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Effects of Roasting Conditions on the Proximate Composition and Functional Properties of Common Bean (*Phaseolus vulgaris*) Flours

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Abstract

Roasting of dry beans presents the possibility of a value-added product with improved nutritional quality and potential use in different food systems. The effect of roasting on the proximate composition and functional properties of dry beans (*Phaseolus vulgaris* L.) was determined. Beans were roasted at 140, 170, and 200 °C for 5, 10, and 15 minutes. The moisture, carbohydrate, protein, dietary fibre, total ash and fat contents of the flours ranged from 4.58 to 6.72%, 56.21 to 60.51%, 23.09 to 26.74%, 4.12 to 7.01%, 3.94 to 4.58% and 1.28 to 2.10%, respectively. An increase in roasting temperature and time significantly reduced moisture and carbohydrate contents, but increased fat, fibre and ash contents. Foaming capacity, foam stability, water absorption index, water solubility index and water absorption capacity varied from 6.16 to 45.14%, 2.10 to 30.68%, 4.20 to 5.12 g/g, 10.74 to 17.15 g/g and 1.77 to 2.2 g/g, respectively. Increasing roasting temperature and time impacted functional properties of flours. Pasting properties of bean flour pastes were significantly reduced. Flour from roasted beans (FRBs) can serve as a functional ingredient and nutrient enhancer in the food industry. In order to increase shelf life and nutrient density of bean flours, the beans should be roasted at 200 °C.

Keywords: Beans; roasting temperature; roasting time.

Introduction

Common beans (*Phaseolus vulgaris*) are a cheap source of protein worldwide (Phillips et al. 2015). Recently, there has been an increasing awareness of the role beans can play in terms of nutrition security and more consumers are considering beans as a potential substitute for red meat. In spite of this, beans have been branded as inferior compared to other sources of protein because they are hard to cook particularly the dry beans (Siddiq and Uebersax 2012a), making bean meals less popular to youth and urban populations who tend to prefer meals that are quick to prepare. In developing countries where protein-energy malnutrition is still a challenge, it is important to promote not only increased yields, but also the processing and utilization of beans at the different levels along their value chain (Siddiq and Uebersax 2012b). Processing of beans into flour avails an opportunity to have a value-added product with improved nutritional quality, reduced cooking time and useful in different food systems. Whole bean flour can be used as a protein supplement in baked products and as a thickening agent in soups and sauces (Alfaro-Diaz et al. 2023).

It has been observed that raw legumes ground without pretreatment develop undesirable odours and flavours which persist after cooking. Lipoxygenases have been held responsible for the appearance of off-flavours by catalysing the formation of hydroperoxides from unsaturated fatty acids. However, treatment of legumes with dry heat can inactivate these enzymes (Shi et al. 2020). Improvement in nutritional quality has also been demonstrated by heating to destroy the heat-labile antinutritional protease inhibitors in legumes. Roasting also extends shelf life and reduces the anti-nutrient factors of cereals and legumes (Nzewi and Egbuonu 2011). Preliminary bean processing techniques including roasting have been found to increase digestibility, improve protein to energy ratio and reduce flatulence from beans (Baik and Han 2012).

Heating of foods containing protein results in changes in water status, solubility of the protein and other changes in functionality of protein (Collar et al. 2020). Lysine, the most predominant amino acid in legumes, in the form of epsilon-amino lysl residues, and methionine are highly reactive and limiting amino acids lost by Maillard reaction (Sterna et al. 2020). These Maillard type browning reactions may occur in stored bean products and contribute to a loss of nutritional value (Karathanos et al. 2006) and decline in sensory quality. Ogechukwu and Ikechukwu (2017) reported that the water absorption, oil absorption, foaming and swelling capacities, solubility index, and bulk density of the flour from Lima beans (*Phaseolus lunatus*) that had been soaked, dehulled and roasted at 240 °C for 40 minutes were significantly ($p < 0.05$) increased compared to the raw beans. On the other hand, Audu and Aremu (2015) reported an increase in water absorption capacity, oil absorption capacity, foaming capacity and a decrease in foam stability of flour from dehulled black turtle beans (*Phaseolus vulgaris* L.) that had been roasted at 85 °C for 75 minutes. Results by Kumar et al. (2020) showed that microwave roasting of black chick peas (*Cicer arietinum*) at 600W for 10 minutes increased the water absorption capacity and oil absorption capacity by 69.51% and 6.41%, respectively as compared with the control.

Presently, there are limited studies on the physicochemical properties of whole bean flour from beans roasted using a wide range of roasting temperature and time conditions, which are typical of household and cottage industry level processing. In a bid to improve roasting conditions, this study was therefore conducted to investigate the effects of different roasting conditions on the chemical and functional properties of bean flours.

Materials and Methods

The dry beans (*Kanyebwa* variety/NABE 15) were purchased from Owino market, in Kampala (capital city of Uganda).

Experimental design

A factorial design with two factors at three levels was employed. Roasting temperature and time were the factors varied to include 140, 170 and 200 °C and 5, 10 and 15 minutes, respectively. The control constituted beans that were not roasted. Triplicate determinations were made for each temperature and time combination and control for the subsequent parameters investigated.

Preparation of flour from roasted dry beans

The bean seeds were freed of dirt and other extraneous materials, washed twice with portable water and dried at 46 to 54 °C in an electric drier for eight hours. The beans were then roasted in an oven (Infrared food oven GL-2A, Guangzhou Itop Kitchen Equipment Co, Ltd. Guangdong, China) at different temperatures (140, 170 and 200 °C) for various times (5, 10 and 15 minutes) with periodic stirring using a wooden spoon to ensure uniform heat distribution. After table cooling to room temperature, the roasted beans were ground to fine flour using a mill (Wonder mill, Pocatello, Idaho, USA) and sieved through a 425 microns mesh size. The flours were packaged into air tight plastic containers and stored at room temperature until needed for analysis.

Proximate analysis

Proximate composition of the bean flours was determined according to the AOAC methods (2015). The moisture content of the flours was determined using the standard Air Oven Method No. 925.10 (AOAC 2015) by means of a hot box oven (Gallenkamp, United Kingdom). Protein content was determined basing on the standard Kjeldahl method (AOAC 2015) using a Kjeltec machine. Fat was determined using a Soxhlet machine (AOAC 2015). Ash was determined by the direct heating method in a muffle furnace as described by AOAC (2015). Dietary fibre was determined gravimetrically using acid detergent fibre reagent (Pearson 1976). Carbohydrate was determined by difference; carbohydrate (%) = (100 – moisture + protein + fat + fibre + ash).

Functional properties

The water and oil absorption capacities (WAC and OAC) of the flours were determined using the centrifugation method (Kaur and Singh 2006). The water absorption index (WAI) and water solubility index (WSI) of samples were determined using methods reported by Kaur and Singh (2006). The foaming properties were determined by employing the method of Seena and Sridhar (2005). The pasting profiles of flour samples were determined using a Rapid Visco-Analyzer (RVA 4500) (Newport Scientific Pty. Ltd. Warriewood, Australia) with the aid of a thermocline for windows version 3.0 software (1998). Flour suspensions were prepared by addition of 3.5 g of flour to 25 ml of distilled water to make a suspension in the RVA sample canister. Test runs were conducted following the profile for heat treated flour, which included: 1 minute of mixing and warming up at 50 °C; 3.7 minutes of heating at 12 °C/minute up to 95 °C; 2.5 minutes of holding at 95 °C; 3.8 minutes of cooling down to 50 °C at 12 °C/minute and 2 minutes of holding at 50 °C. A constant paddle rotational speed (160 rpm) was used throughout the entire analysis, except for rapid stirring at 960 rpm for the first 10 seconds to disperse the sample. The whole cycle was completed within 13 minutes. The parameters measured were: Peak viscosity-the highest viscosity during the heating stage; Breakdown viscosity-the difference between the peak viscosity and the minimum viscosity at the end of the heating stage; Setback viscosity-the difference between the maximum viscosity during cooling and the minimum viscosity during heating; Final viscosity-the viscosity at the end of the cooling stage; and Peak time (minutes)-the time taken for the paste to reach the peak viscosity.

Statistical analysis

Analysis of Variance (ANOVA) was done to determine the significant differences among means using SPSS (version 22.0 Chicago: SPSS Inc). Tukey's Honest Significant test was used to separate means. The differences were considered statistically significant at $p \leq 0.05$. Principal component analysis to test the relationships amongst variables was performed using XLSTAT (version.2012.10.7.01 Addinsoft, Paris, France) and Unscrambler X 10.5 (CAMO Software, AS, Norway).

Results and Discussion

Effects of roasting conditions on proximate composition of bean flours

Results for proximate composition of the raw and roasted bean flour are presented in Table 1. There were significant variations in proximate composition parameters between the control and roasted flour samples and among the roasted flour samples at different temperature and time conditions. The moisture content of the roasted bean flours ranged from 4.58 to 6.72%. Flour from beans (FFBs) roasted at 140 °C for 5 minutes had the highest moisture content (MC), while FFBs roasted at 200 °C for 15 minutes had the least MC. Increase in roasting temperature and time significantly ($p < 0.05$) reduced the MC. The flours from the roasted beans exhibited a decrease in moisture content when compared to the control sample, and the findings are similar to those by Ogechukwu and Ikechukwu (2017) on roasted Lima beans and Nzewi and Egbuonu (2011) on roasted asparagus beans. The observed decrease in MC could have been due to escape of moisture from the sample matrix resulting from the heat (Afolabi 2014). This implies that roasting is effective in reducing the moisture content of bean flours. These results are in line with the recommended moisture content for flours; ≤ 9% (Butt et al. 2004).

The crude fat (CF) content of the roasted bean flours varied from 1.28% (in beans roasted at 140 °C for 5 minutes) to 2.10% (in beans roasted at 200 °C for 15 minutes). There was a significant ($p < 0.05$) increase in CF content with increase in roasting temperature and time (Table 1). In comparison to the control, all roasted flours had higher crude fat content. Similarly, Xu et al. (2016) reported an increase in fat content of flour from roasted Kabuli chick pea (*Cicerarietinum* L.). In contrast, flour from roasted red kidney beans, asparagus beans and Lima beans had reduced fat contents compared to the flour of the raw beans (Audu and Aremu 2011, Nzewi and Egbuonu 2011, Ogechukwu and Ikechukwu 2017). The increase in fat can be attributed to redistribution of nutrients in the beans (Xu et al. 2016) associated with increased extractability of fat secondary to destabilization of the food matrix due to high temperature.

The dietary fibre (DF) content of the roasted bean flours varied from 4.12 to 7.01%. Roasting at 200 °C for 15 minutes resulted in the highest dietary fibre value, while roasting at 140 °C for 10 minutes led to the lowest value relative to the control sample. Increase in roasting temperature and time significantly ($p < 0.05$) increased dietary fibres. These observations are in agreement with results showing increased dietary fibres in roasted soya bean, microwave roasted black chickpea and in soaked, cooked and dehydrated beans (Azizah and Zainon 1997, Aguilera et al. 2009, Kumar et al. 2020). The formation of resistant starch from amylose-lipid complexes and Maillard-reaction products during cooking given the high content of protein and reducing sugars in beans have been described as factors contributing to observed increases in insoluble dietary fibres (Vidal-Valverde and Frias 1991, Su and Chang 1995).

The total ash content (TAC) of the FFRBs varied from 3.94 to 4.58%. Increase in roasting temperature and time significantly ($p < 0.05$) increased TAC of the bean flour as compared to the control. Obatolu et al. (2007) had similarly reported an increased TAC in flour from roasted yam bean. The observed increase in TAC could be attributed to decomposition of organic matter due to elevated temperatures thus concentrations of the inorganic contents of the sample. Furthermore, the crude protein (CP) content in the flours ranged from 27.29 to 28.49% (Table 1). The highest CP value was in flour from beans roasted at 200 °C for 5 minutes. Variations in roasting temperature and time significantly ($p < 0.05$) affected the protein content of the roasted flours. Relative to the control sample, roasting significantly ($p < 0.05$) decreased the protein content and this could be attributed to protein denaturation. Similar results were reported by Nzewi and Egbuonu (2011) and Ogechukwu and Ikechukwu (2017).

The carbohydrate content (CC) of the samples ranged from 50.00 to 55.76% (Table 1). Roasting beans at 200 °C for 5 minutes yielded flour with the lowest CC, while flour from beans roasted at 140 °C for 15 minutes had highest CC. In comparison to the control, roasting significantly ($p < 0.05$) increased CC of flours. However, increase in roasting temperature with time did not significantly ($p < 0.05$) affect the CC of the roasted flour. These findings are in agreement with D'souza (2013) for roasted field beans and Ogechukwu and Ikechukwu (2017) for roasted Lima beans and imply that roasting increased the extractability of the carbohydrates as compared to the control.

Effects of roasting conditions on the functional properties of roasted bean flour

Foaming capacity (FC) significantly ($p < 0.05$) varied between the control sample and roasted samples with the former having higher values than the latter. Furthermore, the foaming capacity reduced significantly from

45.15% in samples roasted at 140 °C for 5 minutes to 6.16% in sample roasted at 200 °C for 15 minutes (Table 2). These results are in agreement with those reported for roasted African yam bean, toasted mung bean, roasted chickpea (Obatolu et al. 2007, Nwosu et al. 2011, Offia-Olua and Madubuike 2015, Jogihalli et al. 2017a) but in contrast to those reported for roasted Lima beans (Ogechukwu and Ikechukwu 2017). The reduction in FC in dry heat-treated samples has been reported to be due to protein denaturation attributed to protein cross-linking caused by the severe heat treatments, which decrease the solubility and flexibility of proteins (Adebowale et al. 2009, Offia-Olua and Madubuike 2015). The ability of food to foam and maintain stable foams is determined mainly by the solubility of its proteins in water. Foaming stability (FS) varied significantly ($p < 0.05$) between the control and roasted samples. The foaming stability of the roasted bean flours ranged from 2.10 to 30.68%. Roasted bean at 140 °C for 5 minutes yielded flours with the highest FS while flour from beans roasted at 170 °C for 15 minutes had the least FS. Increase in roasting temperature and time significantly ($p < 0.05$) reduced the FS (Table 2). Similar results have been reported for roasted pinto beans, toasted mung beans and chickpeas (Audu et al. 2014, Offia-Olua and Madubuike 2015, Jogihalli et al. 2017a). Foam stability is related to the amount of native protein, which gives higher FS than denatured protein. The reduction in amount of native protein brought about by the roasting process was thus signified by a decrease in foam stability.

The water absorption index (WAI) of bean flour varied from 4.20 to 5.12 g/g and the highest value among roasted samples was in samples roasted at 170 °C for 5 minutes that decreased significantly ($p < 0.05$) to lowest in samples roasted at 200 °C for 15 minutes. Relative to the control, a significant decrease in WAI was observed in roasted bean flour samples. Bento et al. (2021a) similarly reported a decrease in WAI of flours from colourful beans (*Phaseolus vulgaris* L.) treated with superheated steam, whereas Jogihalli et al. (2017b) reported an increase in WAI for flour from roasted chickpea. However, results from microwave roasting of chickpea revealed that WAI of chickpea flour increased from 1.98 ± 0.02 (unroasted samples) to 3.41 ± 0.03 (15 min) and 3.60 ± 0.23 (15 min) in 450 and 600 W, respectively and later decreased to 3.24 ± 0.04 at 900 W, 15 min (Jogihalli et al. 2017c), a trend similar to the present study. WAI is generally attributed to the dispersion of starch in excess water which increases the degree of starch damage due to fragmentation. The WAI measures the volume occupied by the starch polymer or granule after swelling in excess water. WAI increases with elevated processing temperature until the dextrinisation of starch, which is dominant during processing conditions like roasting (Sacchetti et al. 2004). Due to the reduced degree of starch damaged during roasting, there is less of it available to disperse in excess water thus reduced WAI.

Table 1: Effects of roasting temperature and time on proximate composition of bean flour (%)

Temperature (°C)	Time (min)	Moisture	Fat	Dietary fibre	Ash	Protein	Carbohydrate
Control		8.43 ^{e} ± 0.20	1.23 ^{a} ± 0.04	5.64 ^{c} ± 0.12	4.18 ^{a} ± 0.12	30.52 ^{b} ± 2.30	50.00 ^{a} ± 2.58
140	5	6.72 ^{d} ± 0.06	1.38 ^{ab} ± 0.06	4.72 ^{ab} ± 0.02	4.27 ^{ab} ± 0.06	27.36 ^{a} ± 0.02	55.54 ^{b} ± 0.11
140	10	6.69 ^{d} ± 0.04	1.66 ^{bc} ± 0.02	4.49 ^{a} ± 0.20	4.27 ^{ab} ± 0.03	27.35 ^{a} ± 0.01	55.53 ^{b} ± 0.22
140	15	6.14 ^{bc} ± 0.16	1.90 ^{cd} ± 0.10	4.76 ^{ab} ± 0.32	4.25 ^{ab} ± 0.11	27.19 ^{a} ± 0.05	55.76 ^{b} ± 0.58
170	5	6.50 ^{cd} ± 0.32	1.96 ^{cd} ± 0.12	5.11 ^{abc} ± 0.20	4.32 ^{abc} ± 0.05	27.29 ^{a} ± 0.09	54.81 ^{b} ± 0.26
170	10	6.34 ^{cd} ± 0.04	1.99 ^{d} ± 0.03	5.12 ^{bc} ± 0.02	4.35 ^{abc} ± 0.09	27.25 ^{a} ± 0.01	54.95 ^{b} ± 0.09
170	15	5.73 ^{b} ± 0.19	2.09 ^{d} ± 0.17	5.25 ^{bc} ± 0.13	4.44 ^{bc} ± 0.11	27.07 ^{a} ± 0.05	55.42 ^{b} ± 0.27
200	5	6.16 ^{bc} ± 0.19	2.05 ^{d} ± 0.14	4.97 ^{ab} ± 0.25	4.17 ^{a} ± 0.06	28.49 ^{ab} ± 2.19	54.16 ^{b} ± 2.05
200	10	5.79 ^{b} ± 0.03	2.19 ^{d} ± 0.19	5.08 ^{abc} ± 0.25	4.56 ^{c} ± 0.02	27.59 ^{a} ± 0.01	55.30 ^{b} ± 0.25
200	15	4.58 ^{a} ± 0.11	2.20 ^{d} ± 0.08	7.35 ^{d} ± 0.36	4.80 ^{d} ± 0.10	26.74 ^{a} ± 0.03	54.33 ^{b} ± 0.55

Values are means (n = 3) ± SD, dry matter basis. Means having different superscripts within the same column are significantly different at $p < 0.05$.

Table 2: Effects of roasting temperature and time on functional properties of bean flour

Temperature (°C)	Time (min)	Foaming capacity (%)	Foaming stability (%)	Water absorption index (g/g)	Water solubility index (g/g)	Water absorption capacity (g/g)	Oil absorption capacity (g/g)
Control		70.32 ^{f} ± 0.18	52.65 ^{g} ±1.39	5.39 ^{e} ± 0.14	16.45 ^{de} ± 0.33	1.90 ^{ab} ± 0.05	0.83 ^{b} ± 0.01
140	5	45.15 ^{e} ± 2.98	30.68 ^{f} ± 0.43	4.79 ^{bc} ± 0.05	17.15 ^{e} ± 0.28	1.77 ^{a} ± 0.04	0.86 ^{b} ± 0.03
140	10	33.11 ^{d} ± 2.57	30.52 ^{f} ± 0.56	4.69 ^{bc} ± 0.13	15.95 ^{d} ± 0.04	1.95 ^{b} ± 0.05	0.91 ^{b} ± 0.04
140	15	35.97 ^{d} ± 1.10	17.27 ^{e} ± 0.21	4.68 ^{bc} ± 0.10	15.01 ^{c} ± 0.17	1.91 ^{ab} ± 0.08	0.84 ^{b} ± 0.04
170	5	19.93 ^{c} ± 0.63	14.49 ^{d} ±1.26	5.12 ^{d} ± 0.06	11.65 ^{b} ± 0.50	2.19 ^{d} ± 0.03	0.87 ^{b} ± 0.01
170	10	14.69 ^{b} ± 0.35	8.04 ^{c} ± 0.54	4.88 ^{cd} ± 0.05	11.32 ^{ab} ± 0.07	2.20 ^{d} ± 0.07	0.80 ^{ab} ± 0.06
170	15	6.30 ^{a} ± 0.15	2.10 ^{a} ± 0.05	4.74 ^{bc} ± 0.07	10.74 ^{a} ± 0.49	2.13 ^{cd} ± 0.05	0.84 ^{b} ± 0.02
200	5	8.45 ^{a} ± 0.21	6.34 ^{c} ± 0.16	4.53 ^{b} ± 0.16	11.14 ^{ab} ± 0.14	2.03 ^{bc} ± 0.06	0.69 ^{a} ± 0.04
200	10	6.16 ^{a} ± 0.07	4.11 ^{b} ± 0.05	4.61 ^{b} ± 0.02	10.95 ^{ab} ± 0.08	2.14 ^{cd} ± 0.02	0.90 ^{b} ± 0.03
200	15	6.62 ^{a} ±0.65	3.83 ^{ab} ± 0.58	4.20 ^{a} ± 0.02	11.11 ^{ab} ± 0.08	1.89 ^{ab} ± 0.02	0.85 ^{b} ± 0.08

Values are means (n = 3) ± SD. Means having different superscripts within the same column are significantly different at $p < 0.05$.

The water solubility index (WSI), which ranged from 10.74 to 17.15 (g/g) decreased significantly ($p < 0.05$) with increase in roasting temperature and time. In relation to the control, WSI decreased significantly ($p < 0.05$) upon roasting the samples. Similar results were reported in flour from roasted chickpea as well as carioca beans (*Phaseolus vulgaris* L.) and colourful beans (*Phaseolus vulgaris* L.) treated with superheated steam (Jogihalli et al. 2017a, Jogihalli et al. 2017c, Bento et al. 2021a, Bento et al. 2022). WSI is a parameter that integrates the effects of gelatinization, dextrinisation and the consequent solubilisation of starch (Ding et al. 2006). Lower WSI correlates with lower degradation of starch. Increase in WSI is associated with increase in starch depolymerisation and the consequent reduction in the length of amylose and amylopectin chains (Balandran-Quintana et al. 1998). Roasting leads to dehydration, denaturation of a protein matrix, dextrinisation of starch and subsequent entrapment of soluble substances in the dextrinised starch mass, thus leading to a decrease in WSI (Alfaro-Diaz et al. 2021). Completion of starch dextrinisation at temperatures above 170 °C could explain the almost constant WSI observed from 170 to 200 °C.

The water absorption capacity (WAC) of the bean flour samples ranged from 1.77 to 2.20 (g/g). Relative to the control sample, roasting significantly ($p < 0.05$) increased WAC of the bean flours. There was a significant increase ($p < 0.05$) in WAC of the roasted the bean flours with increase in roasting temperature and time except at 200 °C for 15 minutes where a decrease was observed. A similar trend of increase in WAC of flour from roasted African yam beans and chickpeas has been reported (Obatolu et al. 2007, Jogihalli et al. 2017c, Kumar et al. 2020). This is probably due to unfolding of proteins upon heating, which exposes previously buried hydration sites, thereby making them available to interact with water (Bento et al. 2022) resulting in increased WAC. The observed decrease at 200 °C for 15 minutes could be attributed to decreased percentage of soluble protein at high temperature long time treatment as observed by Žilić et al. (2006).

Peak viscosity (PV): The peak viscosity of the samples ranged from 4.44 RVU (pastes of beans roasted at 200 °C for 15 minutes) to 82.33 RVU (pastes of beans roasted at 170 °C for 5 minutes). PV is the maximum viscosity attained by gelatinized starch during heating in water. It indicates the capacity of the starch granules to interact with water, and swell freely before they are physically broken down (Ikegwu et al. 2010). The decrease in PV values observed with increase in roasting temperature (Table 3) may be attributed to the denaturation of protein as well as starch–protein interactions which result in structures with reduced capacity for interaction with water (Hernández-Nava et al. 2011). It might also be due to the change in gelatinization temperature of starch granules causing their rupture, even at low water absorption, which reduced the degree of polymerization during gelatinization (Jogihalli et al. 2017c). However, the PV was highest at 170 °C for 5 minutes higher than at 140 °C and control sample. This may be attributed to increased protein solubility at 170 °C secondary to unfolding upon denaturation (Žilić et al. 2006).

Trough (holding strength): The trough for the pastes varied from 4.08 to 78.28 RVU. Pastes from beans roasted at 170 °C for 5 minutes displayed highest trough whereas the lowest trough was observed in pastes from beans roasted at 200 °C for 15 minutes (Table 3). The control sample had lower trough (54.33 RVU) than pastes from beans roasted at 140 and 170 °C with the exception of those at 170 °C for 15 minutes. This could be due to increasing protein solubility from 140 to 170 °C secondary to unfolding upon denaturation (Žilić et al. 2006). Trough is the minimum viscosity after the peak, normally occurring around the commencement of sample cooling. It is a measure of the ability of starch granules to remain undisrupted or withstand breakdown when the flour paste is subjected to a hold period of constant high temperature and mechanical shear stress (Kaur et al. 2007). It also gives an indication of hot paste stability. The smaller the trough value, the higher the stability of the paste. The decrease in trough observed in this study indicates the increased tendency of roasted bean flour to have higher hot paste stability during cooking.

Breakdown viscosity (BV): Breakdown viscosity, which is the difference between the peak viscosity and the lowest viscosity (trough) after the heating ramp, is a measure of the ease with which swollen starch granules can be disintegrated by shear stress (Kaur et al. 2007). The highest break down (5.31 RVU) was from pastes of beans roasted at 170 °C for 10 minutes while the least (0.36 RVU) was from pastes of beans roasted at 200°C for 15 minutes (Table 3). The control sample had the highest BV (6.58 RVU) compared to the roasted samples. High BV is indicative of lower ability of starch to resist shear stress during cooking, resulting in pastes that are less stable (Ikegwu et al. 2010, Lee et al. 2012). Low BV indicates high paste stability (Ragaee and Abdel-Aal 2006). Breakdown viscosity increased with roasting temperature up to a maximum of 5.31 RVU at 170 °C and then decreased to a minimum of 0.36 RVU with further increase in roasting temperature and time. With the exception of beans roasted at 200 °C for 10 and 15 minutes, flours from beans roasted at higher than 140 °C would yield less stable pastes on cooking under shear.

Final viscosity (FV): The final viscosity is the viscosity at the end of the test, indicating the ability of starch to form a viscous paste after cooking and cooling. The highest FV (160.92 RVU) was in pastes from beans roasted at 140 °C for 5 minutes and least value (7.22 RVU) was in pastes from beans roasted at 200 °C for 15 minutes. The control sample had FV value (126.75 RVU) which was lower than pastes from beans roasted at 140 °C and those at 170 °C for 5 minutes. Results obtained in this study indicate that the ability of the bean flour to form a thick paste after gelatinization reduced as the roasting temperature increased beyond 170 °C. Similar results were reported for roasted cowpeas, black chickpea (Adegunwa et al. 2012, Kumar et al. 2020). Increase in heat is likely to have caused a high degree of starch dextrinisation (Sacchetti et al. 2004). This coupled with possible high level of retrogradation of the starch resulted in gradual reduction of final viscosities.

Increase in roasting temperature and time produced bean flours whose pastes are likely to remain stable and be less viscous on cooling besides having low tendency of viscosity breakdown during cooking (Table 3). As such, there is an opportunity for enhancing nutrient and energy density as roasted bean flours could be incorporated into food formulations at a relatively high percentage without substantially increasing the viscosity. This is beneficial when preparing complementary foods like porridges or sauces to attain acceptable viscosity range of between 200 and 250 RVU (Thaoge et al. 2003). Roasted bean flour is also potentially useful as filler in the meat canning industry (Chinomso et al. 2017) as well as in the beverage industry where starches with low final viscosity are of interest (Anton et al. 2008).

Table 3: Effects of roasting temperature and time on pasting properties of bean flour

Temperature (°C)	Time (min)	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (min)
Control		60.9 ^{d} ± 1.01	54.33 ^{d} ± 0.93	6.58 ^{f} ± 0.29	126.75^{d} ± 1.59	72.42 ^{f} ± 0.83	7.00 ^{b} ± 0.00
140	5	75.53^{h} ± 2.87	73.61 ^{g} ± 2.71	1.72^{b} ± 0.17	160.92 ^{f} ± 6.13	87.31 ^{g} ± 3.43	7.00 ^{b} ± 0.00
140	10	73.69^{fg} ± 1.53	67.83 ^{f} ± 1.59	1.86^{b} ± 0.27	137.50 ^{e} ± 4.34	69.67^{ef} ± 2.84	6.98^{ab} ± 0.04
140	15	72.64^{fg} ± 1.30	69.81 ^{f} ± 1.26	2.83^{c} ± 0.08	136.75 ^{e} ± 1.80	66.94^{de} ± 0.75	7.00 ^{b} ± 0.00
170	5	82.53^{g} ± 0.83	78.28 ^{h} ± 1.04	4.25^{d} ± 0.22	143.64 ^{e} ± 1.95	65.36^{de} ± 0.99	7.00 ^{b} ± 0.00
170	10	68.36^{e} ± 0.27	63.06 ^{e} ± 0.47	5.31^{e} ± 0.21	126.86 ^{d} ± 1.25	63.81 ^{d} ± 0.88	7.00 ^{b} ± 0.00
170	15	29.42^{c} ± 0.22	25.22 ^{c} ± 0.32	4.19^{d} ± 0.21	66.47 ^{c} ± 0.48	41.25 ^{c} ± 0.38	7.00 ^{b} ± 0.00
200	5	26.39 ^{c} ± 1.03	22.47 ^{c} ± 0.97	3.92^{d} ± 0.08	61.17 ^{c} ± 1.78	38.69 ^{c} ± 0.82	7.00 ^{b} ± 0.00
200	10	17.56 ^{b} ± 0.21	14.92 ^{b} ± 0.14	2.64^{c} ± 0.10	41.86 ^{b} ± 0.46	26.94 ^{b} ± 0.32	7.00 ^{b} ± 0.00
200	15	4.44 ^{a} ± 0.21	4.08 ^{a} ± 0.22	0.36^{a} ± 0.10	7.22 ^{a} ± 0.51	3.14 ^{a} ± 0.29	6.84 ^{a} ± 0.15

Values are means (n = 3) ± SD. Means having different superscripts within the same column are significantly different at $p \leq 0.05$.

Implications of variations in proximate composition and functional properties of roasted bean flour on product properties

The first two components of the principal component analysis (PCA) explained 54 and 17% of the variations in the data for PC 1 and 2, respectively, expressing 71% of the total variation (Figure 1). PC1 predominantly described functional properties namely; foaming capacity, foaming stability, water absorption index, water solubility index. The raw beans (control) and those roasted at 140 °C for 5, 10 and 15 minutes were characterized by high foaming capacity, foaming stability, water absorption index, water solubility index, oil absorption capacity and were also high in protein content (Figure 1). These flours were however, low in fat, fibre and ash contents. These results are in agreement with those by Siddiq et al. (2010) who reported a positive correlation between protein and foaming properties and negative correlations between fat and foaming stability, ash and foaming capacity and protein and water absorption capacity in flour from unprocessed red kidney, small red kidney, cranberry and black beans. Foaming capacity is used as an index of the whipping characteristics of the flour (Ogechukwu and Ikechukwu 2017). Flours with good foaming capacity are usually desirable in the preparation of whipped cream and salad dressings.

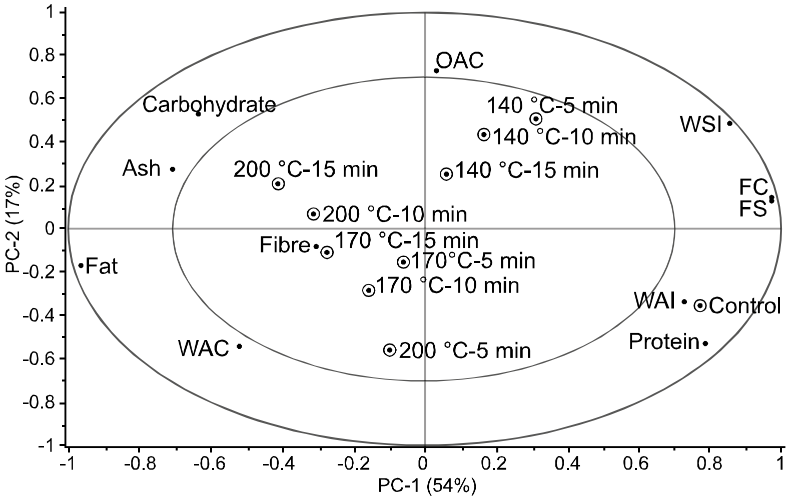

Figure 1: Plot of scores and loadings of the Principal Component Analysis (PCA) of the roasted bean flour proximate composition and functional properties.

Furthermore, flours from beans roasted at higher temperature (170 and 200 °C) and increased time were characterized by high WAC and were also high in fat, total ash and dietary fibres (Figure 1). These flours were low in WAI and WSI. The WAC was negatively correlated with WSI (Figure 1). This can be attributed to the fact that increase in roasting temperature and time decreases the solubility of protein, whereas WAC increases because of denatured protein whose polar amino acids are more available for binding water (Li et al. 2010). Flour from beans roasted at 200 °C for 5, 10 and 15 minutes and 170 °C for 15 minutes would be more useful where WAC is important for certain product characteristics such as the moistness of the product as well as prevention of starch retrogradation and the subsequent product staling (Siddiq et al. 2010). Water absorption capacity is important in consistency and bulking of products, as well as in baking applications (Iwe et al. 2016). Flour with low values of WSI is suitable for pasta and baked products development since it could reduce the loss of solids in water and the optimum cooking time, due to their low water solubilization capacity (Bento et al. 2021b). So, the roasted bean flours might be best suitable for substitution of wheat flour in pasta and baked products development compared to the raw bean flours.

Conclusion

Flours from roasted beans showed increased fat, fibre, and ash contents, and water absorption capacity. Moreover, they exhibited a decrease in moisture, carbohydrate content, foam properties, water solubility index, and water absorption index. These changes were a result of an increase in roasting temperature and time, which also led to the decrease in peak, trough, breakdown, final, and setback viscosities. Flours from roasted beans can thus be used in bakery products to prevent staling by reducing moisture loss because of enhanced water absorption capacity. Owing to the reduced water absorption index and reduced pasting viscosities, they can also be incorporated into food formulations for nutrient enhancement at a relatively high percentage without substantially increasing the viscosity. This study has demonstrated that roasting of beans presents an opportunity to diversely utilize bean flour in the food industry.

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References

Adebowale YA, Henle T and Schwarzenbolz U 2009 Evaluation of some physicochemical and functional characteristics of proteins from *Mucuna pruriens* bean. *Seed Sci. Biotechnol.* 3(1): 8-20.

Adegunwa MO, Bakare HA, Alamu EO, and Abiodun OK 2012 Processing effects on chemical, functional and pasting properties of cowpea flour from different varieties. *Niger. Food J.* 30(1): 67-73.

Afolabi IS 2014 Moisture migration and bulk nutrients interaction in a drying food system: a review. *Food Nutr. Sci.* 5(8): 692-714.

Aguilera Y, Martín-Cabrejas MA, Benítez V, Mollá E, López-Andréu FJ and Esteban RM 2009 Changes in carbohydrate fraction during dehydration process of common legumes. *J. Food Compos. Anal.* 22(7-8): 678-683.

Alfaro-Diaz A, Escobedo A, Luna-Vital DA, Castillo-Herrera G and Mojica L 2023 Common beans as a source of food ingredients: Techno-functional and biological potential. *Compr. Rev. Food Sci. Food Saf.* 1-35.

Alfaro-Diaz A, Urías-Silvas JE, Loarca-Piña G, Gaytan-Martínez M, Prado-Ramirez R and Mojica L 2021 Techno-functional properties of thermally treated black bean protein concentrate generated through ultrafiltration process. *LWT-Food Sci. Technol.* 136: 110296.

Anton AA, Ross KA, Beta T, Fulcher RG, and Arntfield SD 2008 Effect of pre-dehulling treatments on some nutritional and physical properties of navy and pinto beans (*Phaseolus vulgaris* L.). *LWT-Food Sci. Technol.* 41(5): 771-778.

AOAC 2015 Official Methods of Analysis. Association of Official Analytical Chemists. 18th ed, AOAC, Arlington, 806-814.

Audu SS and Aremu MO 2011 Effect of processing on chemical composition of red kidney bean (*Phaseolus vulgaris* L.) flour. *Pak. J. Nutr.* 10(11): 1069-1075.

Audu SS and Aremu MO 2015 Effect of Domestic Processing on the Levels of Some Functional Parameters in Black Turtle Bean (*Phaseolus vulgaris* L). *Food Sci. Quality Manag.* 38: 55-59.

Audu SS, Aremu MO, Lajide L and Oko OJ 2014 Functional properties of processed pinto bean (*Phaseolus vulgaris* L.) grown in Plateau State, Nigeria. *Chem. Process Eng. Res.* 24: 14-20.

Azizah AH and Zainon H 1997 Effect of processing on dietary fiber contents of selected legumes and cereals. *Malays. J. Nutr.* 3(2): 131-136.

Baik BK and Han IH 2012 Cooking, roasting, and fermentation of chickpeas, lentils, peas, and soybeans for fortification of leavened bread. *Cereal Chem.* 89(6): 269-275.

Balandran-Quintana RR, Barbosa-Canovas GV, Zazueta-Morales JJ, Anzaldúa-Morales A and Quintero-Ramos A 1998 Functional and nutritional properties of extruded whole pinto bean meal (*Phaseolus vulgaris* L.). *J. Food Sci.* 63(1): 113-116.

Bento JAC, Bassinello PZ, Carvalho RN, Souza Neto MAD, Caliari M and Soares Junior MS 2021a Functional and pasting properties of colorful bean (*Phaseolus vulgaris* L) flours: Influence of the cooking method. *J. Food Process. Preserv.* 45(11): e15899.

Bento JAC, Bassinello PZ, Morais DK, de Souza Neto MA, Bataus LAM, Carvalho RN, Caliari M and Júnior MSS 2021b Pre-gelatinized flours of black and carioca bean by-products: Development of gluten-free instant pasta and baked snacks. *Int. J. Gastron. Food Sci.* 25: 100383.

Bento JAC, Morais DK, de Berse RS, Bassinello PZ, Caliari M and Júnior MSS 2022 Functional, thermal, and pasting properties of cooked carioca bean (*Phaseolus vulgaris* L.) flours. *Appl. Food Res.* 2(1): 100027.

Butt MS, Nasir M, Akhtar S and Sharif K 2004 Effect of moisture and packaging on the shelf life of wheat flour. *Internet J. Food Saf.* 4: 1-6.

Chinomso AD, Chidi NE and Kelechi AJ 2017 Effect of combined processing methods on the functional and pasting properties of pigeon pea (*Cajanus cajan*) flour. *Int. J. Sci. Qual. Anal.* 3(3): 28-35.

Collar C, Villanueva M and Ronda F 2020 Structuring diluted wheat matrices: impact of heat-moisture treatment on protein aggregation and viscoelasticity of hydrated composite flours. *Food Bioprocess Technol.* 13: 475-487.

Ding QB, Ainsworth P, Plunkett A, Tucker G and Marson H 2006 The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. *J. Food Eng.* 73(2): 142-148.

D'souza MR 2013 Effect of traditional processing methods on nutritional quality of field bean. *Adv. Biores.* 4(3).

Hernández-Nava RG, Bello-Pérez LA, San Martín-Martínez E, Hernández-Sánchez H and Mora-Escobedo R 2011 Effect of extrusion cooking on the functional properties and starch components of lentil/banana blends: Response surface analysis. *Rev. Mex. Ing. Quim.* 10(3): 409-419.

Ikegwu OJ, Okechukwu PE and Ekumankana EO 2010 Physico-chemical and pasting characteristics of flour and starch from achi *Brachystegia eurycoma* seed. *J. Food Technol.* 8(2): 58-66.

Iwe MO, Onyeukwu U and Agiriga AN 2016 Proximate, functional & pasting properties of FARO 44 rice, African yam bean and brown cowpea seeds composite flour. *Cogent Food Agric.* 2: 1142409.

Jogihalli P, Singh L, Kumar K and Sharanagat VS 2017a Novel continuous roasting of chickpea (*Cicer arietinum*): Study on physico-functional, antioxidant and roasting characteristics. *LWT-Food Sci. Technol.* 86: 456-464.

Jogihalli P, Singh L, Kumar K and Sharanagat VS 2017b Physico-functional and antioxidant properties of sand-roasted chickpea (*Cicer arietinum*). *Food Chem.* 237: 1124-1132.

Jogihalli P, Singh L and Sharanagat VS 2017c Effect of microwave roasting parameters on functional and antioxidant properties of chickpea (*Cicer arietinum*). *LWT-Food Sci. Technol.* 79: 223-233.

Karathanos VT, Bakalis S, Kyritsi A and Rodis PS 2006 Color degradation of beans during storage. *Int. J. Food Prop.* 9(1): 61-71.

Kaur A, Singh N, Ezekiel R and Guraya HS 2007 Physicochemical, thermal and pasting properties of starches separated from different potato cultivars grown at different locations. *Food Chem.* 101(2): 643-651.

Kaur M and Singh N 2006 Relationships between selected properties of seeds, flours, and 405 starches from different chickpea cultivars. *Int. J. Food Prop.* 9: 597-608.

Kumar Y, Sharanagat VS, Singh L and Mani S 2020 Effect of germination and roasting on the proximate composition, total phenolics, and functional properties of black chickpea (*Cicer arietinum*). *Legume Sci.* 2(1): e20.

Lee JH, Cho AR, Hong JY, Park DJ and Lim ST 2012 Physical properties of wheat flour composites dry-coated with micro particulated soybean hulls and rice flour and their use for low-fat doughnut preparation. *J. Cereal Sci.* 56(3): 636-643.

Li W, Shu C, Yan S and Shen Q 2010 Characteristics of sixteen mung bean cultivars and their protein isolates. *Int. J. Food Sci. Technol.* 45(6): 1205-1211.

Nwosu JN, Ahaotu I, Ayozie C, Udeozor LO and Ahaotu NN 2011 The proximate and functional properties of African yam bean (*Sphenostylis sternocarpa*) seeds as affected by processing. *Niger. Food J.* 29(2).

Nzewi D and Egbuonu AC 2011 Effect of boiling and roasting on the proximate properties of asparagus bean (*Vigna sesquipedalis*). *Afr. J. Biotechnol.* 10(54): 11239-11244.

Obatolu VA, Fasoyiro SB and Ogunsunmi L 2007 Processing and functional properties of yam beans (*Sphenostylis stenocarpa*). *J. Food Process. Preserv.* 31(2): 240-249.

Offia-Olua BI and Madubuike UB 2015 The dehulling efficiency and physicochemical properties of pre-conditioned mung bean (*Vigna radiata* (L). wilczek) seeds and flour. *Afr. J. Food Sci. Technol.* 6(1): 1-11.

Ogechukwu CO and Ikechukwu JO 2017 Effect of heat processing treatments on the chemical composition and functional properties of Lima bean (*Phaseolus lunatus*) flour. *Am. J. Food Sci. Nutr.* 1(1): 14-24.

Pearson D 1976 The chemical analysis of foods (No. Ed. 7). Longman Group Ltd, New York.

Phillips SM, Fulgoni VL, Heaney RP, Nicklas TA, Slavin JL, and Weaver CM 2015 Commonly consumed protein foods contribute to nutrient intake, diet quality, and nutrient adequacy. *Am. J. Clin. Nutr.* 101(6): 1346S-1352S.

Ragaee S and Abdel-Aal ESM 2006 Pasting properties of starch and protein in selected cereals and quality of their food products. *Food Chem.* 95(1): 9-18.

Sacchetti G, Pinnavaia GG, Guidolin E and Dalla Rosa M 2004 Effects of extrusion temperature and feed composition on the functional, physical and sensory properties of chestnut and rice flour-based snack-like products. *Food Res. Int.* 37(5): 527-534.

Seena S and Sridhar KR 2005 Physicochemical, functional and cooking properties of under explored legumes, Canavalia of the southwest coast of India. *Food Res. Int.* 38(7): 803-814.

Shi Y, Mandal R, Singh A and Pratap Singh A 2020 Legume lipoxygenase: Strategies for application in food industry. *Legume Sci.* 2(3): e44.

Siddiq M and Uebersax MA 2012a Postharvest storage quality packaging and distribution of dry beans. In: Uebersax MA and Siddiq M (Eds) Dry beans and pulses: Production, processing and nutrition First edition (pp. 75-100), John Wiley and Sons, West Sussex.

Siddiq M and Uebersax MA 2012b Dry beans and pulses production and consumption– an overview In: Uebersax MA and Siddiq M (Eds) Dry beans and pulses: Production, processing and nutrition First edition (pp. 1-22), John Wiley and Sons, West Sussex.

Siddiq M, Ravi R, Harte JB and Dolan KD 2010 Physical and functional characteristics of selected dry bean (*Phaseolus vulgaris* L.) flours. *LWT-Food Sci. Technol.* 43(2): 232-237.

Sterna V, Zute S, Jansone I, Ence E and Strausa E 2020 Evaluation of various legume species and varieties grown in Latvia as a raw material of plant-based protein products. *Agronomy Res.* 18(4): 2602-2612.

Su HL and Chang KC 1995 Physicochemical and sensory properties of dehydrated bean paste products as related to bean varieties. *J. Food Sci.* 60(4): 794-797.

Thaoge ML, Adams MR, Sibara MM, Watson TG, Taylor JRN and Goyvaerts EM 2003 Production of improved infant porridges from pearl millet using a lactic acid fermentation step and addition of sorghum malt to reduce viscosity of porridges with high protein, energy and solids (30%) content. *World J. Microbiol. Biotechnol.* 19(3): 305-310.

Vidal-Valverde C and Frias J 1991 Legume processing effects on dietary fiber components. *J. Food Sci.* 56(5): 1350-1352.

Xu Y, Cartier A, Obielodan M, Jordan K, Hairston T, Shannon A and Sismour E 2016 Nutritional and anti-nutritional composition, and in vitro protein digestibility of Kabuli chickpea (*Cicer arietinum* L.) as affected by differential processing methods. *J. Food Meas. Charact.* 10(3): 625-633.

Žilić S, Božović I, Savić S and Šobajić S 2006 Heat processing of soybean kernel and its effect on lysine availability and protein solubility. *Open Life Sci.* 1(4): 572-583.