

Physico-chemical Properties, Pasting Behavior and Functional Characteristics of Flours and Starches from Improved Bean (*Phaseolus vulgaris* L.) Varieties Grown in East Africa

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ABSTRACT

Haricot bean (*Phaseolus vulgaris* L.) starch from improved varieties was isolated by wet milling process and physico-chemical properties, pasting behavior and functional characteristics of bean flours and starches were analyzed. The functional and physical properties of the starches and flours including, swelling power and solubility pattern, color, pH, water and oil absorption capacity of bean starch-water suspension were examined. A rapid visco-analyzer and color flex spectrophotometer were used for evaluation of the pasting properties and color of the flours and starch extracts from beans respectively. Chemical composition of whole bean seed flours and starch isolates such as moisture, crude protein, crude fat, total ash, crude fiber, crude lipid, total carbohydrates, starch, phosphorus and amylose content were assessed. Results of analyses for pasting behavior, functional and physico-chemical properties indicated that significance differences ($P < 0.05$) among bean varieties existed. The factors which influence the pasting characteristics resulting to decrease in peak viscosity (PV), trough (MV) and final viscosity (FV) of starch compared to bean flour are attributed to the interaction of starch with the protein, fat, etc. which in their turn are dependent on the variety. These factors play an important role in governing the pasting properties of starch. The swelling power of the bean flour and starch isolates put them in the category of highly restricted-swelling starch. This characteristic is desirable for the manufacture of value-added products such as noodles and composite blends with cereals. The uses of starch from improved bean varieties to impart viscosity to local processed foods have remarkable potential in the context of East and Great Lakes Regions of Africa where bean consumption of such products are increasing.

Key words: *Phaseolus vulgaris*, haricot bean, starch, flour, physico-chemical properties, pasting behavior, functional characteristics, East Africa

1. INTRODUCTION

Grain legumes are major sources of dietary proteins in the developing countries, as animal proteins are expensive. In addition to their protein contributions, legumes are also rich in other nutrients such as starch, dietary fiber, protective phytochemicals, oil, vitamins and mineral elements (Saikia *et al.*, 1999). Legumes contain about 60% carbohydrate including starch,

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reducing and non reducing sugars, oligosaccharides of the raffinose family, etc. Among the commonly consumed food legumes, haricot bean (*Phaseolus vulgaris* L.) is the most widely produced and consumed legume in the world and occupies an important place in human nutrition in East and Great Lakes Regions of Africa by improving the nutritional status of many low income populations (Shimelis and Rakshit, 2005; Doughty and Walker, 1982; de Godinez *et al.*, 1992).

In order to alleviate protein energy malnutrition and product diversification of beans, greater attention is being paid to the exploitation of haricot beans released from research centers in Africa. This is in addition to the program for development of high-yielding, disease resistant varieties through adaptation, selection and hybridization. In order to increase the haricot bean production and utilization, one of the approaches is to exploit its major components starch through value-added product design and development strategy.

The utilization of haricot beans as a potential raw material for the production of starch is one of the aims of this study. Starch is convertible to many useful materials by chemical and biochemical techniques, as well as by fermentation (Eliasson, 1996). It plays an important role in food industries because it affects the physical properties of many foods, and it mainly uses as thickener, water binding, emulsion stabilizer and gelling agent. Starches from various plant sources have their own unique properties that enable them to tolerate a wide range of processing techniques as well as various distribution, storage and final preparation conditions via either chemical or physical modified methods (Daniel and Weaver, 2000; David and William, 1999; Buléon *et al.*, 1998). Starch characteristics such as swelling power and solubility pattern, pasting behavior, physico-chemical and functional properties are important for improved quality of food products.

This study was undertaken to determine the physico-chemical properties, pasting behavior and functional characteristics of flours and unmodified starches from improved haricot bean cultivars. This could be utilized for the development of composite blends from locally produced improved beans at small scale industry level as value-added products.

2. MATERIALS AND METHODS

2.1 Sources of Beans and Sample Preparation

The improved haricot bean varieties (*Phaseolus vulgaris* L.) used in this study was released from agricultural research centers and grown at Nazareth. Roba, Awash and Beshbesh varieties are popular food and export type of beans in central rift valley of Ethiopia and East African countries. Among the bean samples, Beshbesh is highly resistant to bean stem maggots (BSM) or *Ophiomyia spencerella* insect pest of beans, which is very important field pest in southern Ethiopia and East African countries (EARO, 2000). Beshbesh has been adopted and become very popular in other East African countries (Uganda, Kenya, particularly in Tanzania) and Zimbabwe where BSM is regarded as the principal problem for bean production. The improved bean

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varieties were grown under similar field conditions and normal agronomic practices required for bean crops. Each variety of test samples were clean, uniform in size with natural color, good appearance, and free from foreign or abnormal odors and living or dead insects. For each variety 2-kg portions of breeding seeds were treated with insecticide (protecting treatment, topical solution) and put in plastic bags. They were placed in an aluminum box and transported by air to the Food Engineering and Bioprocess Technology (FEBT) laboratory of the Asian Institute of Technology (AIT), Bangkok, Thailand. For each lot, sufficient amount of haricot bean seeds were taken as required, rinsed four times in deionized water to eliminate the insecticide, dried at room temperature and packed in plastic bags and stored at 4 °C until used. All the chemicals used were analytical grade. Commercial rice starch (S-7260) purchased from Sigma Chemical Co (St. Louis, Mo., U.S.A) and was used as a control.

2.2 Starch Extraction

Starches were extracted from haricot beans by the method adopted by Galvez and Resurreccion (1993). The general scheme used for starch extraction is illustrated in Fig 1, which includes cleaning the seeds, washing prior to stepping process, stepping, wet-milling and settling procedure to isolate starch from the suspension and sieving the fiber out.

2.3 Physico-chemical Properties of Bean Flours and Starch Extracts

2.3.1 Color and pH Value Measurement

Haricot bean flours and starches extract were monitored for their color using color flex spectrophotometer, (Model no. 45/0, CX1075, Hunter Lab Reston, VA, USA, 2002) after being standardized using Hunter lab color standards. The parameters recorded were **L**, **a** and **b** coordinates of the CIE scale. The pH of bean flour and starch was measured immediately on the homogenate at 22 °C by potentiometric technique according to method 14.022 of the Official Methods of AOAC (1984).

2.3.2 Chemical Composition Assessment

The chemical analyses of the seed flours and isolated starch fractions included the determination of moisture using modified vacuum-oven method (AACC, 1983; Method 44-40); crude lipid and fiber contents were analyzed using Sox Tec service unit 1046 and Fibertec I and M systems (Foss Tecator, Sweden) according to method 923.05 and 962.09 respectively, of the Official Methods of AOAC (2000) International. Total ash content was also analyzed according to method 923.03 of the AOAC Official Methods (2000). Crude protein (N x 5.7 for starch; N x 6.25 for bean flour) was performed using Kjeldhal block digestion and steam distillation (2200 Kjeltec Auto distillation, Foss Tecator, Sweden) method according to AOAC (2000) official methods 979.09.

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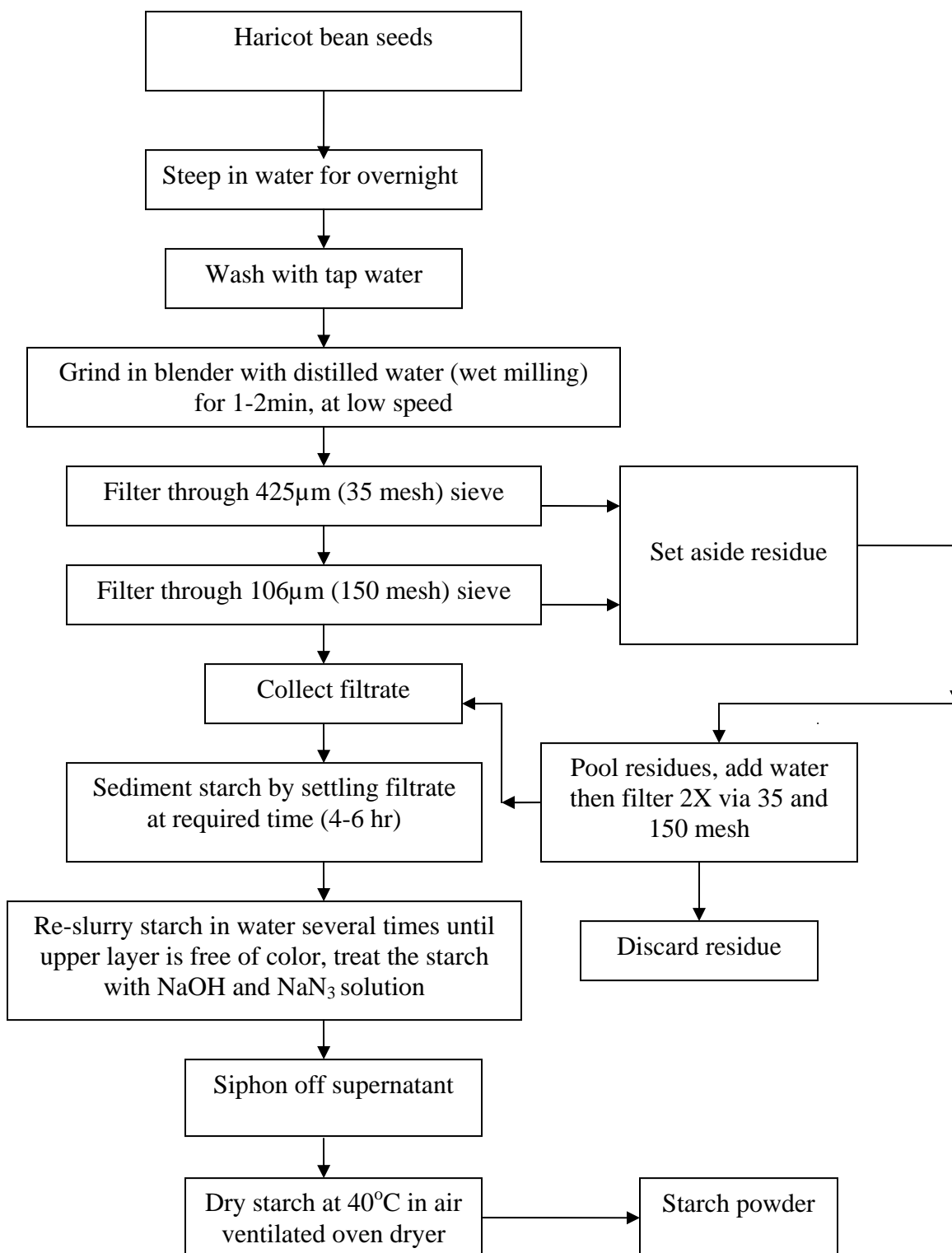


Fig 1. General scheme employed for the extraction of starch from haricot bean

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Crude fat using a butt-type (Goldfish) extraction apparatus (AACC, 1983; method 30-26) and total carbohydrates excluding crude fiber were calculated from the difference. The crude starch content of the sample was analyzed using AOAC Official Methods of Analysis (1984) according to method 14.031. Phosphorus content was determined colorimetrically (Dickman and Bray, 1940) using UV/Visible spectrophotometer (Model 6405, Jenway Ltd. UK, 1999). Amylose was recrystallized three times with n-butanol, precipitated with acetone, and vacuum dried at 40 °C. Amylose content in bean starch was determined by a colorimetric procedure described by McCready and Hassid (1943). Absorbance values were measured at 625 nm.

2.4 Pasting Profiles

The pasting behavior of starch extracts is very important for characterization and their applications. A Rapid Visco Analyzer (Model: RVA-4, Newport Scientific Pty. Ltd., Sydney, Australia, 1995) with ThermoLine for windows software was used to evaluate of the pasting properties of the flours and starch extracts from beans. Viscogram profile/pasting curves show the relationship between time, viscosity and temperature during cooking processes.

Test runs were conducted following standard profile 1 which include 1 min of mixing, stirring, and warming up to 50 °C, 3 min and 42 sec of heating at 12 °C /min up to 95 °C, 2.5 min of holding at 95 °C, 3 min and 48 sec of cooling down to 50 °C, at the same rate as the heating (12 °C /min) and 2 min holding at 50 °C, where the process ends after 13 minutes (Deffenbaugh and Walker, 1989). Starch gelatinization (pasting) curves were recorded on RVA and viscosity was expressed in terms of Rapid Visco Units (RVU) which is equivalent to 10 centipoises.

2.5 Swelling Power and Solubility Pattern

The swelling power and solubility of starch fraction and bean flour were determined according to the methods described by Tester and Morrison (1990) and Anderson *et al.* (1969); respectively. Swelling power is a measure of the hydration capacity of starch and is expressed as the weight of centrifuged swollen granules, divided by the weight of the original dry starch used to make the paste. About 0.2 g ground samples (< 60 mesh) was suspended in 10 mL of water and incubated in a thermostatically controlled water bath at 95 °C in a tarred screw cap tube of 15 mL. The suspension was stirred intermittently over 30 min periods to keep the starch granules suspended. The tubes were then rapidly cooled to 20 °C. The cool paste was centrifuged, at 2200 x g for 15 min to separate the jell and supernatant. Then, the aqueous supernatant was removed and poured in to dish for subsequent analysis of solubility pattern. After this, the weight of the swollen sediment was determined.

Supernatant liquid (dissolved starch) was poured into a tarred evaporating dish and put in air oven at 100 °C for 4 h. Water solubility index was determined from the amount of dried solids recovered by evaporating the supernatant, and was expressed as gram dried solids per gram of sample.

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$$\text{Solubility (\%)} = \frac{W_1 \times 100}{W_s (1 - \text{MC})} \text{----- (1)}$$

$$\text{Swelling power} = \frac{W_2 \times 100}{W_{\text{dm}} (100 - \text{Solubility})} \text{----- (2)}$$

$$\text{Dry matter weight} = W_s (1 - \text{MC}) \text{----- (3)}$$

Where: W_1 , W_2 -Weight of supernatant and centrifuged swollen granules

W_s -Weight of sample

MC-Moisture content of sample, dry basis (decimal)

W_{dm} -Weight of dry matter

2.6 Water and Oil Absorption Capacity

The centrifugal method of Beuchat (1977) was used to determine the oil and water absorption capacities of the isolated bean starches and the bean flour. About one gram of sample was mixed with 10 mL distilled water/oil (Thermolyne, type 37600 mixer, Maxi mix II, Iowa, U.S.A) for 30 sec. The samples were then allowed to stand at 21 °C for 30 min, centrifuged at 5000 x g for 30 min, and the volume of the supernatant noted in a 10 mL graduated cylinder. Density of distilled water was assumed to be 1g/mL and that of oil (Rio, vegetable soya cooking oil, Thailand) was found to be 0.89 g/mL. Results were expressed on a dry weight basis.

2.7 Statistical Analysis

One-way analysis of variance (ANOVA) was conducted on each of the variables and the least significant difference (LSD) test at a significance level $P < 0.05$ was performed using SPSS/12 software for Windows to compare the difference between treatment means. Results were expressed as the means \pm standard deviation of three separate determinations.

3. RESULTS AND DISCUSSIONS

3.1 Physico-chemical Properties of Bean Flours and Starches

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The color of starch due to the presence of polyphenolic compounds, ascorbic acid and carotene has impact on its quality. Any pigmentation in the starch is carried over to the final product. This reduces the quality, hence acceptability of starch product (Galvez and Resurreccion, 1992). A low value for chroma and a high value for lightness are desired for the starch to meet the consumer preference. Among the varieties Awash is the best in terms of starch color (Table 1). It had the highest value of whiteness ($L = 87.70$) and lower value of chroma ($a = 0.18$), while Beshbesh had lowest whiteness value ($L = 85.43$) and highest value of chroma ($a = 1.10$) compared to Roba and Awash haricot bean varieties. Thus, in this study, color of bean starch isolate from Awash variety can meet consumer preference due to the highest whiteness and lower chroma values.

One of the physico-chemical properties of starch important to application is pH value. Starch from the improved varieties has approximately the same pH value compared to other various native starches (Swinkels and vEedam, 1985). Roba, Awash and Beshbesh had 5.81, 5.98 and 6.06 pH values respectively; and they had no significance difference among them.

Table 1. Color analysis and pH value of bean flour and starch

Varieties	Bean seed flour ¹			Starch extracts ¹			pH	pH
	L	a	b	L	a	b	flour	starch
Roba	87.35	0.90	9.30	86.35	0.56	13.25	6.44	5.81
	$\pm 0.02^c$	$\pm 0.01^d$	$\pm 0.01^c$	$\pm 0.10^d$	$\pm 0.10^d$	$\pm 0.22^d$	$\pm 0.01^a$	$\pm 0.09^a$
Awash	87.70	0.18	9.46	88.42	0.29	16.61	6.57	5.98
	$\pm 0.01^c$	$\pm 0.01^e$	$\pm 0.04^c$	$\pm 0.09^c$	$\pm 0.03^c$	$\pm 0.20^c$	$\pm 0.01^a$	$\pm 0.01^a$
Beshbesh	85.43	1.10	9.23	81.26	0.72	10.85	6.58	6.06
	$\pm 0.03^d$	$\pm 0.03^c$	$\pm 0.02^c$	$\pm 0.02^e$	$\pm 0.08^c$	$\pm 0.24^e$	$\pm 0.02^a$	$\pm 0.02^a$

¹ **L**- lightness (black/white), **a**-chroma (green/red) and **b**-hue (blue/yellow).

^{c-e} Means with the same superscript letters with in a column are not significantly different at $P < 0.05$ level.

All values are means of triplicates \pm standard deviation.

The chemical composition of flours and starches from improved beans determines their pasting and other characteristics. Table 2 shows the chemical composition of whole bean seed flours and starch extracts from haricot beans. Protein, fat, ash, fiber and moisture contents showed significant difference ($P < 0.05$) among the bean flours. Protein content ranged 20.28 to 22.05 g/100g, crude fat 1.52 to 3.05 g/100g, ash 3.18 to 4.23 g/100g, crude fiber 4.63 to 5.53 g/100g, carbohydrate 59.01 to 61.59 g/100g and phosphorus 0.16 to 0.17 mg/g. These values were in the range reported for other legumes seeds (Schoch and Maywald, 1968; Lineback and Ke, 1975; Yang *et al.*, 1980; Lii and Chang, 1981; Duke, 1981; Koehler *et al.*, 1987; Barampama and

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Simard, 1993; Bishnoi and Khetarpaul, 1993; Tharanathan and Mahadevamma, 2003). Analysis of phosphorus in starch composition is very important that starch and glycogen are degraded by phosphorolysis in the presence of inorganic phosphorus with starch phosphorylase or glycogen phosphorylase (Eliasson, 1996).

Protein, fat and phosphorus contents showed non-significant difference ($P > 0.05$) among the bean starch extracts. The chemical composition is a simple and convenient way of illustrating the purity of the starch extracts whereby higher starch and lower contents of other components (protein, fat, ash, fiber) are highly desirable. It has been speculated that high contents of other components, especially fat and protein, influence the swelling power and pasting properties of starches (Schoch and Maywald, 1968). Report of many other investigators also indicated that amount of protein, fat; ash and fiber are usually considered as an index of purity of legume starch (Lii and Chang, 1981; Galvez and Resurreccion 1993). The starch content of the improved haricot bean flour used in this study were 46.95, 46.53 and 48.77% for Roba, Awash and Beshbesh varieties in dry matter respectively. These results were in agreement with reported values that starch content ranges from about 35 to 60% of the dry weight of beans (Rockland and Metzler, 1967; Reddy *et al.*, 1984). A similar finding was also reported by Labaneiah and Luh (1981) for starch content of red kidney beans, Gloria pink dry beans and black eye beans 46.95, 42.31 and 41.18% respectively.

The apparent amylose contents of the starch extracts obtained and bean flours in this study ranged from 24.90 to 26.09% and 17.96 to 19.09% in dry matter (Table 3). It had shown non significant difference ($P > 0.05$) in amylose contents with all the three varieties. Thus, the results were similar to those reported for black bean and other legume starches (Lai and Varriano-Marston, 1979; Labaneiah and Luh 1981; Kim *et al.*, 1996; Galvez and Resurreccion, 1993; Su *et al.*, 1998). The amylose portion of the starch affects its swelling and hot-paste viscosities. Schoch and Maywald (1968) stated that as the amylose content increases, the swelling tends to be restricted and the hot past viscosity stabilized. Moreover, higher amylose contents are desired in starches that are to be used for the manufacture of noodles (Lii and Chang 1981). The amylose content of starch samples along with the other components present has a good bearing on the pasting properties and hence these properties were analyzed.

3.2 Pasting Behavior

Rapid Visco-Analyzer (RVA) was used to determine the pasting behavior of the starch extracted and flour from haricot bean. The pasting curves were recorded and the RVA the plots are presented in Fig 2. Several changes may occur upon heating a starch-water system, including enormous swelling, increased viscosity, translucency and solubility, and loss of anisotropy (birefringence). These changes are defined as gelatinization. The gelatinization temperature range of improved haricot bean starches were 84.4 to 86.4 °C. The gelatinization temperature obtained was considerably higher than for wheat starch 55.6 to 63.0 °C, chick pea 63.5 to 69.0 °C and horse bean 61.0 to 70.0 °C starches; Lineback and Ke, (1975). Many investigators have reported that different bean types contain different ranges of pasting temperature, for example;

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purified haricot bean starch ranged with 65.5 to 68.5 °C Naivikul, (1977); great northern bean (65.5-68.5 °C) Sathe and Salunkhe (1981a).

Similarly, lower gelatinization temperature compared to the observed results was also reported for kidney bean Yang *et al.* (1980); black bean Lai and Varriano-Marston, (1979).

Table 2. Chemical composition of bean flours and starches expressed in g/100 g ^z

A. Chemical composition of bean flours

Varieties	Moisture	Crude Protein	Crude Fat	Total Ash	Crude Fiber	Crude Lipid	Total Carbohydrates	Starch (%)	Phosphorus (mg/g)
Roba	11.39 ± 0.02 ^a	22.05 ± 0.11 ^a	2.52 ± 0.07 ^b	3.92 ± 0.02 ^a	5.53 ± 0.03 ^a	0.67 ± 0.09 ^c	59.45 ± 0.06 ^a	46.95 ± 0.89 ^b	0.16 ± 0.04 ^a
Awash	11.99 ± 0.05 ^a	21.99 ± 0.23 ^a	1.52 ± 0.09 ^c	4.23 ± 0.17 ^a	4.63 ± 0.12 ^b	1.24 ± 0.07 ^a	59.01 ± 0.12 ^a	46.53 ± 0.68 ^b	0.17 ± 0.04 ^a
Beshbesh	11.08 ± 0.01 ^a	20.28 ± 0.35 ^b	3.05 ± 0.05 ^a	3.18 ± 0.09 ^b	5.19 ± 0.11 ^a	0.83 ± 0.02 ^b	61.59 ± 0.10 ^a	48.77 ± 0.45 ^a	0.16 ± 0.03 ^a
B. Chemical composition of starch extracts									
Roba	7.49 ± 0.12 ^b	0.97 ± 0.15 ^a	0.08 ± 0.01 ^a	0.08 ± 0.01 ^b	1.12 ± 0.03 ^b	0.20 ± 0.03 ^c	91.18 ± 0.03 ^a	96.55 ± 0.37 ^b	0.02 ± 0.0 ^a
Awash	8.88 ± 0.03 ^a	0.90 ± 0.05 ^a	0.07 ± 0.01 ^a	0.12 ± 0.02 ^a	0.98 ± 0.05 ^a	0.63 ± 0.04 ^a	89.40 ± 0.12 ^a	95.74 ± 0.16 ^b	0.02 ± 0.0 ^a
Beshbesh	8.24 ± 0.13 ^{ab}	0.89 ± 0.08 ^a	0.08 ± 0.02 ^a	0.06 ± 0.00 ^b	1.00 ± 0.02 ^a	0.41 ± 0.02 ^b	90.32 ± 0.02 ^a	98.45 ± 0.28 ^a	0.01 ± 0.0 ^a

All values are means of triplicates ± standard deviation.

^z Each values expressed as 100g of dry seeds (wet basis)

^{a-c} Means not sharing a common superscript letter with in a column are significantly different ($P < 0.05$).

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The high initial gelatinization temperature of improved haricot bean starch (Beshbesh variety) indicated that the granules resisted swelling (Table 3). Generally starch isolates exhibited a lower viscosity during heating to 95 °C, at 95 °C and 50 °C compared to bean flour. The pasting temperature is one of the pasting properties which provide an indication of the minimum temperature required for sample cooking, energy costs involved and other components stability. The peak viscosity also indicates the water binding capacity of starch. Final viscosity is used to define the particular quality of starch and indicate the stability of the cooked paste in actual use; it also indicates the ability to form a various paste or gel after cooling and less stability of starch paste commonly accompanied with high value of breakdown.

RVA results indicated that starch isolates and bean flour from haricot beans had distinct pasting properties compared to other native starches. Bean flour from Roba variety had higher final viscosity (233.25 RVU) compared to other flours and starches from haricot beans. The gelatinization temperatures were 84.40, 84.43 and 86.43 °C for bean starch from Roba, Awash and Beshbesh varieties respectively. All pasting properties of analyzed bean samples were reported by RVA profiles. These did not have distinct peak and troughs for bean starch and flour that are present in starches like wheat, rice, corn, potato, etc. Similar profiles for starch from *Phaseolus vulgaris* were reported by other many investigators (Lai and Varriano-Marston, 1979; Lii and Chang, 1981, Sathe and Salunkhe, 1981; Jacobs et al., 1995). Thus, peak heights in this study were not reported as the amylograms did not have distinct peaks for bean starch and flour.

Classification of viscosity pattern is important to categorize the starch for end product recommendation. According to Schoch and Maywald (1968) viscosity pattern taxonomy of “thick-boiling” starches, the swelling power of 7.23 to 11.27% obtained in our experiments for improved bean starch isolates classifies them as highly restricted-swelling starches. The cross-linkages in their granules reduce swelling and stabilize them against shearing during cooking in water. A restricted type of swelling is mostly desired for the starch extracts for the manufacture of value added products such as noodles. Composite blends with cereals importantly require that the starch granules swell sufficiently and remain intact and stable against shearing during the process (Galvez and Resurreccion, 1993). Sathe *et al.* (1982) observed that black gram starch amylograph had a strikingly different behavior than most legume starches in that it had a distinct peak viscosity. It was observed that pasting properties of whole bean flour made from Roba, Awash and Beshbesh varieties had higher values of peak and viscosity pattern than bean starch which is not a common behavior of most legumes. Legume starches have higher viscosity than cereal starches (Lineback and Ke, 1975) which indicate that these starches are more resistant to swelling and rupture towards shear. The factors which influence this property may include the size and shape of the starch granules, ionic charge on the starch, kind and degree of crystallinity within the granules, presence or absence of fat and protein, and perhaps, molecular size and degree of branching of the starch fractions (Schoch and Maywald, 1968). Furthermore, the viscogram profiles depends on many factors such as, botanic source (type of starch), granule size, concentration, amylose/amylopectin ratio, other endogenous materials (particularly lipids and phosphors), added ingredients (salts, sugar, pH modifier etc.) and physical history after pasting (time, temperature and shear stress/shear rate).

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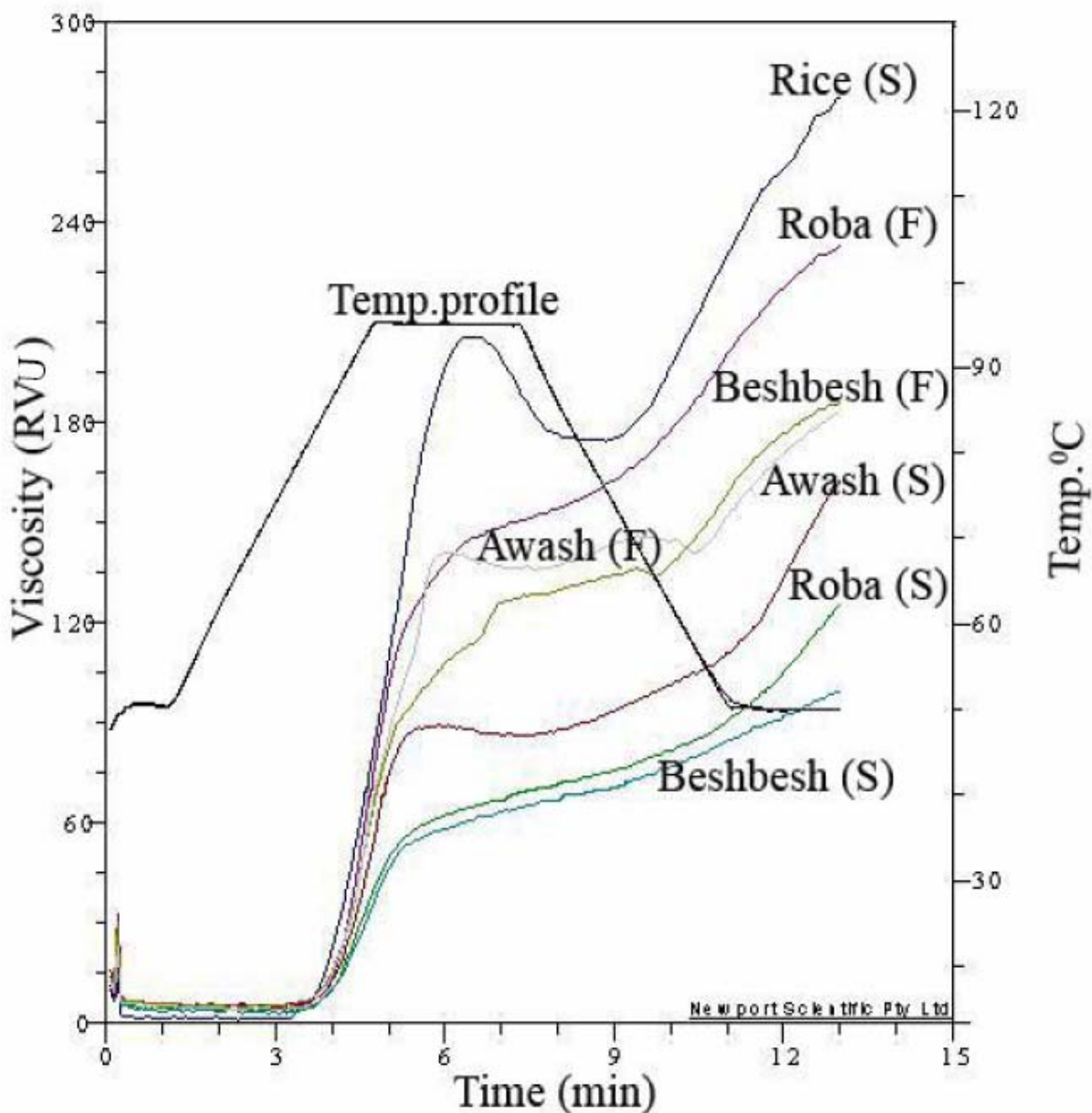


Fig 2. Viscosity profile comparison on bean flours and starches using commercial rice starch as a control.

Where:

F-Flour

S-Starch

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The proteins in the bean flour were believed to restrict starch granules swelling and reduce the amylogram viscosity. Hamaker and Griffin (1993) and Yang and Chang (1999) indicated that proteins in rice flour restrict starch granules swelling and reduce the amylogram viscosity. Protein removal was reported to increase the paste viscosity of starch (Yang and Chang, 1999). But Liang and King (2003) observed the opposite effect.

The pasting profile results and the RVA viscosity curves in this study were consistent with Liang and King (2003) where flour had higher paste viscosity than starch (Fig 2). The decrease in paste viscosities (PV, MV, FV) of bean starch compared to flour were attribute to isolated starch granular properties, development of crystallinity in the amorphous regions of the granule and due to the ordering rearrangement of starch molecules in the granules, which play an important role in governing the pasting properties of starch.

3.3 Swelling Power and Water Solubility Index

The swelling power and water solubility index of bean starch and flour at 95 °C are shown in Table 3. The swelling power (10.40%) and solubility (20.42%) of starch from Roba varieties were the highest followed by Awash variety. Bean flour from Beshbesh variety had highest swelling power (11.27%) and solubility (37.77%) pattern followed by Awash variety. From the obtained results, bean flour and isolated starch exhibited highly restricted swelling power and solubility. Compared with bean flour, the swelling power and solubility patterns of starch isolates indicated the existence of strong bonding forces. This may not be due to its high amount of protein and lipid (Table 2) that might form inclusion complexes with amylose. The starch isolates had less swelling power than bean flour even though their protein, fat and lipid content were lesser than the bean flour in this study. Lower value of solubility and swelling power of starch isolates to bean flour might be due to the protein-amylose complex formation in bean isolated starch and flour. According to Pomeranz (1991), formation of protein-amylose complex in native starches and flours may be the cause of decrease in swelling power.

Starch and protein interact due to attraction of their opposite charges and form inclusion complexes during gelatinization, and this restricts swelling. Leach *et al.* (1959) and Zeleznak and Hoseney (1987) reported that the amylose acts both as diluents and inhibitor of swelling, especially in the presence of lipids which can form insoluble complexes with some of the amylose during swelling and gelatinization. The starch molecules are held together by hydrogen bonding in the form of crystalline bundles, called micelles. Thus, swelling power and solubility patterns of starches have been used to provide evidence for associative binding force within the granules (Leach *et al.*, 1959). When an aqueous suspension of starch granules is heated, these structures are hydrated and swelling takes place. According to Schoch and Maywald (1968), starches have been classified as high swelling, moderate swelling, restricted swelling, or highly restricted swelling. High-swelling starches have swelling power of approximately 30 or higher at 95 °C. Their granules swell enormously and the internal bonds become fragile toward shear when the starch is cooked in water.

Restricted-swelling starches have swelling power in the range of 16 to 20 at 95 °C. The cross-linkages in their granules reduce swelling and stabilize them against shearing during cooking in water (Galvez and Resurreccion, 1993).

In this study, bean starch and bean flour had swelling power ranged 7.23 to 10.40% and 9.17 to 11.27% respectively. Therefore, the resulting swelling power indicated that the starch extracts obtained were highly restricted type according to Schoch and Maywald (1968). The solubility pattern had a correlation with the swelling power (Table 3). With the increase in swelling power, starch solubility similarly increased. This is seen as mainly the result of granule swelling permitting the exudation of amylose (Dengate, 1984). Solubility of bean starch varies with temperature and it can be generally concluded that solubility increases with temperature increment for black bean starch (Lai and Varriano-Marston 1979). Solubility of improved bean starch for all three varieties in this study ranged between 17.69 to 20.42% which is in agreement to the observation reported by Lai and Varriano-Marston (1979) for black bean starch (17.91% solubility at 95 °C). Lii and Chang (1981) also reported that solubility and swelling power for red bean starch was about 25% and 32% respectively.

Table 3. Swelling power, solubility properties^w and amylose^Z contents of haricot bean starch extracts and flours

A. Haricot bean starch

Varieties	Solubility (%)	Swelling power (%)	Starch amylose (%)
Roba	20.42 ± 0.28 ^a	10.40 ± 0.18 ^a	24.90 ± 0.24 ^a
Awash	20.04 ± 0.10 ^a	10.00 ± 0.15 ^a	26.09 ± 0.12 ^a
Beshbesh	17.69 ± 0.07 ^b	7.23 ± 0.05 ^b	25.40 ± 0.16 ^a
B. Haricot bean flour			
Roba	33.47 ± 0.68 ^b	9.17 ± 0.16 ^a	17.96 ± 0.24 ^a
Awash	37.03 ± 0.70 ^a	10.66 ± 0.37 ^a	19.09 ± 0.12 ^a
Beshbesh	37.77 ± 0.81 ^a	11.27 ± 0.22 ^a	18.84 ± 0.16 ^a

^w The percent soluble and swelling power were calculated on dry basis.

^Z Amylose content in dry matter.

All values are means of triplicates ± standard deviation.

^{a-c} Means with the same superscript letters with in a column are not significantly different at P < 0.05 level.

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3.4 Water and Oil Absorption Capacity

Results of the water and oil absorption capacity of improved bean flour and starch are shown in Table 4. Starch from Roba variety registered the highest water and oil absorption capacity 1.68 and 3.43 g/g, respectively among the varieties studied. It is known that water binding by starches is a function of several parameters including size, shape, conformational characteristics, steric factors, hydrophilic-hydrophobic balance in the starch molecule, lipids and carbohydrates associated with the proteins, thermodynamic properties of the system (energy of bonding, interfacial tension, etc.), physicochemical environment (pH, ionic strength, vapor pressure, temperature, presence/absence of surfactant etc.), solubility of starch molecules and others (Chou and Morr, 1979).

Oil absorption trends were higher than those for water absorption in bean starch and flour. Bean starch and flour from Roba variety registered the highest oil and water absorption (3.43 g/g and 3.52g/g, respectively) capacity among all the varieties studied. The bean flour had higher water and oil absorption (2.45 g/g and 3.52 g/g, respectively) compared to bean starch (1.68 g/g and 3.43 g/g). Sosulski and Fleming (1977) reported that water absorption by soybean flour, soybean concentrate, sunflower flour and sunflower concentrate to be 2.4, 3.6, 1.8, and 3.9 g/g; respectively.

Table 4. Water and oil absorption capacity of starch and flour from haricot beans

Varieties	Water absorbed (g/g)		Oil absorbed (g/g)	
	Starch	Flour	Starch	Flour
Roba	1.68 ± 0.05 ^a	2.45 ± 0.02 ^a	3.43 ± 0.02 ^a	3.52 ± 0.01 ^a
Awash	1.46 ± 0.03 ^b	2.21 ± 0.03 ^b	2.46 ± 0.01 ^b	2.81 ± 0.01 ^b
Beshbesh	1.37 ± 0.02 ^b	2.14 ± 0.01 ^b	2.28 ± 0.03 ^c	2.49 ± 0.02 ^c

All values are means of triplicates ± standard deviation.

^{a-c} Means with the same superscript letters within a column are not significantly different at $P < 0.05$ level.

Results of water absorption in this study was 1.68 g/g for starch and 2.45 for flour at 21°C and which were less compared to previous observations of starch from beans. Sathe and Salunke, (1981a) reported that water and oil absorption capacity of Great Northern bean starch had 2.93g/g and 2.94 g/g; respectively. The high water absorption at 21°C observed may have been due to the nature of the starch and possible contribution to water absorption by the cell wall material(s) which was not removed completely (Sathe and Salunkhe, 1981b). Studies on purification, modification and properties of pea starch reported by Comer and Fry (1978) have concluded that cold water absorption of purified pea starch was 92-105% and that water uptake was a function of temperature.

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4. CONCLUSIONS

The functional characteristics of the flour from different varieties had significant variance. The swelling power of flour and starch isolate from improved varieties of the bean studied fall on the group of highly restricted-swelling starches. This characteristic is desirable for starch extracts to be used for the manufacture of value-added products such as noodles and composite blends with cereals. In spite of the differences among the beans of the three varieties of haricot bean, the isolated starches had similar physico-chemical, pasting and functional properties. The decrease in paste viscosities of bean starch compared to flour obtained in this study are attributed to the interaction of starch with the protein, fat, etc. which depend on the varietal differences and plays an important role in governing the pasting properties of starch.

Overall, the physico-chemical, pasting and functional properties obtained indicate that bean starch have useful technological properties for many applications. It can be used in the food processing industry and non-food applications of starch such as in paper and textile industries. The functionality and pasting curve data show that the bean starch can be used as a functional ingredient in food systems, particularly in East and Great Lakes Regions of Africa where bean production and utilization is enormous. Research and development studies on African varieties of beans which are constantly released from various research centers will help to meet new demands in the region. Finally, in order to boost the small scale bean production and develop new market opportunities to stimulate economic growth in the region, one would have to expand alternative utilization/processing techniques in Agrifood systems, and strengthen farmers-research linkages as a view of possible new and potential technologies implementation in the region. Further research and development programs in these aspects which can be integrated with other currently ongoing research activities are necessary.

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