrudates based on Factor 1, Factor 2 and Factor 4