In Vitro Protein Digestibility and Physicochemical Properties of Dry Red Bean (*Phaseolus vulgaris*) Flour: Effect of Processing and Incorporation of Soybean and Cowpea Flour

N. Y. Njintang,[†] C. M. F. Mbofung,*[,‡] and K. W. Waldron[§]

Faculty of Science and Department of Food Science and Nutrition, ENSAI, University of Ngaoundere, P.O. Box 455, Ngaoundere, Cameroon; and Institute of Food Research, Norwich, United Kingdom

A study was carried out to determine the effect of germination and drying temperature on the in vitro protein digestibility and physicochemical properties of dry red bean flours. A 2 × 3 factorial experiment with two treatments (germination and nongermination) and three drying temperatures was used for this purpose. The effect of particle size on water absorption capacity of bean flour was investigated. In addition, the effect of incorporating soybean and cowpea into the red bean flour on functional properties was equally investigated. Results reveal that protein digestibility increased with germination and also with drying temperature. Drying at 60 °C produced flours of optimum functional characteristics, although the hydrophilic/lipophilic index was high and the solubility index reduced. Germination and particle size as well as drying temperature all affected the water uptake properties of bean flours. Incorporation of soybean and cowpea flour into germinated bean flour at levels of 10 and 30%, respectively, produced a composite with higher functional properties.

Keywords: *Dry beans; germination; drying temperature; composite flour; physicochemical properties; in vitro protein digestibility*

INTRODUCTION

Legumes are grown and used as food in many parts of the world. With particular reference to common beans (*Phaseolus vulgaris*), they serve as a potential good source of proteins and complex carbohydrates (*1*). However, postharvest handling and storage under adverse conditions induce changes in their physicochemical properties, thus resulting in a reduction in their cooking, eating, and nutritional quality as well as consumer acceptance (*2*). In regions of the world where beans constitute the main potential sources of proteins, these defects could be partially or completely reversed through several methods. The use of alkaline salts to improve the cooking quality of beans has been suggested as one such method, but this has a limited advantage because their use tends to reduce the nutritional quality of the cooked product (*3*).

According to Uebersax et al. (*4*) improved utilization of dry beans can be maximized through an understanding of bean physical and chemical components and through the implementation of diverse processing strategies to facilitate the development of economically viable alternative products. In this respect, some recent studies have indicated that the consumption of dry beans could be improved by processing them into ingredients that can be used in combination with cowpea (*Vigna unguicuilata*), which is commonly used for the production of akara (deep fried paste) or koki (steamed cooked paste) (*5*, *6*). In the face of growing urbanization in developing countries, such an alternative can go a long way to satisfying the nutritional needs of consumers. Although the results of these studies provide an alternative method for increasing the consumption of dry beans, it is important to point out that traditional methods of preparation adapted in the said studies are generally labor and time intensive and certainly unsuitable for urban settings where time is very often a major constraint.

Use of cowpea flour for the production of akara has been thought of as a way of reducing the time constraints associated with the classical method of processing akara (*7*).

The use of flours as ingredients for food processing is dependent on its functional properties (*8*). To convert dry beans into flour for use as an ingredient in food processing, therefore, research must be carried out to ascertain the functional properties of the flours as well as the sensory qualities that would render the end product acceptable to consumers. Preliminary studies in this direction by Tunkap et al. (*9*) had revealed that cowpea flour could be replaced by up to 30 wt % with dry bean flour without significantly changing its functional properties. This level of dry bean incorporation into cowpea for use in the processing of cowpea-based foods could be improved through better processing methods.

The present study is part of a larger study aimed at producing dry bean flours as ingredients for food processing. Specifically, the study was carried out, first, to determine the effect of germination and drying on the functional and nutritional properties of common red bean flour and, second, to evaluate the effect of incorporating different levels of cowpea and a constant level of soybean into red bean flour on the functional properties of the composite.

* Author to whom correspondence should be addressed (fax 237 25 25 99).

[†] Faculty of Science, University of Ngaoundere.

[‡] Department of Food Science and Nutrition, University of Ngaoundere.

[§] Institute of Food Research.

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Table 1. Formulation of Composite Flours

flour	% germinated red bean	% cowpea	% soybean
BCSF1	30	60	10
BCSF2	40	50	10
BCSF3	50	40	10
BCSF4	60	30	10
BCSF5	70	20	10
BCSF6	80	10	10

MATERIALS AND METHOD

Production of Bean Flours. Dry red beans commonly cultivated in Cameroon were purchased from the market in Ngaoundere (Cameroon), cleaned of debris, washed, and soaked for ∼18 h in distilled water in the ratio of 1:3 (w/v) to attain a moisture content of between 58 and 60%. Grains so treated were then separated into two lots, one of which was placed on wet muslin cloth and allowed to germinate at room temperature (28 ± 2 °C) for 48 h with regular wetting. The second lot was further divided into three fractions and dried at 40, 60, and 80 °C to a moisture content of 10%. Germinated seeds were equally subdivided into three portions and similarly dried at the different temperatures. Dried bean seeds were decoated by the abrasive action of rubbing the grains between the palms followed by fanning off of the seed coats. Cowpea (*Vigna unguiculata*) and soybean (*Glycine max*) also obtained from the Ngaoundere market were soaked for 16 h, dried to a moisture content of 10% at 40 °C, and separately milled into flours. These flours were subsequently used along with germinated bean flour for the formulation of flour composites. All grains were milled in a hammer mill (Monto type campsas 82370, Labastide St-Pierre) to pass through a 500 μm sieve.

Extraction Rate. The extraction of the dry bean flours was estimated as the ratio of the weight of decorticated seeds to that of the dried treated seeds before decortication multiplied by 100.

Composite Flours. Bean flour produced from dry red beans germinated and dried at 60 °C was used in different proportions with a constant level of soybean flour and various levels of cowpea flour to obtain six different composite flours. The formulation of the composite flours is as shown in Table 1.

Proximate Analysis. Analyses of bean flours for crude protein, ether extract, and ash and moisture contents were carried out essentially according to the standard methods of the Association of Official Analytical Chemists (*10*). Flour samples were acid-hydrolyzed, and the reducing sugar known as available carbohydrate was determined by the dinitrosalicylic acid (DNS) method as described by Fisher and Stein (*11*).

In Vitro Protein Digestibility. In vitro protein digestibility was measured as follows: 0.5 g of finely ground flour sample was suspended in 17 mL of 0.1 N HCl and incubated for 5 min in a shaking water bath at 37 °C. The pH of the mixture was then adjusted to 1.9 and the total volume made up to 20 mL. The lot was then transferred into a dialysis tubing (molecular weight cutoff of ∼1200; Medicell International Ltd., London, U.K.), to which was added 2.5 mL of freshly prepared pepsin (2500−32000 units/g obtained from Sigma Chemical Co., St. Louis, MO) enzyme solution (7 mg/mL). The dialysis tube was then introduced into a beaker (placed in a shaking water bath set at 37 °C) containing 200 mL of 0.1 N HCl (175 mL of 0.1 N HCl and 25 mL of distilled water) for a period of 3 h. One hundred microliters of dialysate samples was withdrawn in duplicate after 0, 20, 40, 60,90, 120, 150, and 180 min of incubation and analyzed for protein content according to the method of Lowry et al. (*12*). The digestibility of each flour was calculated and expressed in terms of milligrams of proteins dialyzed per gram of protein.

Water absorption capacity (WAC) was determined essentially according to the method of Beuchat (*13*). A 2 g flour sample was mixed with 20 mL of distilled water in a 50 mL centrifuge tube votexed for 1 min and then centrifuged at 2000*g* for 30 min and the supernatant removed. The difference in the weight of the precipitate corrected for the dissolved solids in the supernatant was taken as the amount of water absorbed per unit weight of flour. The rate of water rehydration of a flour is an important property that affects the processing of some foods. The bean flours were therefore also evaluated for this property using a Baumann apparatus as described by Pilosof (*14*) and making use of the mathematical equation

$$q = \frac{Qt}{B + t}$$

where q represents the total quantity of water absorbed by the flour during the time t, Q is the maximum quantity of water absorbed at equilibrium, and B is the time required to half saturate the flour. Data obtained from this experiment were later used to calculate Q that was then compared with the WAC determined according to the method of Beuchat (*13*) described above.

Oil absorption capacity (OAC) was estimated by centrifuging a known quantity of flour saturated with cottonseed oil (Sodecoton, Cameroon) after the procedure of Sosulski (*15*).

Hydrophilic/lipophilic index (HLI) was determined as the ratio of WAC to that of OAC and used to define the relative affinity of flour for water and oil.

Water solubility index (WSI) was measured according to the method of Anderson et al. (*16*). A 2.5 g sample of each flour was dispersed in 25 mL of distilled water; special care was taken to break up any lumps using a glass rod. After 30 min of stirring, the dispersion was rinsed into tarred centrifuge tubes made up to 32.5 mL and then centrifuged at 3000*g* for 10 min. The supernatant was then decanted and the weight of its solid content determined after it had been evaporated to a constant weight. The WSI was then calculated as

$$\text{WSI} = \frac{\text{wt of dissolved solids in supernatant}}{\text{wt of dry flour sample}}$$

Emulsifying Properties [Emulsion Activity (Ea) and Emulsion Stability (Es)]. These properties were evaluated essentially according to the method of Yatsumatsu et al. (*17*). A 0.5 g sample of each flour was suspended in 3 mL of distilled water contained in a graduated tube followed by the successive addition of 3 mL of cottonseed oil. The mixture was then vigorously mixed for 10 min using an agitator. The resulting emulsion was centrifuged at 2500 rpm for 30 min. The height of the emulsified layer divided by that of the whole slurry multiplied by 100 was taken as the emulsifying activity of the flour. To determine the emulsion stability, the homogenized mixture of flour, water, and oil was heated at 80 °C for 30 min before centrifugation. The emulsifying stability was then calculated as the height of the emulsifying layer divided by that of the heated slurry multiplied by 100.

Bulk Density (Bd). The flour bulk density was estimated by using the method of Okezie and Bello (*18*): A 10 mL graduated cylinder, previously tarred, was gently filled to the mark with each flour sample. The sample was then packed by gently tapping the cylinder on the benchtop from a height of 5 cm until there was no further diminution of the sample level after filling to the 10 mL mark. The weight of the filled cylinder was taken and the bulk density calculated as the weight of sample per unit volume of sample (grams per milliliter).

Foaming Properties [Foaming Capacity (FC) and Foaming Stability (FS)]. These properties were determined according to the method of Coffman and Garcia (*19*). One gram of flour was dispersed in 50 mL of distilled water and whipped for 5 min with a food mixer (model Aka-Multifex) at high speed and immediately poured into a 250 mL graduated cylinder. The volume of the foam formed was then recorded as the foam capacity and monitored at regular intervals for 60 min to evaluate the foam stability.

Statistical Analysis. All measurements were carried out in triplicate. Data obtained were subjected to the analysis of variance (ANOVA) and Duncan's multiple-range test when there was a significant difference using the SPSS statistical

Table 2. Extraction Rate and Proximate Composition of Beans Flours

	flour source							
	ungerminated beans				germinated beans			
characteristic	40 °C[a]	60 °C	80 °C	P^b	40 °C	60 °C	80 °C	P
extraction rate	82.51 ± 1.53[b]	89.60 ± 0.63[a]	90.66 ± 0.76[a]	0.02	86.93 ± 0.90	89.61 ± 0.41	91.49 ± 1.40	0.08
moisture (%)	9.46 ± 0.11	8.82 ± 0.54	9.11 ± 0.24	0.37	9.21 ± 0.94	9.21 ± 0.03	9.33 ± 0.04	0.50
proteins (%)	26.67 ± 1.02	28.27 ± 0.98	25.71 ± 0.58	0.13	27.03 ± 1.02	22.16 ± 3.9	26.53 ± 2.89	0.50
ash (%)	3.73 ± 0.00	3.97 ± 1.16	3.05 ± 0.31	0.48	4.61 ± 0.11	3.56 ± 0.74	4.78 ± 0.00	0.12
lipids (%)	2.56 ± 0.59[a]	2.02 ± 0.20[a]	1.90 ± 0.18[b]	0.03	2.18 ± 0.25[a]	1.63 ± 0.04[b]	1.37 ± 0.13[b]	0.04
available carbohydrate (%)	60.62 ± 2.09	51.75 ± 6.27	56.19 ± 4.18	0.26	59.15 ± 4.19	65.05 ± 4.18	57.67 ± 2.09	0.15

[a] Drying temperature of beans. [b] P, level of significance following one-way analysis of variance. For each flour type, means in a row not sharing a common superscript are significantly ($P < 0.05$) different as determined by Duncan's multiple-range test.

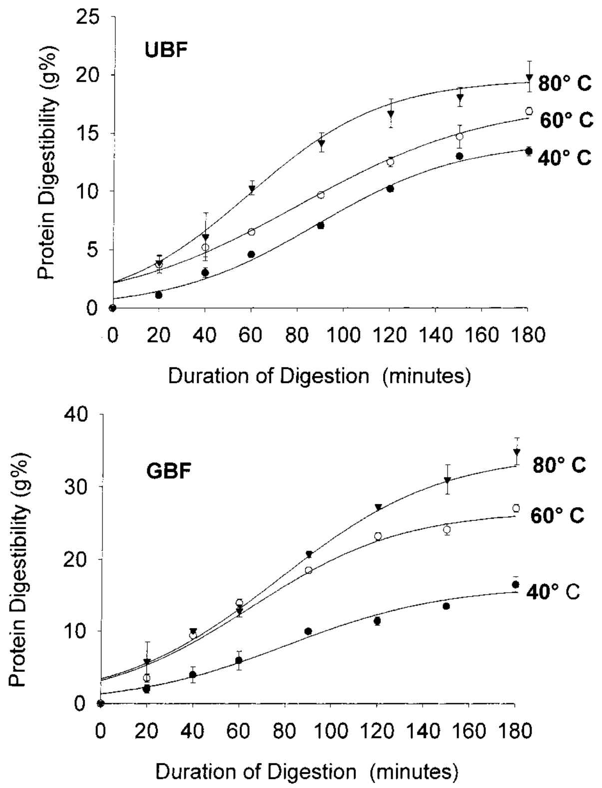

Figure 1. Effect of germination and drying on the in vitro digestibility of red bean proteins.

package (*20*). Graphic representation was carried out using the Statsoft graphic package for Windows (*21*).

RESULTS AND DISCUSSION

The extraction rate is an index of the decorticating efficiency of grains. In the present study the extraction rate (Table 2) increased with an increase in drying temperature. Irrespective of treatment, the extraction rate was observed to vary significantly with drying temperature. However, no significant differences were observed in the extraction rates of grains dried at 60 and 80 °C. Grains dried at 40 °C had a poor extraction rate, probably as a result of the low drying rate. On a comparative basis, germination improved decorticating.

Table 2 also presents the proximate composition of flours produced from germinated and ungerminated beans dried at different temperatures. No statistical differences were observed in the moisture content of the different samples. Protein content ranged between 22.76 and 28.27%. On average, germination brought about a decrease in protein content of flour (26.88 versus 25.24%). Although this observation is in agreement with that of King and Puwastein (*22*), who had shown that germination slightly reduces protein nitrogen content in legume grains, it is at variance with other reports in the literature. In particular, the results differ from those of Idouraine et al. (*23*), who reported an increase of ~12% in the protein content of Sudan beans (*Phaseolus acutifolius*) following a 48 h germination. The authors attributed the increases to protein synthesis that might have occurred during the germination process. The germination of cowpea for 48 h has been reported to lead to an increase in total carbohydrate content (*24*). In the present study the average available carbohydrate content of dry red beans increased following germination.

Table 3. Kinetic Constants (Q and B) of Water Uptake by Flours of Different Particle Sizes

bean flour type	drying temp (°C)	particle size (μm)	Q (mL/g)	B (min)	correl coeff (r)[a]
ungerminated	40	353	2.66	5.00	0.98
		251	2.66	2.50	0.99
		150	2.44	2.00	0.98
	60	353	2.00	7.50	0.98
		251	2.00	0.50	0.99
		150	1.66	1.40	0.98
	80	353	1.77	0.26	0.97
		251	1.93	0.23	1.00
		150	1.77	0.20	0.99
germinated	40	353	2.44	5.00	0.98
		251	2.00	2.50	0.98
		150	1.90	0.50	0.98
	60	353	1.88	0.75	0.97
		251	1.88	1.50	0.99
		150	1.77	1.70	0.99
	80	353	1.77	0.22	0.98
		251	1.88	0.20	0.99
		150	2.00	0.16	1.00

[a] Correlation coefficient between calculated and experimental data.

In Vitro Protein Digestion. For all drying temperatures, germination was observed to improve in vitro protein digestibility (Figure 1). The positive effect of germination on protein digestibility may be related to metabolic activities during germination. An increase in protein digestibility with an increase in drying temperature has also been recorded in in vivo studies carried out by Sathe and Salunke (*25*).

WAC represents the ability of a food system to associate with water under conditions of varying water content during preparation. In this respect the rate at which the association takes place is also important. Table 3 shows the values of semisaturation time (B) and maximum water absorption (Q) obtained for each bean flour type obtained by fitting the Pilosof et al. (*14*) equation to the measurements made for the different flours fractionated into different particle sizes. Q increased with particle size, germination time, and drying temperature. The time needed to absorb half the

Table 4. Functional Properties of Flours Obtained from Germinated and Ungerminated Beans

characteristic	flour	drying temp 40 °C	60 °C	80 °C	P^{**a}
WAC (g/100 g)	UBF	205.10 ± 2.50[a]	183.40 ± 3.20[b]	186.40 ± 5.50[b]	0.04
	GBF	186.40 ± 1.50[a]	163.10 ± 1.60[c]	176.70 ± 0.70[b]	0.001
	P^{*b}	0.001	0.001	ns	
OAC (g/100 g)	UBF	73.83 ± 0.83	73.99± 1.27	77.28 ± 1.95	ns
	GBF	87.83 ± 0.19[a]	77.31 ± 1.06[b]	86.35 ± 1.81[a]	0.006
	P^*	0.002	ns	0.04	
HLI	UBF	2.78 ± 0.00[a]	2.48 ± 0.09[b]	2.41 ± 0.16[b]	ns
	GBF	2.12 ± 0.00	2.11 ± 0.00	2.05 ± 0.00	ns
	P^*	0.0005	0.03	ns	
Ea (mL/100 mL)	UBF	42.8 ± 1.3[a]	42.5 ± 0.9[a]	4.0 ± 0.8[b]	0.001
	GBF	45.1 ± 2.0[a]	44.4 ± 2.9[a]	3.5 ± 1.7[b]	0.001
	P^*	ns	ns	ns	
Es (mL/100 mL)	UBF	51.8 ± 0.0[a]	54.3 ± 1.2[a]	11.6 ± 1.1[b]	0.002
	GBF	48.0 ± 2.1[a]	48.5 ± 1.3[a]	12.8 ± 1.9[b]	0.004
	P^*	ns	0.04	ns	
WSI (g/100 g)	UBF	9.63 ± 0.38[b]	17.19 ± 1.25[a]	11.66 ± 1.22[b]	0.01
	GBF	21.28 ± 0.46[a]	16.16 ± 0.00[b]	13.18 ± 0.00[c]	0.002
	P^*	0.001	ns	ns	
Bd (g/mL)	UBF	0.67 ± 0.03	0.63 ± 0.01	0.63 ± 0.02	ns
	GBF	0.69 ± 0.02[a]	0.68 ± 0.01[a]	0.62 ± 0.01[b]	0.04
	P^*	ns	ns	ns	

[a] P^{**}, level of significance following one-way analysis of variance. Means in a row not sharing a common superscript are significantly ($P < 0.05$) different as determined by Duncan multiple range test. ns= no significant difference. [b] P^*, level of significant difference between germinated and ungerminated flour.

maximum amount of water ($Q/2$) was generally shorter for germinated than for ungerminated bean flour. Flours obtained from germinated seeds hydrated more rapidly than those from ungerminated seeds. Although flour of finer particle size would be expected to have a larger surface area in contact with water, an inverse relationship was observed to exist between particle size and Q. The increase in Q with increase in bean flour particle size is similar to that reported by McWatters (*26*) working on cowpea flour. Bean flours obtained from grains dried at higher temperatures rehydrated relatively much more rapidly but had a low WAC than flours dried at low temperatures. This may be due to the fact that increasing the drying temperature augments the hydrophobic properties of the bean proteins. The WAC, Q, estimated by the kinetic method for the different flours and particle size was highly correlated ($P < 0.001$) with that obtained by the gravimetric method of Beuchat (*13*).

The other functional properties of the different flours are as shown in Table 4. The WAC of ungerminated bean flour was consistently higher than that of flours from germinated beans. This observation is in agreement with the results of other studies, which showed that germination leads to a decrease in the WAC of flours (*27*). In the present study, the decrease was inversely related to the drying temperature of the beans. The OAC of germinated bean flour was equally higher than that of ungerminated bean flours and varied significantly ($P < 0.01$) with drying temperature.

The germination of beans has also been reported to enhance the OAC of the flours produced from it (*27*). The mechanism of oil absorption may be explained as a physical entrapment of oil related to the nonpolar side chains of proteins. As a result, the protein content and in particular its nonpolar amino acid concentration as well as its sequence of its polypeptide chains and conformational features all contribute to the oil-retaining properties of food materials. Any processing method that influences these parameters would tend to influence the oil absorption characteristics of the food system. The observed effect of germination and drying temperature suggests that these factors influence the nature of proteins in the beans.

Generally, the WAC of the flours was systematically higher than their OAC. As a result, the ratio of WAC to OAC, described here as the hydrophilic/lipophilic index (HLI), was >2 in all cases. This value was significantly different from that of 1.12 obtained for cowpea flour. It is important to point out that cowpea is the ideal ingredient commonly used for the preparation of food emulsion from which foods such as akara are obtained. On the whole, HLI decreased with an increase in grain drying temperature. This was evident because an increase in drying temperature had been observed to be accompanied by a relatively higher WAC than OAC. Also, because germination influenced the OAC of flours, the HLI of germinated flours was relatively lower than that of flours obtained from ungerminated beans. In particular, flours obtained from germinated seeds dried at 40 or 60 °C had significantly lower HLI values than flours obtained from ungerminated seeds dried in similar conditions.

Although germination affected HLI, it did not have any important influence on the Ea. On the contrary, it had an effect on Es. Both the Ea and Es varied significantly ($P < 0.001$) with drying temperature. An oil-in-water emulsion is a two-phase system in which a hydrophobic phase (oil droplets) is surrounded by a continuous aqueous phase. Once formed, the droplets in the emulsion are stabilized by a protein film at the interface. In this respect, it seems that the presence of soluble proteins will favor emulsion stability. The differences observed in the stability of the emulsion containing flours made from germinated and ungerminated beans may, partly, be due to the differences in their respective soluble protein contents. Generally the WSI of germinated bean flours was higher than that of flours produced from ungerminated beans. Similar observations have been reported for fluted pumpkins (*27*).

Bulk Density. The average Bd of flours obtained from ungerminated beans (UBF) was higher than that of germinated bean flours (GBF). Bd values for UBF

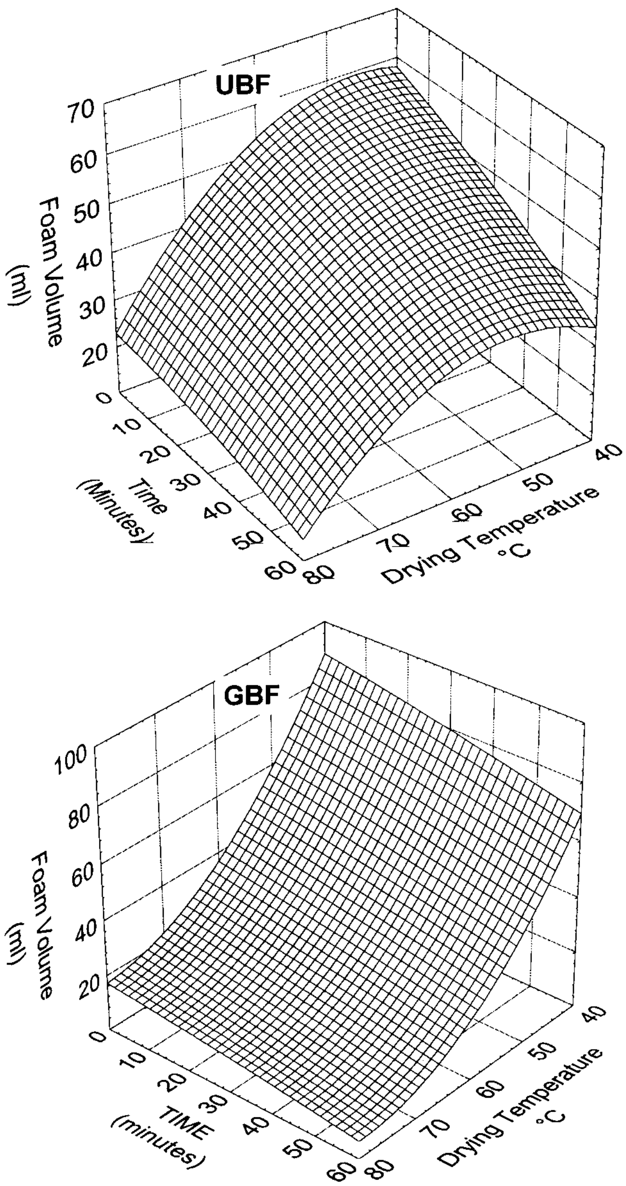

Figure 2. Response surface plot of the effect of drying temperature on the Fc and Fs of UBF and GBF.

ranged between 0.63 and 0.69 g/mL, whereas those for GBF ranged from 0.61 to 0.63 g/mL. In general, germination was accompanied by a 7.23% reduction ($P < 0.05$) in bean flour Bd. Unlike for flours obtained from ungerminated bean seeds, the Bd of flours obtained from germinated seeds varied significantly ($P < 0.004$) with drying temperature. In all cases, an inverse relationship was observed between Bd and drying temperature.

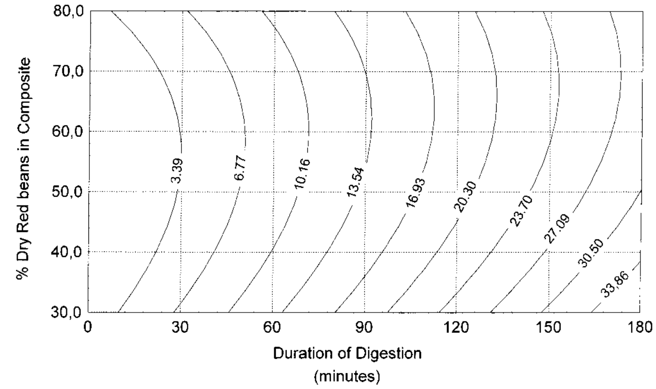

Figure 3. Contour plot of the effect of dry bean content of composite flour on the changes in in vitro protein digestibility (percent) with time.

Foaming Properties. The Fc and Fs of flours decreased with increases in temperature (Figure 2). Similar observations have been reported for several varieties of African yam bean (*28*). Although flour obtained from germinated beans had higher Fc and Fs values than that produced from ungerminated beans, the latter seemed to have better stability. Stable foams are known to occur when low surface tension and high viscosity occur at the interface, forming a continuous cohesive film around the air vacuoles in the foam. Germination of beans probably affects the viscosity, its proteins, and hence its foaming properties.

Composite Flours. The incorporation of various levels of cowpea flour and a constant level of soybean flour into germinated bean flour significantly influenced its nutritional and functional properties (Table 5). The composite flours obtained at the various combination levels were generally significantly higher in protein content than the base GBF. In vitro protein digestibility was observed to be influenced by the dry bean content of composite and increased with duration of digestion (Figure 3). In general, the rate of protein digestion decreased with an increase in dry bean content of the composite up to 60%, after which there was a reverse trend. Although the exact reason for this pattern of behavior may not be readily explained, the change in the relative proportion of the individual native proteins of the different legumes in the composite may partially be responsible. The WAC of the composite flour increased with an increase in the GBF content. Deshpande et al. (*29*), working on bean−wheat composite flours, had also made similar observations. Incorporation of cowpea and soybean flours into GBF significantly reduced its WAC. On the other hand, the WSI varied significantly ($P < 0.001$) with the GBF content of the

Table 5. Composition and Functional Characteristics (Means ± SD) of Bean Composite Flour

characteristic	% germinated bean flour						P^{*a}
	30	40	50	60	70	80	
protein (g/100 g)	28.62 ± 1.03[a]	25.86 ± 0.34[c]	26.90 ± 0.01[b]	27.59 ± 0.01[a]	26.21 ± 0.69[bc]	26.55 ± 0.34[bc]	0.01
available carbohydrate (g/100 g)	57.67 ± 1.48[b]	62.10 ± 0.01[a]	48.79 ± 1.48[c]	51.75 ± 1.48[c]	53.23 ± 2.96[c]	59.14 ± 0.01[b]	0.01
WAC (g/100 g)	114.71 ± 0.73[f]	120.26 ± 1.39[e]	131.06 ± 0.44[d]	133.91 ± 0.86[c]	141.87 ± 0.19[b]	153.52 ± 1.13[a]	0.03
OAC (g/100 g)	133.98 ± 1.39[a]	129.81 ± 4.94[a]	112.38 ±10.78[b]	81.56 ± 1.56[c]	77.27 ± 6.85[c]	69.89 ± 3.38[c]	0.001
HLI	0.86 ± 0.00[d]	0.93 ± 0.02[d]	1.17 ± 0.11[c]	1.64 ± 0.04[b]	1.84 ± 0.17[b]	2.20 ± 0.12[a]	0.001
WSI (g/100 g)	26.14 ± 1.02[a]	24.53 ± 0.33[b]	21.41 ± 0.06[c]	21.38 ± 0.38[c]	20.87 ± 0.04[c]	19.65 ± 0.69[d]	0.001
Fc (mL/100 mL)	97.5 ± 6.4[a]	93.0 ± 4.2[a]	59.0 ± 26.9[b]	85.0 ± 7.1[ab]	58.0 ± 11.3[b]	75.0 ± 7.1[ab]	0.05
Ea (mL/100 mL)	44.1 ± 1.6	43.6 ± 2.4	42.3 ± 1.3	44.2 ± 3.3	44.2 ± 3.3	45.4 ± 1.6	0.90
Es (mL/100 mL)	42.1 ± 0.4[b]	42.9 ± 0.8[b]	46.4 ± 0.1[b]	45.9 ± 5.8[b]	54.1 ± 3.3[a]	53.3 ± 0.5[a]	0.01

[a] P^*, level of significance following one-way analysis of variance. Means in a row not sharing a common superscript are significantly ($P < 0.05$) different as determined by Duncan's multiple-range test.

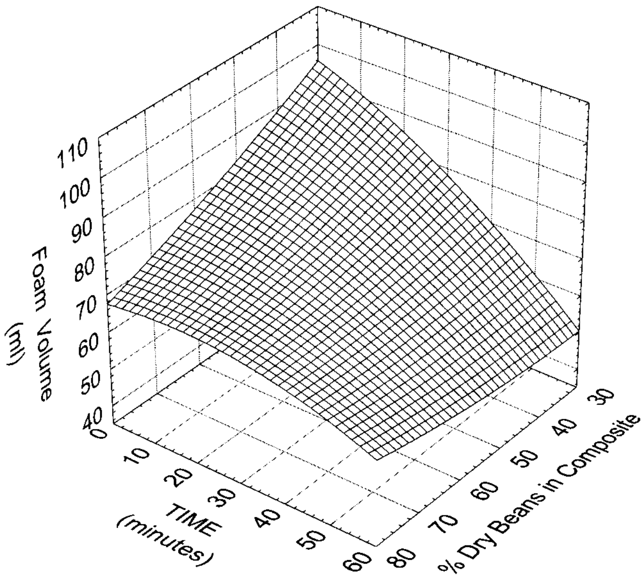

Figure 4. Response surface plot of the effect of GBF content on the Fc and Fs of composite flour.

composite flour. In general, WSI decreased with an increase in the GBF content of the composite. Cowpea is the ideal ingredient for the production of such quick foods as akara and koki (*5*, *6*). Composite legume flour intended for the same product should not have a WSI much different from that of cowpea. Except for the composite flour, BCSF1, containing 30% GBF, for which the WSI was significantly much higher than that of cowpea (26.14 versus 21.46; $P < 0.05$), all other composite flours (BSCF2, BSCF3, BSCF4, BSCF5, and BSCF6) were not significantly different from that of cowpea flour.

Generally, the OAC values of composite flours were inversely related to their GBF content. The OAC of the composite flours containing up to 60% GBF was not significantly different from that of cowpea flour. The HLI increased with an increase in the GBF content of the composite ($r = 0.774$; $P < 0.001$). Using the linear regression equation which relates these two factors, it was estimated that a composite flour containing between 53 and 57% GBF had relatively the same HLI properties as cowpea. This observation indicates the potential of cowpea and soybean as enhancers of the functional properties of GBF.

Changes in the GBF content of composite flour did not significantly influence its Es. They did, however, affect its Es (Table 5). Es decreased with the GBF content of the composite flour. The WSI of cowpea is significantly much higher than that of GBF. The observation of an inverse relationship between WSI and Es ($r = -0.68$; $P < 0.01$) may thus be related to the effect of changing cowpea content (compared to that of GBF) on its WSI. Composite flours with high HLI possessed better emulsion stability than those with lower HLI ($r = 0.80$; $P < 0.001$).

As observed in the case of emulsion properties, the whipping properties of the composite flours were observed to be a function of its WSI. Fc and Fs changed with an increase in the GBF content (Figure 4). However, no differences were observed in the stability of foams produced by composites containing as much as 60% GBF.

On the whole, germination and the temperature of drying of red beans were observed to influence the nutritional and functional properties of flours produced from such beans. On average, germinated beans dried at a temperature of 60 °C produced flours of better nutritional and functional properties as compared to those obtained from either ungerminated beans or germinated beans dried at lower temperatures. The particle size of flours was an equally important influencing factor on the rate of water absorption by bean flours. Incorporation of cowpea and soybean flours into GBF further improved its functional properties. A composite flour containing up to 60% GBF, 30% cowpea, and 10% soybean showed good functional properties and as such constitutes a potential good ingredient for the production of food products commonly made from whole cowpea flours. The performance of this composite in the preparation of some of these foods is currently being evaluated.

ABBREVIATIONS USED

GBF, germinated bean flour; UBF, ungerminated bean flour; WAC, water absorption capacity (estimated by gravimetric method); OAC, oil absorption capacity; HLI, hydrophilic/lipophilic index; Ea, emulsion activity; Es, emulsion stability; WSI, water solubility index; Bd, bulk density; Fc, foaming capacity; Fs, foaming stability; *Q*, maximum water uptake.

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