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WATER ABSORPTION AND SWELLING IN DRY BEAN SEEDS

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ABSTRACT

A modified first-order reaction model composed of an initial linear phase followed by a diffusion-controlled phase closely predicted water absorption and swelling in several varieties of fresh and stored beans. Dehulling resulted in increased rates of water absorption, but equilibrium values for both water absorption and swelling were reduced as a result of elimination of the water held between the seed coat and the cotyledons as well as between the cotyledons. Swelling of dehulled seeds was reduced initially, since the seed coat swells faster than the cotyledons in the initial stages of water uptake. Addition of carbonate salt to the soaking solution generally reduced water absorption and swelling. The hard-to-cook defect was manifested by reductions in the rates of water uptake and diminished effects of dehulling and salt soaking on water absorption and swelling. Water absorption was significantly and negatively correlated with cooked bean hardness.

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INTRODUCTION

The rate of water uptake of a bean seed sample during soaking in water is determined by the product of two quantities, namely a proportionality factor and a driving force. When the imbibition process is described by Darcy's law of hydraulic flow, the proportionality factor is the hydraulic conductivity coefficient, whereas the driving force is the difference in water potential (Ψ) between the soaking medium and cotyledon cells (Bewley and Black 1985; Woodstock 1988; Vertucci 1989). The Ψ of the soaking solution decreases as the concentration of added solutes increases. Cellular Ψ, on the other hand, is affected by three components; namely the osmotic (Ψ_π), matric (Ψ_m), and pressure (A_p) potentials. Ψ_π and Ψ_m decrease as a result of binding of water by dissolved solutes or macromolecules of cell walls, starch granules, and protein bodies, respectively. Ψ_p increases as the force exerted by the cell wall on cell contents increases to counteract water imbibition-associated swelling.

The imbibition process can be also described by using Fick's law of diffusion, in which water uptake follows a gradient in moisture along the seed and is proportional to the diffusion coefficient or diffusivity of water (Vertucci 1989). Water diffusivity, a complex function of the microstructure, chemical composition, moisture, and temperature of the seed, is thought to determine the rate of water uptake during soaking (Vertucci 1989). Microstructural features such a thin seed coat, seed coat pores, large and open micropyle and hilum, loose cellular arrangement of raphe and narrow tracheid bar tend to increase imbibition rates of beans (Deshpande and Cheryan 1986; Agbo *et al.* 1987). Seed coat composition may also affect imbibition rates. Dark-colored seed coats were reported to be less permeable to water than light-colored ones, probably as a result of oxidative reactions of phenolic substrates resulting in hydrophobic substances (Marbach and Mayer 1974, 1975; Tully *et al.* 1981).

It is reasonable to expect a reduced water uptake of hard-to-cook (HTC, manifested by a reduced softening rate during cooking as compared to nondefective samples) beans as compared to unaffected samples during soaking due to the strengthening of cell walls (Hincks and Stanley 1987) and degradation of cellular membranes (Richardson and Stanley 1991) associated with development of the HTC defect. These would result in increased mechanical resistance to cellular swelling and reduced water binding capacity of dissolved solutes due to leakage into the soaking medium, respectively. Both of these two effects lead to an increased water potential. Previous work in this laboratory (Plhak *et al.* 1989) indicated that measurements of water uptake in beans using traditional gravimetric and volumetric methods are inadequate for assessing the HTC defect of beans. Water-holding capacity (WHC), the alternative method developed by Plhak *et al.* (1989), on the other hand, provided a more reliable measure of water

taken up by the cotyledon than the former methods because of the elimination of a layer of bulk water that collects between the seed coat and the cotyledons. These authors felt that an alternative to the traditional water displacement method would have been required to accurately measure bean swelling during soaking in this study.

García-Vela *et al.* (1991) indicated that the HTC defect of beans was partially alleviated by soaking in an aqueous carbonate salt solution. This was explained as due to the destabilizing effect of carbonate ions on the structure of storage proteins that favored thermal denaturation and subsequent softening during cooking. The effect of added carbonate salt on water relations in beans soaked in aqueous solutions, however, was not studied by these authors.

The main objective of this work was to expand the study of Phlak *et al.* (1989) so as to further clarify the role of the HTC defect on water absorption and swelling of bean cotyledons. Soft and HTC bean seeds of different color were utilized to isolate varietal effects. Since dehulling prior to soaking would be expected to isolate differences in cotyledonary rather than bulk water uptake between HTC and nondefective beans, seed coat removal was employed as a treatment. Addition of carbonate salt to soaking water was also included as a treatment to establish the effect of carbonate ions on water uptake.

THEORETICAL CONSIDERATIONS

Hsu (1983) proposed a theoretical model for water diffusion in cotyledons that took into account the resistance of seed coats to water imbibition by assuming a gradual increase in surface moisture (first order process). This model also assumed an exponential increase in diffusivity with moisture to conform with experimental observations. This increase in diffusivity may have resulted from microstructural modifications of cotyledons due to water imbibition and swelling of cell contents.

Schwartzberg and Chao (1982) reviewed the mathematics of diffusional processes in food materials. Experimental data for the final stages of diffusion-controlled mass transfer processes fit a linear relationship between logarithm of dimensionless concentration [$C = (c - c_o)/(c_e - c_o)$] and time (t). Both the intercept of the line with the vertical axis (C_i) and its slope, which is proportional to the diffusion coefficient (D_s), depend on the geometry of the solid. A similar functional relationship between ln(c) and t applies for chemical reactions controlled by first-order kinetics, in which case C_i is zero. Modified ($C_i \neq 0$) chemical reaction models can also account for concentration-dependent diffusion coefficients. For example, the following functional relationship between D_s and k, the reaction rate constant, applies for n-order reaction kinetics in a spherical body of diameter D_p:

$$D_s = \frac{k D_p^2 (c_e - c)^{n-1}}{4\pi^2} \quad [1]$$

A n-order kinetic model for chemical reactions was adapted to simulate water absorption (WA) of beans as a function of soaking time (t). The model was:

$$WA = W_e - (W_e - W_i) \sqrt[n-1]{[1 - k_w (1 - n) (W_e - W_i)^{n-1} t]^n} \quad [2a]$$

$$WA = W_e - (W_e - W_i) \exp(-k_w t) \quad [2b]$$

for $n \neq 1$ and $n = 1$, respectively, where W_i and W_e denote pseudoinitial and equilibrium WA, respectively.

A similar model but with WA, W_i, W_e, and k_w replaced by S, S_i, S_e, and k_s, respectively, was employed to simulate transient changes in swelling (S) of beans during soaking. In addition, linear relationships between model parameters and bean size (D_p) were investigated, i.e.:

$$S_i = S_{ia} + \alpha (D_p - D_{pa}) \quad [3a]$$

$$S_e = S_{ea} + \beta (D_p - D_{pa}) \quad [3b]$$

$$k_s = k_{sa} + \gamma (D_p - D_{pa}) \quad [3c]$$

The pseudoinitial condition was incorporated into the model to account for an initial period ($\leqslant$ 1–2 h soaking) in which WA and S were slower than predicted by the kinetic model. This transient period was modelled assuming that the initial variation in either WA or S was proportional to t, e.g.:

$$WA = (mi)_w t \quad [4]$$

where $(m_i)_w$ represents the initial ($t \leqslant t_t$) rate for WA. Values of t_t, the time limit for the zero-order or straight line portion of the curve, and $(m_i)_w$ were estimated assuming that the rate of change in WA at the beginning of the period in which the kinetic model applied equaled the transient rate $(m_i)_w$, e.g., for $n = 1$:

$$(1 + k_w t_t) \exp(-k_w t_t) = \frac{W_e}{W_e - W_i} \quad [5a]$$

$$(m_i)_w = k_w (W_e - W_i) \exp(-k_w t_t) \quad [5b]$$

A similar model but with WA, W_i, W_e, k_w, and $(m_i)_w$ replaced by S, S_i, S_e, k_s, and $(m_i)_s$, respectively, was employed to simulate initial changes in S during soaking.

MATERIALS AND METHODS

Beans

Nonstored (fresh) dry bean seeds used in these studies consisted of *Phaseolus vulgaris* varieties Seaforth (white beans), Black turtle (black beans) and Redkloud (red kidney beans) from the 1989 harvest which were obtained from Agway Inc., Geneva, NY. Stored beans consisted of Ontario-grown white bean samples (*Phaseolus vulgaris*, var. OAC Rico) from the 1987 crop which were stored in controlled environment chambers for 1 year at either LL conditions (low temperature, 15C, and low humidity, 35% RH), to minimize storage-induced changes (soft or control samples), or at HH conditions (high temperature, 30C, and high humidity, 85% RH), to promote the HTC defect (hard or HTC samples). Soft and hard black beans (*Phaseolus vulgaris*, var. Orfeo) from the 1988 crop were supplied by the Catholic University of Chile, Santiago, Chile. These beans had been also stored under LL and HH conditions for one year. Fresh and HTC samples were placed under LL conditions prior to sample analysis. Both hulled (H) and dehulled (D) samples were utilized in this study. Dehulling was performed manually.

Soaking and Cooking

Approximately 15 g of beans (weighed accurately) were soaked in 75 mL of deionized water for 18 h prior to boiling for 30 min in 150 mL of deionized water (including soaking solution). The cooking solution was discarded and the beans were allowed to adjust to room temperature (approximately 20C) for 1 h. Cooked samples were weighed accurately and water absorption (WA_c) estimated as:

$$WA_c = \frac{w_c - w_o}{w_o} \qquad [6]$$

where w_o and w_c are the weights of the unsoaked and cooked sample, respectively.

Approximately 30 g of cooked beans (weighed accurately) were then used to determine cooked hardness (H_c) with a M5K Tensile Testing Machine (J.J. Lloyd Instruments, Hamilton, Ont.) equipped with a 10 cm^2 Ottawa Texture Measuring System cell (García-Vela

Water Absorption

Distilled water (DW) and a salt solution (SS = 0.1% $NaHCO_3$ + 2.5% K_2CO_3/pH 11) were utilized. Approximately 5 g (weighed accurately) of H or D beans were placed in 100 mL beakers together with 27 mL of either soaking

solution. Following 1, 2, 4 or 8 h soaking time, beans were removed from the soaking solution, blotted dry, weighed accurately and placed back in the soaking solution ($\leqslant$ 3 min/sample). WA was calculated as:

$$WA = \frac{w - w_o}{w_o} \quad [7]$$

where w is the weight of the soaked sample. Duplicate determinations of WA during soaking were performed.

Swelling

Samples of 60 H or 48 D bean were placed in separate 5 mL wells in a 100-well germination tray, which was then filled with DW or SS. The tray with a reference length indicator and a thermometer was placed in a controlled environment chamber at 20C and photographed initially and following 1, 2, 4 and 8 h soaking time. A Zidas image analysis system (Zeiss Inc., Oberkochen, West Germany) was utilized to measure changes in cross-sectional area (A) and perimeter (P) of each sample. Each photograph was analyzed by two operators and averaged.

Area-based estimates of bean diameter [$D_p = 2(A/\pi)^{0.5}$] and volume [$V = 1.333(A^3/\pi)^{0.5}$] were calculated assuming a spherical geometry. The coefficient of variation of volume estimates was $\leqslant$ 20% for every bean and was usually smaller than the percent error of perimeter-based volume estimates ($V = 0.167\ P^3/\pi^2$). S was defined as:

$$S = \frac{V - V_o}{V_o} \quad [8]$$

where V_o is the initial sample volume. Samples which had S values $\leqslant$ 0.10 after 8 h of soaking were assumed to have the hardshall (HS) defect and were disregarded. Beans that tumbled in the well between measurements of projected cross section area had anomalous swelling profiles and were also eliminated. S of these anomalous samples differed considerably from predicted values and were readily discernable as outliers in plots of model residuals. Prior to sample elimination, photographs were visually inspected to confirm the HS defect or tumbling during the experiment. Overall, the rejects represented ca. 5% of the bean samples. Data for swelling of whole black beans soaked in salt solution were not obtained, since the solution extracted polyphenolics that rendered the solution opaque. Duplicate determinations of S during soaking were performed.

Adjustment of Model Parameters

Parameters for the prediction of transient changes in WA during soaking according to the modified chemical reaction model (Eq. 2) were estimated by using

a nonlinear iterative regression procedure, the modified Gauss-Newton method, in a Statistical Analysis System package (SAS Institute 1982). In this method, the residuals on the partial derivatives of the model with respect to the model parameters were regressed iteratively until a convergence criterion was met. Convergence was assumed when the reduction in the sum of squares of the error term (SSE) was less than $10^{-6}\%$ in an iteration. The same method was utilized to estimate model parameters for the prediction of changes in S, but in this case W_i, W_e and k_w in Eq. (2) were replaced by $[S_{ia} + \alpha(D_p - D_{pa})]$, $[S_{ea} + \beta(D_p - D_{pa})]$, and $[k_{sa} + \gamma(D_p - D_{pa})]$, respectively. Values of $(m_i)_w$, $(m_{ia})_s$, and t_t for the modified first-order reaction model were determined by solving Eq. (5a) and (5b) simultaneously. Diffusivity values $[(D_{saw}, (D_{sa})_s]$, on the other hand, were calculated according to Eq. (1) based on the average size of the bean at equilibrium (D_{pe}), i.e.:

$$(D_{sa})_w = \frac{k_w D_{pe}^2}{4\pi^2} \quad [9a]$$

$$(D_{sa})_s = \frac{k_{sa} D_{pe}^2}{4\pi^2} \quad [9b]$$

$$D_{pe} = D_{pa} \sqrt[3]{1 + S_{ea}} \quad [9c]$$

Statistical Analysis

The statistical significance of particular terms in the models for the prediction of transient changes in WA and S during soaking was tested by performing tests on F values, which followed a Fisher-Snedecor distribution.

The effects of bean color (Col), size (D_p), storage condition (SC) and pretreatment (Pr), and soaking solution (SkSl) were investigated by ANOVA, categorical and correlation analysis using a Statistical Analysis System package (SAS Institute 1982). Duncan's New Multiple Range test was utilized for multiple comparison among means.

RESULTS AND DISCUSSIONS

Sample Characterization and Incidence of Hardshell

General characteristics of the bean samples utilized in this study are presented in Table 1. The hardshell (HS) defect was not found in fresh beans. HS also did not occur in dehulled stored samples, an observation which supports the view that this is a seed coat-associated defect (Rolston 1978; Welker 1980; Bewley

TABLE 1.
CHARACTERISTICS OF WHOLE BEAN SEEDS

Bean Sample	Bean Diameter[1] (mm)	Hardshell (%)	Cooked Hardness (N)	Water Absorption (g water/g bean)
Fresh white	7.24^{e}	0.00	358^{d}	1.49^{b}
Soft white	7.12^{e}	2.96^{b}	310^{d}	1.58^{a}
Hard white	7.19^{e}	2.50^{b}	982^{b}	1.09^{e}
Fresh black	7.86^{d}	0.00	472^{c}	1.25^{c}
Soft black	8.15^{c}	10.42^{a}	305^{d}	1.43^{b}
Hard black	8.31^{b}	2.50^{b}	1173^{a}	1.17^{d}
Fresh kidney	11.26^{a}	0.00	341^{d}	1.28^{c}

[1]Diameters correspond to initial values (t = 0) for hulled bean samples soaked in distilled water. Different superscripted letters in the same column indicate significant ($P \leq .05$) differences using Duncan's New Multiple Range test.

and Black 1985). Soft black beans had the highest incidence of this defect. Figure 1 shows the size distributions and incidence of HS as a function of diameter for stored whole beans soaked in distilled water or salt solution. Soaking treatment did not have a significant influence on whether the HS beans would absorb water . Development of HS in white and black samples during storage did not depend significantly on diameter. This does not agree with Bourne's (1967) prior assessment that the defect is concentrated in smaller beans.

Modelling of Water Uptake Phenomena

The modified first-order reaction kinetic model best represented transient changes in water absorption and swelling during water uptake. For water absorption, the initial water absorption (W_i) was negative or did not differ significantly fro 0 for most samples. For swelling, the equilibrium values (S_e) depended significantly on bean diameter, but diameter did not significantly influence either the initial values (S_i) or the reaction rate constant (k_s). S_i was either slightly negative or did not differ significantly from 0 for most samples.

The reaction order for both water absorption and swelling ranged between 0.5 and 2.0 but did not significantly differ from 1.0 for most samples. The later stages in the water uptake process can thus be modelled as a diffusion-controlled process with constant diffusivity. Transient water absorption curves for stored white and black beans are presented in Fig. 2 and transient swelling curves are shown in Fig. 3. Values for the modified first-order kinetic model of these parameters for fresh as well as stored samples are given in Table 2. In the proposed model

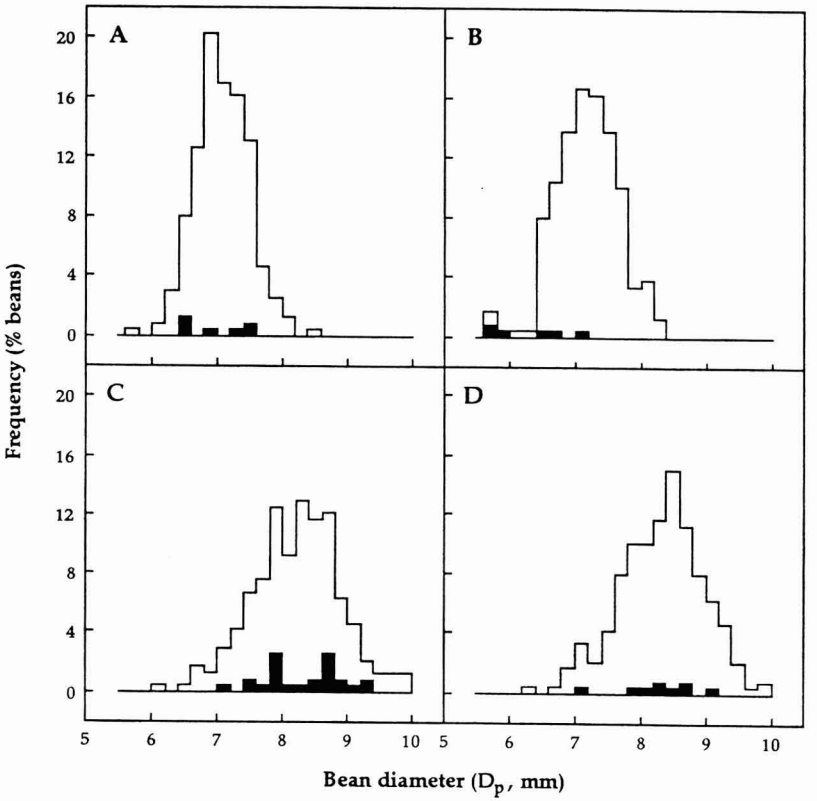

FIG. 1. SEED SIZE HISTOGRAMS FOR STORED BEANS
(A) Soft white; (B) hard white; (C) soft black; (D) hard black.
Shaded areas represent seed size histograms for hardshells.

$(m_i)_w$ and $(m_{ia})_s$ are directly proportional to the initial rates of change of water absorption and swelling, respectively. Similarly, $(D_{sa})_w$ and $(D_{sa})_s$ are related to transient changes in the diffusion-controlled stage of water uptake and W_e and S_{ea} are proportional to their respective equilibrium states. The duration of the transient, zero-order kinetics period (t_t) varied from 0 to 148 min for water absorption and 0 to 116 min for swelling, but no significant effect of experimental factors was found.

Vertucci (1989) summarized room temperature (25–30C) values of diffusion coefficients previously reported in the literature. These included $3.0 \times 10^{-3} - 4.0 \times 10^{-3}$ cm^2/h for favabean, $0.4 \times 10^{-3} - 3.0 \times 10^{-3}$ cm^2/h for soybean, $0.4 \times 10^{-3} - 0.9 \times 10^{-3}$ cm^2/h for cowpea and $10^{-12} - 10^{-4}$ cm^2/h for rapeseed. Diffusivity values reported in this study were typically larger than literature values. Differences may have been due to such factors as species, ex-

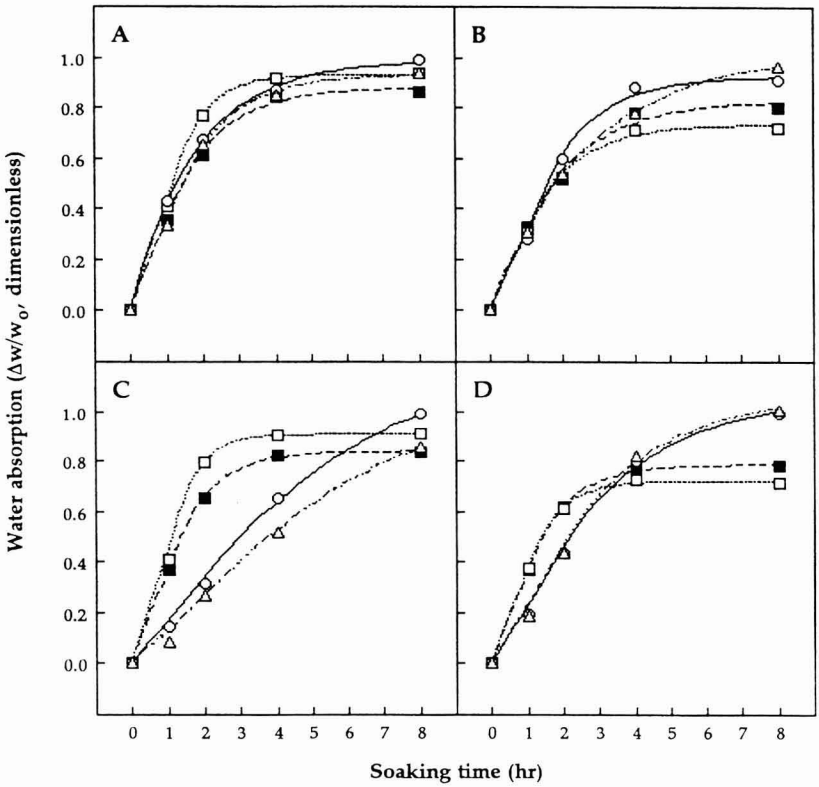

FIG. 2. TRANSIENT WATER ABSORPTION CURVES FOR STORED BEANS
(A) Soft white; (B) hard white; (C) soft black; (D) hard black. (○——○) Whole samples soaked in distilled water. (△——△) Whole samples soaked in salt solution. (□——□) Dehulled samples soaked in distilled water. (■——■) Dehulled samples soaked in salt solution. Symbols represent experimental data points; lines indicate values predicted by the modified first-order kinetic model.

perimental procedures (some of the literature values corresponded to water uptake from wetted soils) or seed moisture range. Various authors (Shaykewich and Williams 1971; Hsu 1983; Hsu *et al.* 1983; Vertucci 1989) have recognized that the diffusivity of water in seeds increases during soaking. One can estimate from the work of Hsu (1983) that the diffusion coefficient would increase from 2.8 $\times$ 10^{-3} cm^2/h, initially, to 9.3 $\times$ 10^{-3} cm^2/h, at near equilibrium conditions, during soaking of favabean at 30C. These values were estimated disregarding dimensional changes associated with swelling of the seed, which should not be discounted for water uptake by beans.

Although diffusion coefficients for swelling reported here do not have a physical meaning, they were useful since they allowed comparison of water absorption

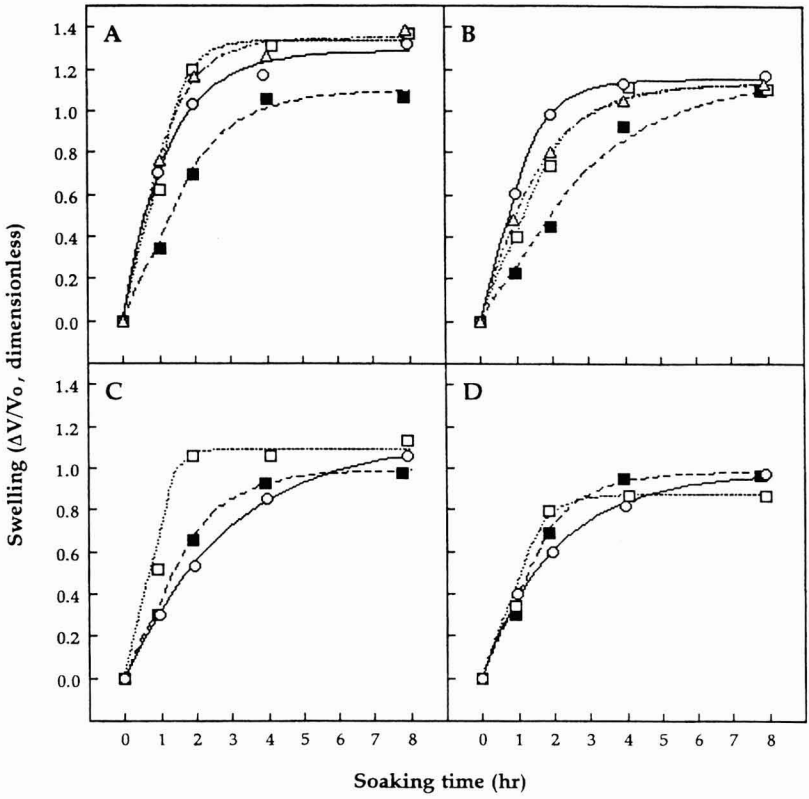

FIG. 3. TRANSIENT SWELLING CURVES FOR STORED BEANS
(A) Soft white; (B) hard white; (C) soft black; (D) hard black. (○——○) Whole samples soaked in distilled water. (△——△) Whole samples soaked in salt solution. (□——□) Dehulled samples soaked in distilled water. (■——■) Dehulled samples soaked in salt solution. Symbols represent experimental data points; lines indicate values predicted by the modified first-order kinetic model

and swelling in the diffusion-controlled stage of water uptake. Corresponding reaction rate constants ranged between 0.35 and 1.18 h^{-1} for whole samples soaked in distilled water. Leopold (1983) modelled transient changes in swelling of various seeds during soaking in water using an unmodified ($S_i = 0$) first-order kinetic model and reaction rate constants ranged between 0.09 h^{-1} for castor bean and 0.42 h^{-1} for cowpea.

Water Absorption

A summary ANOVA table detailing the dependence of the main kinetic parameters of water absorption on experimental factors and their interactions is

TABLE 2.
KINETIC PARAMETERS OF MODIFIED FIRST ORDER KINETIC MODEL FOR WATER ABSORPTION AND SWELLING OF FRESH AND STORED BEAN SAMPLES AS A FUNCTION OF EXPERIMENTAL FACTORS

			Water absorption				Swelling				
Bean Sample	Sample Treat	Soak Soln	$(m_i)_w$ g water/g/min $\times 10^{-3}$	t_t min	$(D_{sa})_w$ cm^2/h $\times 10^{-3}$	W_e g water/g	$(m_{ia})_s$ min^{-1} $\times 10^{-3}$	t_t min	$(D_{sa})_s$ cm^2/h $\times 10^{-3}$	S_{ea} dimension-less	β mm^{-1}
Fresh beans											
White	H[1]	DW[2]	10.95^{a}	0	17.4^{b}	$0.877^{b..e}$	16.99^{a}	0	18.2^{ab}	1.300^{a}	-0.335
White	H	SS[3]	7.43^{bc}	46	20.3^{ab}	$0.855^{b..d}$	16.35^{a}	0	19.2^{ab}	1.191^{ab}	-0.406
White	D[4]	DW	$6.26^{b..e}$	70	20.0^{ab}	0.778^{ef}	7.46^{b}	92	22.6^{ab}	1.039^{bc}	-0.137
White	D	SS	$5.94^{b..e}$	34	11.4^{cd}	0.745^{f}	6.04^{b}	59	10.1^{b}	$0.974^{b..d}$	-0.208
Black	H	DW	$5.14^{c..e}$	0	8.3^{d}	0.917^{bc}	16.74^{a}	0	25.6^{ab}	$0.964^{b..d}$	-0.185
Black	H	SS	$5.28^{b..e}$	75	ND[5]	$0.852^{b..e}$	-[6]	-	-	-	-
Black	D	DW	$7.09^{b..d}$	75	25.5^{a}	$0.855^{b..e}$	8.66^{b}	75	31.5^{a}	$0.976^{b..d}$	-0.230
Black	D	SS	$6.30^{b..e}$	65	16.9^{bc}	$0.809^{c..f}$	5.02^{b}	89	13.2^{b}	0.855^{cd}	-0.129
Kidney	H	DW	3.82^{e}	134	24.7^{a}	0.942^{b}	6.17^{b}	0	23.2^{ab}	0.741^{d}	-0.070
Kidney	H	SS	4.26^{de}	148	24.0^{a}	1.090^{a}	4.72^{b}	52	20.4^{ab}	0.845^{cd}	-0.159
Kidney	D	DW	8.39^{ab}	0	20.8^{ab}	$0.868^{b..e}$	5.93^{b}	72	34.5^{a}	0.797^{cd}	-0.107
Kidney	D	SS	$6.44^{b..e}$	37	22.1^{ab}	$0.785^{d..f}$	4.26^{b}	77	20.5^{ab}	0.714^{d}	-0.081
Stored beans											
Soft white	H	DW	9.25^{a}	0	12.5^{ef}	$0.988^{b..d}$	17.18^{a}	0	$17.1^{d..f}$	1.287^{ab}	-0.395
Soft white	H	SS	$5.81^{b..e}$	76	15.7^{de}	$0.932^{c..e}$	13.13^{a}	45	$22.8^{c..e}$	1.350^{a}	-0.353
Soft white	D	DW	$7.20^{a..c}$	78	20.8^{c}	$0.931^{c..e}$	11.52^{b}	82	30.9^{c}	1.339^{a}	-0.448
Soft white	D	SS	$5.86^{b..e}$	68	12.6^{eg}	$0.878^{d..f}$	6.27^{de}	93	12.5^{fg}	1.099^{cd}	-0.395
Hard white	H	DW	$5.28^{c..f}$	93	16.1^{de}	$0.924^{c..e}$	10.57^{b}	58	25.8^{cd}	1.153^{bc}	-0.360
Hard white	H	SS	$6.25^{b..e}$	0	7.9^{gh}	1.017^{bc}	8.53^{bc}	45	$14.7^{e..g}$	1.134^{bc}	-0.342
Hard white	D	DW	$5.10^{d..f}$	65	13.7^{ef}	0.735^{g}	$6.96^{c..e}$	86	14.0^{fg}	1.132^{bc}	-0.348
Hard white	D	SS	$5.30^{c..f}$	55	10.8^{fg}	$0.828^{e..g}$	4.26^{e}	116	7.0^{g}	1.161^{bc}	-0.227
Soft black	H	DW	2.83^{g}	142	5.3^{h}	1.302^{a}	5.42^{de}	36	9.6^{fg}	1.136^{bc}	-0.068
Soft black	H	SS	12.24^{g}	176	ND	1.215^{a}	-	-	-	-	-
Soft black	D	DW	7.54^{ab}	80	34.8^{a}	$0.907^{c..f}$	11.67^{b}	74	72.5^{a}	1.090^{cd}	-0.241
Soft black	D	SS	$6.25^{b..d}$	72	20.3^{cd}	$0.839^{e..g}$	6.13^{de}	82	$16.0^{e..g}$	0.990^{de}	-0.187
Hard black	H	DW	3.83^{fg}	119	10.4^{fg}	1.063^{b}	8.03^{cd}	0	13.6^{fg}	0.979^{de}	-0.178
Hard black	H	SS	$3.88^{e..g}$	124	ND	1.069^{b}	-	-	-	-	-
Hard black	D	DW	$6.30^{b..d}$	64	26.3^{b}	0.723^{g}	7.69^{cd}	77	36.1^{b}	0.876^{e}	-0.246
Hard black	D	SS	$6.13^{b..d}$	64	20.2^{cd}	0.786^{fg}	6.49^{de}	83	$18.9^{d..f}$	0.983^{de}	-0.112

[1]Hulled bean
[2]Distilled water
[3]Salt solution
[4]Dehulled bean
[5]Nondeterminable
[6]Missing data point
Different superscripted letters in the same column within fresh and stored data indicate significant ($P \leq .05$) differences using Duncan's New Multiple Range test.

presented in Table 3. Generally similar effects were seen for fresh and stored samples. There was a significant effect of sample variety on initial water absorption rate for stored beans but not for fresh samples, with white beans being more absorptive than black ones. This may indicate a preferential permeability to water of white bean seed coats as compared to those of black beans. Both Deshpande

TABLE 3.
SUMMARY ANOVA TABLE FOR DEPENDENCE OF MAIN KINETIC PARAMETERS OF MODIFIED FIRST ORDER KINETIC MODEL FOR WATER ABSORPTION AND SWELLING OF FRESH AND STORED BEAN SAMPLES ON EXPERIMENTAL FACTORS AND THEIR INTERACTIONS

	Water Absorption				Swelling			
Factor	df[1]	$(m_i)_w$	$(D_{sa})_w$	W_e	df[1]	$(m_{ia})_s$	$(D_{sa})_s$	S_{ea}
Fresh Beans								
Color (Col)	2	5.42*[2]	10.30**	7.53**	2	0.32	0.40	2.44
Pretreat. (Pr)	1	0.91	2.25	30.56**	1	5.84*	0.02	1.40
Soak. sol. (SkSl)	1	2.30	3.01	0.17	1	6.71*	4.13	1.40
Bean size (D_p)	-[3]	-	-	-	1	1.30	0.00	0.51
Col x Pr	2	12.62**	9.53**	3.80*	2	1.34	0.20	0.82
Col x SkSl	2	0.69	1.22	1.17	2	0.29	0.52	0.02
Pr x SkSl	1	0.04	2.62	4.39	1	0.14	2.43	0.61
Error[4]	14[5]				11			
Stored Beans								
Col	1	16.15**	20.34**	19.00**	1	0.35	0.06	12.03**
Stor. cond. (SC)	1	3.80	3.96	28.23**	1	2.57	0.78	0.66
Pr	1	21.87**	36.90**	127.39**	1	4.94*	1.98	26.61**
SkSl	1	4.93*	8.36*	0.06	1	9.41**	26.42**	3.99
D_p	-[3]	-	-	-	1	2.27	0.14	20.37**
Col x SC	1	9.22**	0.72	7.12*	1	10.60**	0.97	0.49
Col x Pr	1	39.69**	52.81**	32.90**	1	19.79**	42.13**	1.13
Col x SkSl	1	0.37	5.11*	0.34	1	0.30	10.17**	1.89
SC x Pr	1	1.96	4.13	0.08	1	0.08	6.11*	1.59
SC x SkSl	1	7.87*	0.00	6.72*	1	0.52	0.84	1.94
Pr x SkSl	1	0.00	0.84	0.02	1	0.81	1.89	0.62
Error[4]	21[6]				16			

[1] degrees of freedom (df) of numerator unless otherwise specified
[2] * = significant effect at P≤.05 level; ** = significant effect at P≤.01 level
[3] factor not included in study
[4] df of denominator
[5] 11 df for tests on $(D_s)_w$
[6] 16 df for tests on $(D_s)_w$

and Cheryan (1986) and Agbo *et al.* (1987) found that white beans imbibed water faster than black samples during 2 h soaking. The diffusion coefficient and equilibrium water absorption were influenced significantly by bean variety for both stored and fresh samples. Black beans absorbed water at a rate and to an

extent intermediate between white beans (smallest) and red beans (largest). Stanley *et al.* (1990) found that phenol content, highly correlated with seed coat color, was the most important factor influencing water absorption in fresh and aged bean seeds and concluded that darker stored cultivars may absorb more water but tend to bind less of it to the cellular structure.

As expected, dehulling generally caused a significant increase in initial water absorption. Sample dehulling also caused a significant increase in the diffusion coefficient for stored beans but not for fresh samples. The influence of dehulling, however, depended significantly on sample variety. The effect of dehulling on water absorption during the diffusion-controlled stage was more pronounced for black than for white beans. Transverse cracks resulting from mechanical stresses caused by fast water uptake and associated swelling of cotyledons (Spaeth 1986) can facilitate water transport into the cotyledons and increase the diffusion coefficient. Transverse cracking has been observed to be more limited in whole than dehulled seeds (Simon 1984), due probably to decreased initial rates of water uptake and/or mechanical restrictions to swelling of cotyledons imposed by seed coats.

Dehulling produced a significant decrease in equilibrium water absorption, but this effect was significantly more pronounced for stored black than white beans. This likely resulted from the water collected in the free space between the seed coat and the cotyledons (Plhak *et al.* 1989) and the cavity formed between adaxial cotyledon surfaces in whole beans (Bourne 1967). Losses of proteins as a result of transverse cracking of cotyledons (Spaeth 1987; Spaeth and Hughes 1987) may cause reductions in water binding capacity and be partially responsible for decreases in water absorption of dehulled beans. Singh and Kulshrestha (1987) and Sopade and Obekpa (1990) investigated water absorption in soybean and peanut, respectively, and reported that, as in the present study, sample dehulling generally caused an increase in initial and a decrease in equilibrium water absorption. Varietal differences in the equilibrium water absorption of dehulled as compared to whole beans may be partially due to differences in water binding capacity of different seed coats.

Beans soaked in distilled water generally exhibited a higher initial water absorption rate, diffusion coefficient, and equilibrium water absorption than those soaked in salt solution, but these differences were not significant. Solutes in soaking solutions would be expected to reduce the driving force for water uptake due to decreased osmotic pressure gradients across membranes of cotyledon cells (Woodstock 1988). The binding of water by solutes may reduce water absorption at equilibrium (Hsu *et al.* 1983). Hsu *et al.* (1983) found that the initial rate of water uptake and water absorption at equilibrium for imbibition in a 1% $NaHCO_3$ solution were similar to values for imbibition in distilled water. However, reductions in water absorption were apparent in the intermediate stages of water

uptake. Additional decreases in initial and equilibrium values were apparent for a 5% $NaHCO_3$ solution as compared to distilled water. Similar trends were observed for most samples in the present study, red kidney and whole white and black beans being exceptions. Carbonate ions in the soaking solution can interact with biopolymers in cotyledon cells to cause molecular unfolding and exposure of new sites for water binding (Leopold 1983). García-Vela *et al.* (1991) demonstrated that ions in a salt soaking solution interacted with storage proteins in beans and that this influenced solubilization and denaturation properties. This solute effect may have overcome the water-binding effect for the red kidney and whole white and black beans.

The development of the HTC defect has been associated with chemical modifications of cotyledon cell walls. These chemical modifications may be responsible for increased rigidity of cell walls (Hincks and Stanley 1987) and would be expected to increase the pressure potential and reduce transverse cracking. Although 10% and 8% reductions in the initial rate and the diffusion coefficient resulted from the development of the HTC defect, these effects were not statistically significant. On the other hand, a significant decrease of 12% in equilibrium water absorption resulted from the development of HTC. The effect of storage conditions on rate depended significantly on sample variety in that initial water uptake by white beans was faster for soft samples than their hardened counterparts, but the opposite trend was observed for black samples. This result may be related to the previous observation of elevated hardshell in soft black beans. Sample dehulling affected water uptake rates of hard beans to a smaller extent than soft samples. Overall increases in initial water absorption and diffusion coefficients for stored beans as a result of sample dehulling were 29% and 92% for soft beans and 15% and 46% for hard samples, respectively. This was due probably to a more predominent role for resistance to water transport in the cotyledons of HTC beans. Salts also affected water uptake rates of hard beans to a lesser degree than soft samples. The overall reductions in initial water absorption and diffusion coefficients for control beans as a result of carbonate salts were 28% and 7%, whereas a 4% and 7% increases were observed for HTC samples, respectively. Membrane degradation resulting from the development of the HTC defect (Richardson and Stanley 1991) may have been partially responsible for this effect, since intact cell membranes are essential for the maintenance of osmotic potential.

Swelling

A summary ANOVA table detailing the dependence of the main kinetic parameters of swelling on experimental factors and their interactions is presented in Table 3. It may be seen that these factors did not significantly affect swelling of fresh beans. There was no significant effect of sample variety on initial swell-

ing rate or diffusivity values for stored samples. Although 28% and 33% reductions in these parameters resulted from the development of HTC, these were not significant. Furthermore, the effect of storage conditions on initial swelling was significantly dependent on sample variety in that decreases in initial swelling rate caused by HTC were more pronounced for white than black samples. On the other hand, there was a significant effect of sample variety on equilibrium swelling values for stored beans, with white beans exhibiting enhanced swelling when compared to black samples; a significant decrease of 11% in equilibrium swelling resulted from the development of the HTC defect.

Sample dehulling generally caused a decrease in initial swelling and an increase in diffusivity but these effects were found to be nonsignificant. Again, the effects of these treatment depended significantly on sample variety. Dehulled soft black beans swelled faster initially than their whole counterparts. The diffusivity values for whole white beans were greater than those for dehulled samples, with the opposite trend being observed for black beans. The overall decrease in initial swelling rate for hard beans as a result of sample dehulling was 23%, whereas no change was observed for soft samples. Diffusivity increased 130% for control beans and 26% for HTC samples as a result of sample dehulling. Dehulling, on the other hand, caused a significant decrease in equilibrium swelling for stored beans (7% and 5% reduction for soft and hard beans, respectively).

Values of initial swelling and diffusivity were significantly larger in distilled water soaked beans as compared to those soaked in salt solution. The swelling rate of black beans in the diffusion-controlled stage of water uptake was more affected by salt than that of white samples. The initial swelling rate and diffusion coefficient decreased 60% and 128% for control beans and 21% and 53% for HTC samples, respectively, as a result of the addition of carbonate salts. On the other hand, equilibrium values of swelling were slightly larger in distilled water soaked than in salt soaked samples, but this effect was not significant. A 9% reduction in equilibrium swelling was observed for soft beans, whereas a 5% increase occurred for hard samples.

Equilibrium values tended to decrease as the seed diameter increased ($\beta \leqslant 0$ in Eq. 3b). Furthermore, samples exhibiting relatively large equilibrium swelling also tended to be more size dependent. However, when equilibrium diameter values were estimated as a function of the original diameter and equilibrium swelling values according to Eq. (9c), it was observed that at equilibrium soaked beans tended to have a more homogeneous size distribution than corresponding unsoaked samples.

Correlation Among Hardness, Water Absorption and Swelling Values

Correlation coefficients for hardness and water absorption of cooked samples, and the main kinetic parameters for water absorption as well as swelling during

soaking are presented in Table 4. The increases in water absorption were significantly correlated with accompanying decreases in instrumental hardness. A large scattering of experimental points, however, was apparent when plotting the data. Fresh black beans, in particular, did not appear to follow the trend of their stored counterparts, due possibly to variety (Black Turtle versus Orfeo) differences.

Initial water absorption and swelling rates were not significantly correlated with hardness. These values for white beans decreased as hardness increased, while values for black samples remained practically unchanged. Data for initial swelling rate of fresh black beans, however, did not appear to follow the trend associated with their stored counterparts. Varietal factors may explain these results. Values of initial water absorption were smaller than corresponding swelling values for samples soaked in distilled water except dehulled red kidney beans. Initial water absorption, however, was larger or only slightly smaller than initial swelling for all samples soaked in salt solution with the exception of whole white beans. In general, these two parameters were usually closer for dehulled than whole samples. Variations of trends for kinetic parameters describing initial rates of water uptake seem to indicate that seed coat swelling precedes water transfer across it.

TABLE 4.
CORRELATION COEFFICIENTS FOR VALUES OF HARDNESS AND WATER ABSORPTION WITH THE MAIN KINETIC PARAMETERS FOR WATER ABSORPTION AND SWELLING OF BEAN SAMPLES

		Water absorption			Swelling		
Factor	WA_c	$(m_i)_w$	$(D_{sa})_w$	W_e	$(m_{ia})_s$	$(D_{sa})_s$	S_{ea}
Cooked hardness (H_c)	-0.78**	-0.24	-0.19	-0.12	-0.20	-0.15	-0.04
Water absorption (WA_c)		0.33	0.07	0.11	0.40*	0.08	0.43*
Water absorption							
$(m_i)_w$			0.29	-0.50**	0.54**	0.30	0.32
$(D_{sa})_w$				-0.34	-0.04	0.76**	-0.32
W_e					0.08	-0.10	0.20
Swelling							
$(m_{ia})_s$						0.25	0.61**
$(D_{sa})_s$							-0.07

* =significant at $P \leq .05$; ** =significant at $P \leq .01$

Spurny (1973) has shown that during the initial stages of water uptake by peas, the seed coat swells to a greater extent than the cotyledons and separates from the cotyledon, leaving an empty interstitial space to be filled with water. In the present study this effect was seen as an initial wrinkling of the seed coat.

Diffusion coefficients were not significantly correlated with bean hardness. The former values were smaller for white beans than black samples and showed minimal variation between fresh beans and stored samples; fresh white and black beans did not appear to follow the trends associated with their stored counterparts. Varietal differences may explain these results.

Equilibrium water absorption and swelling also were not significantly correlated with hardening. Fresh white and black beans did not follow the patterns associated with their stored counterparts. Equilibrium water absorption values were smaller for white than black beans, but the opposite trend was observed for swelling values. Equilibrium water absorption values were smaller than parallel swelling values except for red beans and the whole black stored samples soaked in distilled water. These two parameters were much closer for black beans than white samples. Varietal differences may explain these results as well. Generally, similar effects of experimental factors on values of kinetic parameters describing transient changes in diffusion-controlled water uptake as well as equilibrium values were observed. These trends were not as significant for swelling as for water absorption, due probably to larger differences among replicates in swelling experiments.

Assuming that conservation of volume applies during water uptake, the following relationship between water absorption and swelling would apply (Singh and Kulshrestha 1987):

$$S = \frac{\rho_s}{\rho_w} WA \qquad [10]$$

where ρ_w and ρ_s represent the densities of the soaking solution and seeds, respectively. Equation 10 indicates that if beans are denser than the soaking solution ($\rho_s > \rho_w$), conservative swelling associated with water uptake would surpass water absorption. Furthermore, increases in ρ_w brought about by adding solutes to soaking solutions should reduce the difference between these two parameters. This effect may partially explain the more accentuated effects of soaking solution composition on swelling than on water absorption.

Nonconservative swelling effects can help explain the observed differences between both the rates of change and equilibrium values for water absorption and swelling. Gas expansion upon desorption and unfolding of macromolecules may contribute volume changes that exceed the volume of the absorbed water. Displacement of adsorbed gases in the cotyledons by water can be accompanied by a substantial volume increase and desorbed gases can be prevented from escaping the seed by semipermeable barriers in the seed coat (Parrish and Leopold 1977).

Water can also interact with storage proteins and pectins in cotyledon cells and cell walls to cause unfolding and nonconservative swelling (Leopold 1983). Allocations of water in void spaces between the seed coat and the cotyledons, the cavity formed between adaxial cotyledon surfaces, and intercellular spaces within the cotyledons result in increases in water absorption without appreciable change in swelling. A relatively large cavity between the cotyledons could have a markedly different effect on water absorption and swelling after the initial resistance of the seed coat to water transport has been overcome. Easy allocation of water to this empty space would result in higher diffusion coefficients and equilibrium water absorption values at the expense of small diffusivity and equilibrium values for swelling. Note that these trends were observed for red beans, which are characterized by a large cavity (Bourne 1967).

CONCLUSIONS

HS of stored beans was not related to seed size but did occur more frequently in soft black beans than other varieties. A modified first-order reaction model composed of an initial linear phase followed by a diffusion-controlled phase was found to closely predict water absorption and swelling in the varieties of fresh and stored beans used in this study.

White beans had a faster initial rate of water absorption than black or red beans due probably to greater permeability of white bean seed coats. Red beans imbibed water faster during the diffusion-controlled stage and reached larger equilibrium values than white or black beans. This was not accompanied by increased swelling and was attributed to the presence of a large cavity between the cotyledons of red beans. Small beans swell more than larger samples during water uptake so that the final bean size at equilibrium appeared to be independent of initial size.

Sample dehulling resulted in improved rates of water absorption due to the elimination of an important external barrier to mass transfer into the seed. Initial swelling was reduced as a result of sample dehulling, since the seed coat swells faster than the cotyledons in the initial stages of water uptake. Equilibrium values for both water absorption and swelling were reduced as a result of elimination of the water held between the seed coat and the cotyledons as well as between the cotyledons and perhaps due to increased protein losses in dehulled samples. Addition of carbonate salt to the soaking solution generally reduced water absorption and swelling, due probably to water binding and a reduced driving force for water uptake.

The HTC defect was manifested by reductions in the rates of water absorption, the end equilibrium values and diminished effects of dehulling and addition of carbonate salt of water absorption and swelling. These effects were probably

related to increased structural rigidity of HTC cotyledons and degradation of membranes. Water absorption of cooked beans was significantly and negatively correlated with cooked bean hardness, emphasizing the importance of these water relationships to quality of cooked beans. When dealing with hardened beans the amount of water absorbed does not necessarily equate to cotyledon cell hydration, a prerequisite to softening during cooking.

LIST OF SYMBOLS

Lower Case Symbols

c = solute concentration (g L^{-1})
c_e = solution concentration at equilibrium conditions (g L^{-1})
c_o = initial solute concentration (g L^{-1})
df = degrees of freedom
k = (first order) reaction rate constant (h^{-1})
k_s = (first order) reaction rate constant for swelling (h^{-1})
k_{sa} = average (first order) reaction rate constant for swelling (h^{-1})
k_w = (first order) reaction rate constant for water absorption (h^{-1})
$(m_i)_s$ = initial ($t \leqslant t_t$) rate of swelling (min_{-1})
$(m_{ia})_s$ = average initial ($t \leqslant t_t$) rate of swelling (min^{-1})
$(m_i)_w$ = initial ($t \leqslant t_t$) rate of water absorption (g water g^{-1} min^{-1})
n = reaction order (dimensionless)
t = time (min)
t_t = transition time (min)
w = weight of soaked sample (g)
w_o = weight of unsoaked sample (g)
w_c = weight of cooked sample (g)

Upper Case Symbols

A = cross-sectional area (mm^2)
ANOVA = analysis of variance
C = concentration (dimensionless)
C_i = pseudoinitial concentration (dimensionless)
C_{ol} = bean color
D = dehulled sample
D_p = diameter (mm)
D_{pa} = average diameter (mm)
D_{pe} = average diameter at equilibrium conditions (mm)
D_s = diffusion coefficient (cm^2 h^{-1})

$(D_s)_s$ = diffusion coefficient for swelling ($cm^2\ h^{-1}$)
$(D_{sa})_s$ = average diffusion coefficient for swelling ($cm^2\ h^{-1}$)
$(D_s)_w$ = water diffusivity ($cm^2\ h^{-1}$)
$(D_{sa})_w$ = average water diffusivity ($cm^2\ h^{-1}$)
DW = distilled water
F = Fisher-Snedecor distribution
H = hulled sample
H_c = cooked hardness ($N\ (30\ g)^{-1}$)
HH = high temperature and high humidity conditions
HS = hardshell
HTC = hard-to-cook
LL = low temperature and low humidity conditions
P = cross-sectional perimeter (mm)
Pr = pretreatment
S = swelling (dimensionless)
S_e = swelling at equilibrium conditions (dimensionless)
S_{ea} = average swelling at equilibrium conditions (dimensionless)
S_i = pseudoinitial swelling (dimensionless)
S_{ia} = average pseudoinitial swelling (dimensionless)
SC = storage condition
SkSl = soaking solution
SS = salt solution
SSE = sum of squares of error term
V = volume (mm^3)
V_o = volume of unsoaked sample (mm^3)
W_e = water absorption at equilibrium conditions (g water g^{-1})
W_i = pseudoinitial water absorption (g water g^{-1})
WA = water absorption (g water g^{-1})
WA_c = water absorption of cooked sample (g water g^{-1})
WHC = water holding capacity (g water g^{-1})

Greek Letter Symbols

α, β, γ = parameters
ρ_s = seed density ($g\ L^{-1}$)
ρ_w = density of soaking solution ($g\ L^{-1}$)
Ψ = water potential (bar)
Ψ_m = matrix potential (bar)
Ψ_p = pressure potential (bar)
Ψ_π = osmotic potential (bar)

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RETARDATION OF SURFACE LIGNIFICATION ON FRESH PEELED CARROTS

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ABSTRACT

The development of a white material on the surface of freshly peeled carrots can be inhibited by a 20–45 s dip in a 60C, pH 1.0 solution. This treatment insures better retention of the original carrot color and flavor, compared to untreated, and can also be easily incorporated into a production system. A level above pH 1.0 will also offer protection, but only for shorter time.

INTRODUCTION

Current trends for the American consumer are towards a preference for fresh fruits and vegetables over processed. A recent report of a survey in *Food Processing* indicates "Over 70% of those interviewed think that 'raw' vegetables are more nutritious, fresher, better for the environment, have less additives and preservatives. . ." (Hlavacek 1991). There are also scientific studies indicating the importance of fresh vegetables such as raw carrots in the diet. In addition, nutrition research suggests heating can reduce nutrient availability. For example, heating carrots can cause a conversion of insoluble fiber to soluble (Phillips and Palmer 1991) and affects the importance of raw carrots to reducing serum cholesterol (Robertson *et al.* 1979). In addition to nutritional interest, consumers also want products in a convenient 100% ready-to-eat form. This requires that the fresh product be lightly processed in some manner (peeled, cored, sliced, chopped, etc.). Light minimal processing results in a rupturing of plant cells, leading to undesired chemical reactions caused by an intermixing of the cellular chemical components. These undesirable reactions must be minimized for the fruit or vegetable to maintain its "fresh" flavor, texture and appearance.

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Light minimum processing procedure for carrots consists of peeling, washing, centrifuging and packaging. However, shortly after peeling, the bright orange appearance of the carrots is rapidly masked by the development of a white material on the surface. Abrasion peeling results in a rupturing of numerous cells and causes both an intermixing of enzymes with substrates, and an exposure of these ruptured cells to oxygen. The resultant white material that forms on the surface, is reported to be a lignin material (Bolin and Huxsoll 1991). The enzymes that intiate lignification can be partially inactivated by exposing the cut surface to a 70C 2% citric acid solution for about 30 s. Regular size peeled carrots submitted to this treatment will retain their bright orange color during cold storage. However, in more recent research, darkening caused by heat damage has sometimes occurred in the core area with smaller carrots. This present study was undertaken to determine if a lower temperature or pH dip treatment would provide the same, or better, protection against lignification on the surface of abrasion peeled carrots.

MATERIAL AND METHODS

Carrots (*Daucus carota*) were obtained from a wholesale produce market and stored at 2C before treatment. Lower pH solution was obtained by adding citric, phosporic or hydorchloric acid to 4 L of water to obtain the desired level. The treatment sequence consisted of first abrasion peeling the carrots under cold running water using a coarse sandpaper. Peeled carrots were immersed into the dip solutions for 15–60 s, drained for 1 min, immersed into cold running water for 1 min and held in a 2C refrigerator until the carrots had cooled and most of the free moisture had evaporated. The carrots were packaged in polyethylene pouches and stored at 2C. Five replicates of each treatment and the control were evaluated periodically for changes in appearance by rating visually from zero to nine (0 = no white, 9 = maximum white on surface) and instrumentally. A Minolta Chromameter CR-200 was used to measure the optical properties of the surface. The L*, a* and b* readings were recorded and statistically evaluated, reporting the final results as individual values, chroma, $[(a^{*2} + b^{*2})^{1/2}$, or whiteness index $[WI = 100 - ([100 - L^*]^2 + a^{*2} + b^{*2}]^{1/2}$. A sensory triangle taste panel (ASTM 1968), consisting of 20 judges, evaluated the product at two different times to determine flavor differences and preferences.

RESULTS AND DISCUSSION

A high concentration of citric acid is required to lower a solution much below 2.0 (pH 1.0 requires a 33% solution). Using a citric acid solution of greater than

approximately 10% caused noticable cellular breakdown, resulting in a plasmolysis of the exposed cell walls. Cell plasmolysis caused leakage of cellular fluids, providing a moist surface which could support microbial growth. Carrots dipped in a 60C bath of 11% citric acid solution (pH 1.5) maintained their bright appearance for about 2 weeks during 2C storage. However, beyond two weeks storage slimy material began to form on the surface. Phosphoric acid was more effective than citric but hydrochloric (0.09N) worked the best; therefore it was used throughout the rest of the experiments.

Minimizing solution temperature and dip time is critical for maintaining the desired fresh quality of the product. Too much heat affects cell permeability and turgor. Therefore, only the minimum amount of heat that will inactivate the enzymes needed to be determined, the possible enzymes involved are discussed by Bolin and Huxsoll (1991); and Bell (1981). The dip time required varied, depending upon the solution pH and temperature. A pH 1.0, 50C solution provided some protection with a 30 s dip, but the effectiveness was greatly reduced when the time was shortened (Fig. 1). After extensive experimentation a minimum dip temperature of 60C was determined to be optimum for providing enzyme inactivation. At this temperature a 30 s pH 2.5 dip provided no protection. However, lowering the pH to 2.0 did decrease the rate of lignin development on the abraded

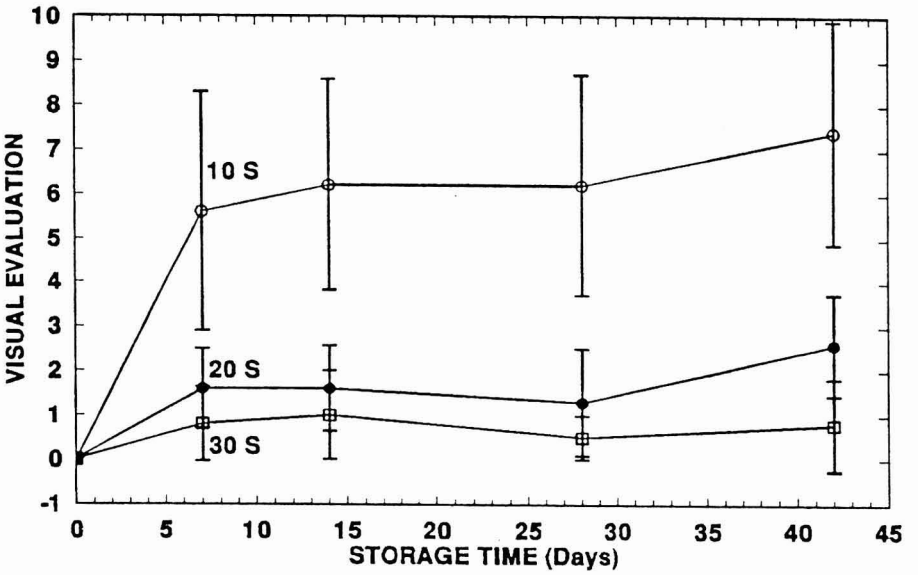

FIG. 1. VISUAL EVALUATION OF ABRASION PEELED CARROTS STORED AT 2C AFTER DIPPING IN A 50C SOLUTION TO WHICH HCl WAS ADDED TO LOWER THE pH TO 1.0
0 = No white, 9 = max white.

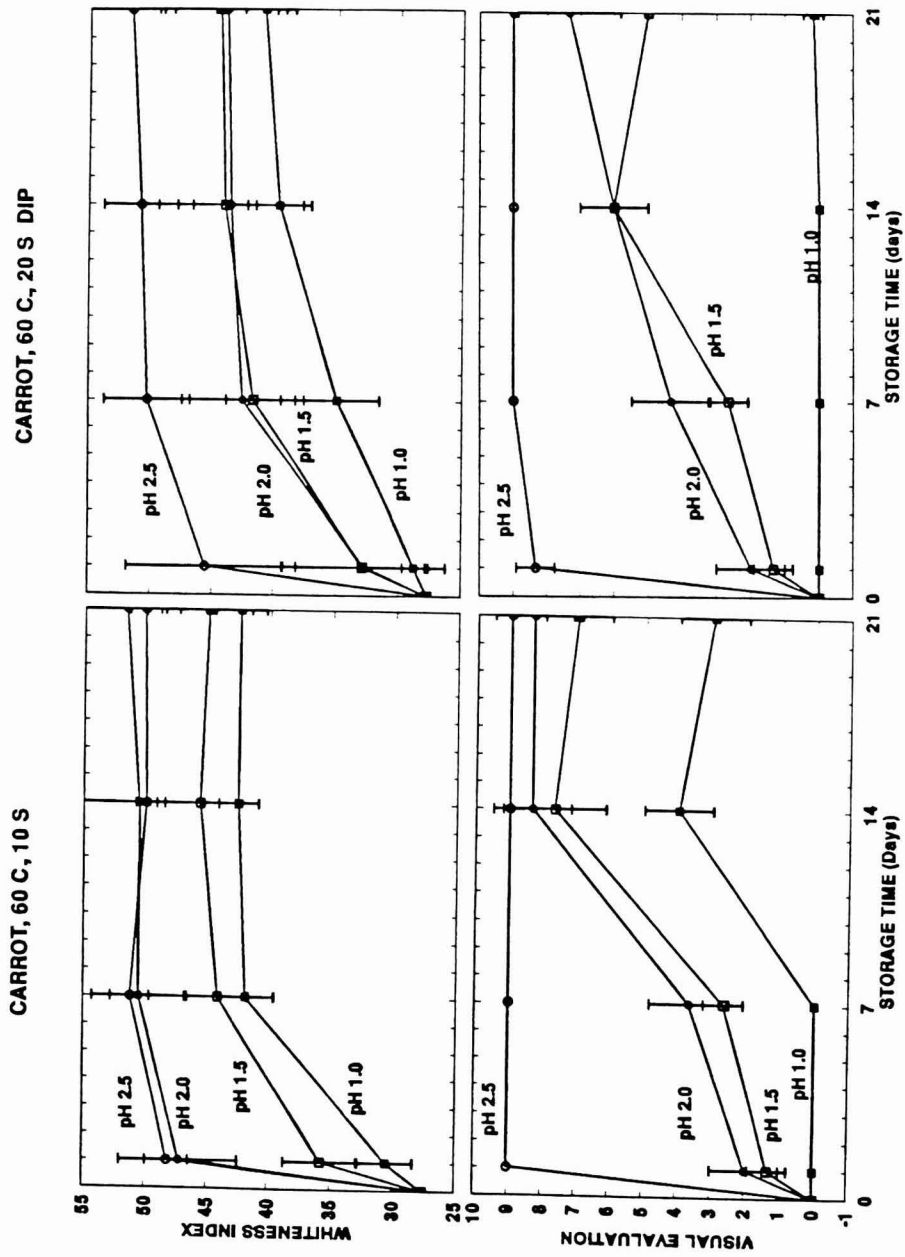

FIG. 2 INSTRUMENTAL AND VISUAL EVALUATION OF ABRASION PEELED CARROTS DIPPED IN 60C SOLUTION

$$WI = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2}$$

surface. Reducing the solution to pH 1.0 provided complete protection for the carrots up to 3 weeks with just a 20 s dip (Fig. 2). This figure also indicates how the optical properties of the peeled surface changes, as measured instrumentally, but is not detected visually. This is especially noticeable in the pH 1.0, 20 s dip. This change in reflectance readings could be caused by a slight drying out, or compaction, of the cells on the surface, which could result in more light being reflected back to the meter. The whiteness index was used to express the reflectance values because this expression had a better correlation to visual evaluation results (0.929) than either the "L*" (0.816) or the "chroma" (0.869).

The acid dipping treatment also offer some protection from loss of flavor in the peeled carrots. Carrots dipped for 30–45 s in the 60C, pH 1.0 HCl solution were differentiated from the control by a taste panel at the 1% level. Sixty percent of the panelists that indicated a flavor difference also indicated the treated samples had more fresh carrot flavor than the untreated control. Evidently, some of the oxidative enzymatic chemical reactions that result in flavor loss is retarded by the enzyme inactivation. Lund and Bruemmer (1991) indicated that acetylenic compounds can form in fresh packaged carrots, affecting flavor changes.

This short-time low temperature dip also did not cause any visible physical changes in the cells that might result in exudation of cellular fluids. The treatment also has a sterilizing effect on the carrot surface. Microbial growth was not a problem in any of the samples dipped in the 60C, pH 1.0 solution for 20–45 s.

The 60C dip for 20–45 s offers complete protection from the development of a white lignin material on a peeled carrot surface. This simple, dip treatment can easily be introduced into a food processing line, providing effective protection to peeled carrots for at least 3–6 weeks when stored at 2C.

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PROCESSING AND UTILIZATION OF COWPEAS IN DEVELOPING COUNTRIES: A REVIEW

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ABSTRACT

*Cowpeas (*Vigna unguiculata *or* Vigna sinensis*), also known as blackeye beans or southern peas, are important grain legumes in Africa and other developing countries where they serve as good sources of protein, energy and other nutrients. Despite their potential in upgrading diets of the poor people of the world, there are certain constraints to optimal utilization of cowpeas as food. These are attributed to factors such as pest infestation of the beans, beany flavors, extended cooking times and presence of antinutrients that cause low digestibility and abdominal upsets. Methods of circumventing these constraints to cowpea utilization are outlined. The literature on various processing techniques such as milling, dehulling, soaking, germination, fermentation and heat treatment are reviewed, and popular ways of preparing cowpea foods are discussed. Utilization of cowpeas in both infant and adult foods is recommended in the preparation of traditional and novel products in order to avert the perennial problems of malnutrition in developing countries.*

INTRODUCTION

Cowpeas (*Vigna unguiculata* and *Vigna senensis*) is an important grain legume in East and West Africa as well as other developing countries (Dovlo *et al.* 1976). The beans are also known by other names such as blackeye beans, southern peas, colossus peas and crowther peas. The pulse is indigenous to Africa (Okigbo 1986), though it is now grown in other continents, such as Central America (Bressani *et al.* 1961) as well as North and South America and Asia (Table 1). Higher meat prices during recent years and the need for protein-rich foods have led people

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TABLE 1.
LEADING COWPEA PRODUCING COUNTRIES IN THE WORLD

Country	Production (× 1000 Tons per Year)
Nigeria	850; (1000)[1]
Niger	271
Ghana	57
Boukina Faso	95
Kenya	48
Uganda	42
Malawi	42
Tanzania	21
Senegal	22
South America (Brazil)	600
The Carribean	Variable
U.S.A.	60
China	Variable
Asia (India, Indonesia, Sri Lanka, Phillipines)	Variable

Source: Rachie (1985).
[1]Onwuka (1989).

in most developing countries to shift their consumption to cowpeas and other grain legumes. Cowpea is grown mainly for the seed and sometimes pods in West Africa, India and South America, but it is grown for both seeds, pods and leaves in East Africa. It is also utilized as fodder and as a quick growing cover-crop. It improves soil fertility because of its ability to fix Nitrogen efficiently (up to 240 kg N per hectare) and can leave a fixed-N deposit in the soil of up to 60–70 kg/ha fro the succeeding crop (Rachie 1985). Cowpea can be interplanted easily with other food crops, and some varieties of the pulse are early-maturing, drought and stress tolerant. It is an annual tropical plant that grows in regions of low relative humidity, in rich loamy soils especially in Savannah regions such as parts of Northern Nigeria (with annual rainfall of 760–1520 mm). In Africa, Nigeria is the highest producer of cowpeas, which is the most popular legume consumed in this country together with groundnuts, pigeon peas, bambara groundnuts and locust beans. The popularity and high acceptability of cowpeas have been based on their low cost, easy availability and versatility in food preparation. The seeds are usually harvested in Nigeria around the months of October and November in the arid Northern region. After harvesting, cowpeas usually contain high amounts of moisture that must be removed before storage. It is common practice for small farmers in developing countries to expose the grains to solar radiation. This is achieved by placing the beans on mats layed out on roadsides or in certain clearings in the farms. The exposure time varies from one farmer to another and

also depends on the intensity of the sun during the harvest season. Over-exposure to very high temperatures, at high relative humidity can result in textural problems such as hard-to-cook defects (Stanley and Aguilera 1985). Storage of cowpea seeds under the right conditions of temperature, moisture content and relative humidity (of the storage environment) will ensure good-quality stored product in terms of nutrient retention and cooking characteristics (Onigbinde and Akinyele 1990). After sun-drying, the beans are bagged and transported to areas of sale or consumption. When transported for marketing to humid regions, cowpeas may become heavily infested with weevils or bruchids (Koleoso and Onyekwerre 1979). Consumers prefer uninfested beans or beans with good cooking qualities, for preparing various dishes. The present review discusses processing and utilization of cowpeas in developing countries.

VARIETIES

Several cowpea varieties have been described (Longe 1980, 1983; Akinyele *et al.* 1986; Kochhar *et al.* 1988; Aletor and Aladetimi 1989; de Mooy and de Mooy 1990) based on the color and texture of the seed coat and hilum as well as the seed shape. The chemical composition of these cowpea varieties can vary due to genetic manipulation, agronomic practices, postharvest handling and storage, age of the seeds and processing treatments applied in the preparation of the legume seed for human consumption. There are three major cowpea varieties (Table 2) commonly seen in local Nigerian markets (Obizoba 1984). These varieties have various food uses.

TABLE 2.
COWPEA VARIETIES IN NIGERIAN MARKETS

Variety	Description	Food Use
1. Blackeye beans	white testa and black hilum with tight-fitting seedcoat	boiled beans; moin-moin and akara after dehulling for paste production
2. Brown beans e.g., Ife brown	brown seed coat and white hilum	combination dishes with cereals tubers, plantains and other legumes; not suitable for akara and moin-moin because of unpleasant brown coloration
3. White beans	white testa and while hilum	paste products e.g., moin-moin and akara

COWPEA AS FOOD

Cowpea is eaten in the form of dry seeds, green pods and tender green leaves (Rachie 1985). Like other grain legumes, cowpeas are a good source of energy, proteins (amino acids), vitamins, minerals and dietary fiber (Tables 3 and 4). Legumes are sometimes referred to as a "poor man's meat" or the "rich man's vegetable" (Walker 1981). They are useful sources of good quality protein during the hungry season. Cowpeas contain about 20–30% protein, but protein digestibility is low in the beans (Onigbinde and Akinyele 1989). The food value of cowpeas is highly rated by the nutritionists, as they can provide supplementary proteins to traditional diets based on cereals, starchy roots and tubers (Aykroyd *et al.* 1982; Matthews 1989). Cowpeas are rich in lysine and other essential amino acids but low in sulphur amino acids (Bressani 1985; Kochhar *et al.* 1988; Aremu 1990). The high lysine content of cowpea makes it an excellent improver of the protein quality of foods low in lysine, such as cereals, which are low in lysine but rich in sulphur amino acids. The quality of a food legume is highest when such food contains high level of sulphur amino acids (Bressani and Elias 1980). Maximum nutritional benefits are therefore achieved by complementing cereals with cowpeas in the right amounts so that cereal-cowpea mixes yield amino acid scores closer to the FAO/WHO/UNU standard found in meats, fish and egg. Addition of methionine to cowpea protein (Bressani 1985; Sherwood *et al.* 1954) significantly increased protein quality estimated by biological value (BV) and net protein utilization (NPU) (Table 5). Cowpea-cereal mixtures provide the highest quality protein at a weight ratio of 45 parts cereal to 15 parts cowpea (Bressani 1985).

Cowpeas are a major source of protein in developing countries where consumption of certain animal foods is taboo because of religious or customary beliefs. This trend has been observed in parts of Northern Nigeria where pork and pork products, horse meat, donkey meat and meat from camels and asses are avoided by Muslims.

Cowpeas are an excellent source of thiamin and niacin and also contain reasonable amounts of other water-soluble vitamins, riboflavin, pyridoxine and folacin. In addition, they supply the essential minerals, calcium, magnesium, potassium, iron, zinc and phosphorus (Aykroyd *et al.* 1982). This is important, since in most developing countries milk is hardly an important part of the diet; the need for calcium can be met by consuming cowpeas and other vegetable foods. The low Na content of cowpeas makes it a good food for individuals on low sodium diets, while their high potassium content should be of special interest to those individuals who take diuretics to control hypertension and who need increased intake of K^+ to replace that excreted. Cowpeas are also low in fat and contain no cholesterol. Immature cowpea seeds are good sources of vitamin A, beta carotene and vitamin C (Eheart and Sholes 1948).

TABLE 3.
CHEMICAL COMPOSITION OF COWPEAS (%)

Component	a	b	c
Crude protein (g/100g)	24.2 ± 0.1	23.5	24.80 ± 0.48
Carbohydrate (g/100g)	54.4 ± 0.9[1]	—	63.60 ± 2.40
Fat (ether extract, g/100g)	1.2 ± 0.0	1.4	1.90 ± 0.62
Ash (g/100g)	3.5 ± 0.0	3.5	3.60 ± 0.17
Crude fiber (g/100g)	N.D.	N.D.	6.30 ± 0.64
Thiamin (mg/100g)	0.77	0.8	0.74 ± 0.22
Riboflavin (mg/100g)	0.25	0.2	0.42 ± 0.14
Niacin (mg/100g)	3.48	2.8	2.81 ± 0.26

Sources: [a]Uzogara *et al.* (1988, 1991a,b);[b]Soucci *et al.* (1986); [c]Bressani (1985).
[1]Available carbohydrate.
N.D. Not determined.

TABLE 4.
ESSENTIAL AMINO ACID COMPOSITION (g/16g N) AND PROTEIN CONTENT (g/100g; % DRY WEIGHT BASIS) OF COWPEA SEEDS

Component	a (Range in 24 Cultivars)	b (Range in 9 varieties)
Lysine	6.6–8.1	6.74–7.70
Histidine	2.9–44.7	2.71–3.31
Arginine	5.4–8.0	5.97–8.92
Threonine	3.6–4.5	3.09–3.88
Valine	4.9–5.7	4.39–5.42
Isoleucine	4.2–4.8	3.97–4.48
Leucine	7.6–8.5	7.08–8.73
Tyrosine	2.2–3.6	2.68–3.05
Phenylalanine	5.5–6.2	5.20–5.99
Methionine	1.5–2.3	1.35–1.70
Crude protein (%N × 6.25)	23.1–31.3	24.40–30.90

Sources: [a]Kochhar *et al.* (1988); [b]Evans and Boutler (1974).

TABLE 5.
EFFECT OF SULPHUR AMINO ACID SUPPLEMENTATION TO COWPEA ON PROTEIN QUALITY

Protein Source	Biological Value (BV) (%)	Net Protein Utilization (NPU) (%)
Cowpea meal (CM)	58.17 ± 2.31	50.60 ± 1.83
CM + cystine	80.25 ± 1.87	72.74 ± 0.94
CM + cystine + methionine	94.61 ± 1.26	82.12 ± 1.07
CM + methionine	95.84 ± 1.45	81.46 ± 0.87
Albumin	101.72 ± 2.54	99.52 ± 1.85

Source: Bressani (1985).

Cowpeas and other legumes are a good source (up to 20%) of dietary fiber (Walker 1982; Shutler *et al.* 1987) whose high consumption has been correlated with decreased incidence of the so-called "diseases of affluence" (i.e., diverticular diseases, colon cancers, obesity, coronary heart disease, diabetes, dental caries, etc.) (Walker 1982). According to Burkitt and Trowell (1975), such diseases of affluence are not commonly observed in developing countries where legumes and other high fiber plant foods are common staples. Dietary fiber is reported to have a hypo-cholesterolemic effect (Shutler *et al.* 1987) as well as a hypoglycemic effect (Jensen and Jepsen 1982); it leads to a decrease in intestinal transit time and also increases faecal bulk; it binds bile acids, and degrades to short chain fatty acids in the large intestine; it increases viscosity and slows digestion (Passmore and Eastwood 1986). Cowpeas like other legumes contain both insoluble (13%) and soluble (7%) dietary fiber (Anderson and Bridges 1988). Water soluble fiber is particularly effective in lowering serum cholesterol, while the water insoluble fiber provides bulk, pushing food through the digestive system at a faster rate.

Cowpeas also have a great potential in upgrading traditional weaning foods based on cereal paps (Odum *et al.* 1981; Oyeleke *et al.* 1985). The beans are sometimes fed as the main food to infants in developing countries unless such infants show intolerance to the cowpea diet. Bressani (1985) stated that a food product for weaning small children made of 75% cereal grain and 25% cowpea would be about 13% good quality protein.

Cowpeas are relatively cheap compared to meat foods and, as they have a high carbohydrate content (50–65%) (Longe 1980), act as high energy foods for peasants and nomadic farmers. Cowpeas also add variety to monotonous high carbohydrate staples common in the tropics. Starch contributes about 30–50% of cowpea carbohydrate and as in other food legumes over 50% of the starch is in the form of amylose. Srinavasa-Rao (1976) showed that high amylose content caused slow digestibility. However carbohydrate digestibility of cowpea was increased *in vitro* by baking, roasting and germination and these processes might also facilitate *in vivo* carbohydrate digestibility (Srinavasa-Rao 1976; Geervani and Theophilus 1981; Reddy *et al.* 1984; Carbezas *et al.* 1982).

In addition, cowpeas also contain some indigestible sugars known as oligosaccharides. These oligosaccharides, stachyose, raffinose and verbascose cause gas or flatus in some individuals who consume cowpeas.

RESEARCH INTO COWPEA UTILIZATION

The potential of cowpeas to contribute more to the African or tropical diets has been investigated (IDRC 1973) with an emphasis on reducing postharvest

losses (Beuchat 1983), on developing appropriate technologies to alleviate the heavy labor inputs required in many traditional preparations (Reichert *et al.* 1979; Hudda 1983), and on development and promotion of acceptable cowpea products (Okaka and Potter 1979; Chinnan *et al.* 1983). The potential of cowpea for increasing protein consumption in developing countries is such that the Protein Advisory Group (PAG) of the Food and Agricultural Organization of the United Nations (FAO/UN) has recommended that this crop be accorded priority research status (Milner 1973). Consequently, a collaborative research project was conducted by the University of Georgia at Athens, Georgia, USA, and the University of Nigeria, Nsukka, Nigeria, under the auspices of the Bean Cowpea Collaborative Research Support Program (BCCRSP) of the United States Agency for International Development (USAID) (McWatters and Chinnan 1985). The research project was titled "Appropriate Technology for Cowpea Preservation and Processing with a study of its socioeconomic impact on rural population in Nigeria" and has been supported by USAID since 1981 (Phillips and McWatters 1991). The project is seeking to improve the processing, preservation and utilization of cowpea as well as optimizing the conditions for processing and utilization of cowpea meal. Recently the University of Georgia/University of Nigeria research teams received the IFT Industrial Achievement award for developments in the cowpea project (Anon. 1991). The University of Ghana's Department of Nutrition and Food Science is currently planning to join the cowpea collaborative research project (Sefa-Dedeh 1991). A similar collaborative research project has been undertaken between the Technical University of Denmark and a research laboratory in Nigeria under the auspices of the Danish International Development Agency, DANIDA (Djurtoft 1982).

Various agricultural research institutes such as the International Institute for Tropical Agriculture (IITA) in Ibadan Nigeria, universities, polytechnics, and government-owned research institutes of agriculture are also carrying out research on cowpeas. In the Indian subcontinent, research on cowpeas is going on at the Central Food Technological Research Institute (CFTRI) in Mysore, India (Kurien 1987), while in South America, some scientists at the Institute de Nutricion de Centro America y Panama (INCAP) have also done some work on cowpeas and other beans (Bressani *et al.* 1961; Molina *et al.* 1976).

CONSTRAINTS TO USE OF COWPEAS AS FOOD

Despite their values as good sources of protein, energy and other nutrients and their relatively low cost with respect to other high protein foods, cowpeas are not regularly selected as food. This is because of the following problems (Table 6).

TABLE 6.
CONSTRAINTS LIMITING UTILIZATION OF COWPEAS

Constraints	References
1. Pest infestation	Caswell (1961); Swaminathan (1977); Gatehouse *et al.* (1979); Etokakpan *et al.* (1983); Kapu *et al.* (1989); Dellagata *et al.* (1990)
2. Beany flavor and odor	Okaka and Potter (1979); Stanley and Aguilera (1985)
3. Antinutrient	
(a) Tannin	Price *et al.* (1980); Rockland and Radke (1981); Laurena *et al.* (1984, 1986); Akinyele (1989); Ogun *et al.* (1989); Uzogara *et al.* (1990b)
(b) Phytates	Ologhobo and Fetuga (1984); Laurena *et al.* (1984); Ogun *et al.* (1989); Uzogara *et al.* (1990b)
(c) Protease in inhibitors	Kochhar *et al.* (1988); Dellagata *et al.* (1989); Ogun *et al.* (1989)
(d) Flatulence factors	Phillips and Abbey (1989); Ofuya *et al.* (1989); Ndubuaku *et al.* (1989); Nnanna and Phillips (1990)
4. Hard-shell defect	Bourne (1967); Stanley and Aguilera (1985)
5. Hard-to-cook defect	Sefa-Dedeh *et al.* (1979); Stanley and Aguilera (1985); Akinyele *et al.* (1986); Hentges *et al.* (1990, 1991)
6. Hardness due to water quality (Ca)	Uzogara *et al.* (1992b)

Pest Infestation

Pests usually infest cowpeas during storage (Ramcharran and Walker 1985). Storage of cowpeas is essential, as the crop is seasonal and there is need to store the surplus from the harvests for later use in homes, markets or for industrial processing. Pests such as insects, rodents, lizards, molds, are the main cause of damage to stored cowpeas. Other causes of damage include high moisture content (especially rain and ground water inadvertently entering the stored beans in granaries) and fire burning warehouses in which beans are stored. If cowpea seeds are dried down from 20% to 12% moisture, the problem of molding is reduced. Cowpea weevils (*Callosobruchus maculatus* and *C. chinensis*) are the major insects that infest cowpeas during storage and transportation, especially if the cowpea has a high moisture content (up to 20%) suitable for insect survival (Koleoso and Onyekwerre 1979; Caswell 1961). Losses of cowpea from insect infestation in Nigeria range from 2.5% annually (Onwuka 1989) to 20% (Olayide and Olayemi 1978). It has also been reported that cowpeas low in anti-trypsin factors are prone to insect attack (Gatehouse *et al.* 1979). Other workers (Dellagata *et al.* 1990) have also shown a relationship between fatty acid composition and insect resistance in cowpeas. Further research on cowpea resistance to insect infestation is being carried out at IITA Ibadan, Nigeria. Apart from consumer aver-

sion to infested beans, the nutritional value of infested cowpea is also reduced (Sowunmi 1978; Rajan *et al.* 1975; Etokapkan *et al.* 1983) and insect infestation leads to a loss of dry matter (Caswell 1961). The loss in nutritional value may have been caused by contamination from uric acid, a protein metabolite of insects, as well as the increases in fatty acidity and microbial contamination and perhaps to losses in grain fractions (Bressani 1983). There are also decreases in essential amino acids and B-vitamins in infested beans (Rajan *et al.* 1975; Swaminathan 1977); when such beans were fed to weaning rats, it led to decreased growth rate and PER (Table 7) as well as other toxic effects (Swaminathan 1977).

Improperly packaged and stored cowpea could be a very effective means of spreading the enteric bacterial and protozoal diseases such as typhoid, diarrhea and dysentary, which are often transmitted by cockroaches and food pests that come in contact with stored foods.

Weevil infestation during household storage of cowpeas could be prevented by use of air-tight storage containers, such as enamel dishes sealed with lids, air-tight metal containers, clay pots or earthenware jars with sealed lids, or stored in jute bags, basket and enamel basins. In some Nigerian villages, hot peppers, wood ash and local vegetable oils are used for preventing weevil infestation of stored cowpeas by coating the grains with these materials. Perhaps these treatments have insect repellant properties. Of three cooking oils (corn oil, peanut oil and palm oil) tested for their effectiveness in providing continuing protection against insect infestation of cowpea seeds by weevils, palm oil was by far the most effective and did not affect the sensory quality of the cooked beans (Worthington and McWatters 1983). Palm kernel oil, groundnut oil and other oils (Pereira 1983) at dosage levels of 5–10 mL/kg seeds were also effective in protecting cowpeas from weevil infestation. Lemon oil was found effective in the control of cowpea weevils in blackeye beans (Su *et al.* 1972).

Insect infestation of cowpeas during storage under atmospheric conditions could be prevented by leaving the cowpeas in the pod (Dovlo *et al.* 1976) or by breaking the beans into halves (or dahls) with removal of the hull so that the bruchid insect will not find a suitable enclosure in which to live and grow. Onwuka (1989) as well as Ngoddy (1989) suggest that for short periods of storage, it may be

TABLE 7.
EFFECT OF INSECT (*C. chinensis*) INFESTATION ON PER AND GROWTH RATE OF RATS FED COWPEAS

Food Source	PER	Body Weight Gain
Infested cowpeas	1.47	15.0 (g/4 weeks)
Uninfested cowpeas	2.22	23.3

Source: Swaminathan (1977).

safer to store dehulled than undehulled seeds. Storage losses can also be prevented by treating cowpea seeds with insecticides such as phostoxin, or aluminum phosphide, which is marketed in form of tablets (Ngoddy 1989). When this tablet absorbs moisture from the grain, it disintegrates and produces phosphine gas, which is toxic to insects.

Rodent problems can be combatted by rodent-proofing of buildings, storage in metal containers and good sanitary handling of grains. For proper storage of cowpea seeds or flours, a temperature of 21–25C, relatively humidity (RH) of 65% of the storage environment and moisture content of seeds less than 12% in polythene, laminated plastic bags or metal containers is recommended (Onwuka 1989). Flours can also be stored for up to one year in inert atmosphere (N_2 or CO_2) with the addition of an antioxidant, such as butylated hydroxy toluene (BHT).

Beany Flavor and Odor

Lipids are important constituents of legumes including cowpeas, and these lipids break down during storage. Unsaturated lipids are easily oxidized, yielding carbonyl compounds that cause off flavors and odors. Carbonyl compounds can react with decomposition products of proteins to yield cross-linked end products.

The characteristic beany flavor of cowpeas results from the action of lipoxygenase enzymes on free fatty acids present in the seeds. This leads to the formation of ketones, giving undesirable flavors (Kon *et al.* 1970). Storage of cowpeas with a moisture content of 10% or less will slow down this process, while heat treatment higher than 80C will denature lipoxygenase enzymes. Okaka and Potter (1979) reduced beany flavor of drum-dried cowpea powders by acidified water soaking followed by blanching of cowpeas. Storage of legumes can result in loss of quality (off flavors and odors), nutritional quality, and functionality (Stanley and Aguilera 1985).

Antinutrients

Antinutrients are common in many legumes, including cowpeas. Liener (1980) has defined these toxic components in legumes as "those causing adverse physiological response in man or animals when consumed." These leguminous antinutrients include protease inhibitors, amylase inhibitors, hemagglutinins, allergens, aflatoxins, cyanogenic glycosides, favism factors, lathyrogens, metal binding factors (phytates, oxalates, saponins), antivitamins, estrogens, pressor amines, flatulence factors and polyphenols. The content of each antinutrient varies in different legume varieties. These toxicants lower digestibility (Liener 1976), protein efficiency ratio (PER) and overall nutritive value of the uncooked or improperly cooked seeds and can cause diarrhea and vomitting (Anon. 1976).

TABLE 8.
CONTENTS OF SOME ESSENTIAL NUTRIENTS IN INFESTED (*C. CHINENSIS*) AND UNINFESTED COWPEA SEEDS

Nutrient	Infested Seeds	Uninfested Seeds
Lysine (g/16gN)	6.8[a]	7.4[a]
Methionine (g/16gN)	1.2[a]	1.4[a]
Cystine (g/16gN)	0.8[a]	0.9[a]
SAA (g/16gN)	2.0[a]	2.3[a]
Threonine (g/16gN)	3.1[a]	3.5[a]
Tryptophan (g/16gN)	1.3[a]	1.3[a]
Thiamin (mg/100g)	0.32[b]; (0.41)[c]	0.47[b]; (0.91)[c]
Carotenes/provitamin A (μg/100g)	8.4[c]	14.6[c]
Riboflavin (mg/100g)	0.08[c]	0.17[c]

Sources: [a]Rajan *et al.* (1975); [b]Swaminathan (1977); [c]Etokakpan *et al.* (1983).

Cowpeas contain antinutrients such as polyphenols, trypsin inhibitors, lectins and phytates which may decrease protein digestibility and reduce protein quality (Bressani and Elias 1978). Elias *et al.* (1979) obtained lower PER for beans combined with cook water than for drained beans alone. They suggested that tannins and/or other bean pigments interfered with protein utilization. Elias *et al.* (1979) also found that tannin concentration was high in colored seed coats but low in white-coated seeds. However, Rockland and Radke (1981) observed that PER values were identical for the white variety of blackeye beans both with and without cook water. Tannin also lowers protein digestibility in cowpeas (Laurena *et al.* 1984, 1986). The unfavorable influences of tannin on nutritional properties of cowpea have been discussed by Price *et al.* (1980). The adverse effects of tannin may be related to the fact that tannins interfere with protein digestion, affecting digestive action of trypsin and alpha amylase either by binding the enzymes themselves or by binding dietary protein into an indigestible form (Bressani *et al.* 1982). Tannins can also be complexed with vitamin B_{12} causing a decrease in absorption of the vitamin in rats. Cooking decreased tannin and increased *in vitro* protein digestibility in cowpeas (Laurena *et al.* 1984, Uzogara *et al.* 1990a). Various workers (Akinyele 1989; Ogun *et al.* 1989) observed increased losses in tannin when cowpeas were soaked and cooked. Tannin loss may be due to heat degradation of the tannin molecule or formation of water-soluble complexes between tannin and other tissue molecules of the beans. Such water-soluble complexes could leach out into the cook liquor. Uzogara *et al.* (1990a) observed increased removal of tannins in beans cooked in alkaline solutions especially under pressure cooking.

Phytic acid (myo-inositol 1, 2, 3, 4, 5, 6 hexaki-dihydrogen phosphate) is common in cowpeas and other legumes and is the principal storage form of phosphorus

in many dry beans. Phytic acid occurs as a complex (phytin) with divalent cations or monovalent cations in discrete regions of the beans and accounts for up to 80% of the total phosphorus content (Reddy *et al.* 1982). Most of the phytates in dry beans are located in the cotyledons and not in the seed coat. A nutritional concern about the presence of phytates in dry beans arises from the fact that phytate decreases the bioavailability of essential minerals (Ca, Mg, Mn, Zn, Fe, Cu) and may possibly interfere in the utilization of proteins due to phytate-protein and phytate-mineral-protein complexes (Oberleas and Harland 1981). Under physiological conditions these complexes may be insoluble thereby making proteins unavailable for proteolysis in humans and animals. It has been shown that phytate can inhibit enzymes such as alpha amylase, pepsin and trypsin under *in vitro* conditions (Reddy *et al.* 1982), which may further reduce substrate utilization. In foods high in phytate, zinc may not be readily available for absorption since a phytate:zinc molar ratio of above 20 is reported to be associated with chemical zinc deficiency (Oberleas and Harland 1981). Processing, especially presoaking followed by boiling in water or in alkaline solutions at atmospheric pressure, reduces the phytic acid content of cowpeas (Ogun *et al.* 1989; Uzogara *et al.* 1990a) while pressure cooking or autoclaving caused less loss of phytic acid (Uzogara *et al.* 1990a; Ologhobo and Fetuga 1984).

Protease inhibitors in food are substances that have the ability to inhibit proteolytic activity of certain enzymes (Liener and Kakade 1980). They are present in cowpeas and other legume seeds (Kocchar *et al.* 1988; Dellagata *et al.* 1989). Their importance lies in their possible adverse effect on nutritive value of plant proteins. Plant breeders in their effort to produce insect resistant varieties of cowpea have sometimes increased levels of trypsin inhibitors (Gatehouse *et al.* 1979). These toxicants lower protein quality by decreasing PER. Protease inhibitors can be reduced by soaking and dehulling the seeds followed by heating (Ogun *et al.* 1989).

Cowpea carbohydrates are rich in total sugars including flatus-causing oligosaccharides, raffinose, stachyose and verbascose (Phillips and Abbey 1989). These oligosaccharides are largely unavailable for human nutrition due to lack of specific degrading enzymes, namely alpha-galactosidases and beta-fructosidases. Following ingestion, these oligosaccharides, as well as phytate salts not hydrolyzed by the gastro-intestinal secretions, pass to the lower gut where a variety of microorganisms of the colon hydrolyze and ferment the oligosaccharides with the production of gas or flatus as well as free fatty acids. These flatulence factors alter water retention and faecal bulk. Flatulence can be very uncomfortable especially for infants and sick old people. It can be accompanied by frequent belching, abdominal distention, diarrhea and weakness (Ndubuaku *et al.* 1989).

Generally most of the antinutrients such as trypsin inhibitors, hemagglutinins, antivitamins, tannins, and goitrogens are heat labile and can be denatured using

appropriate food processing techniques such as presoaking, dehulling, fermentation, grinding, sterilization, boiling, steaming, wet milling and heating in alkaline solutions. Heat treatment of legumes also increases their digestibility and PER and causes increases in the availability of various amino acids and thus brings about an improvement in protein quality. Not all antinutrients can be fully inactivated by normal food processing techniques. For example, Korte (1972) reported that residual lectin activity was found in 22% of bean-maize mixtures prepared and soaked under local village conditions in a mountainous region of Tanzania where there is a lower boiling point for water. Although hemagglutinins and trypsin inhibitors are inactivated by heat, inadequate heating can result in residual activity in these factors. Secondly, complexes formed between these factors and bean proteins may not be completely dissociated and could interfere with *in vivo* digestion.

Extended Cooking Times

Cooking of cowpeas to an eating-soft condition may take a long time and consume a lot of scarce fuel energy. Extended cooking times of cowpeas may be caused by hard-shell, hard-to-cook defect or may be due to hardness of the cooking water (Table 9).

Hard-Shell Defect. Hard-shell defect in cowpea is due to failure of the legume to imbibe sufficient amount of water after soaking for a reasonable length of time (6 to 24 h) prior to cooking (Bourne 1967). Hard-shell is inheritable and partly influenced by storage conditions (Rolston 1978; Leberdeff 1943). It has been stated that storage over extended periods of time (6–12 months) at low relative humidity and low moisture content but at high temperatures favors hard-shell formation in beans (Jackson and Varriano-Marston 1981; Stanley and Aguilera 1985). The defect is assumed to be primarily physical in nature. The structural element responsible for hard-shell is the testa but more specifically the palisade layer contained within the seed coat, the hilum and various waterproofing substances. These waterproof materials are formed enzymatically from oxidized monophenols, which can produce pigmented polyphenol complexes that may interact with protein. This reaction could be important because it leads to lignification. It has been observed that the seed coat of hard soybeans was much denser, tougher and contained more calcium than those of normal beans (Saio 1976). Scanning electron microscope studies have shown that peas which do not absorb water have denser seed coats than normal peas (Swanson *et al.* 1985).

Hard-shell is a problem for seed growers because such seeds do not sprout easily. Hard-shell also causes problems for food processors as the beans neither absorb water nor soften during cooking. The development of hard-shell conditions in

TABLE 9.
COOKING DEFECTS WHICH INFLUENCE COOKING TIME AND COOKED COWPEA TEXTURE

Cooking Defect	Description	Causes
Hard-shell defect	Failure of beans to imbibe sufficient water after soaking for a reasonable length of time prior to cooking, thereby increasing cooking time	Beans with a low moisture content subjected to extended storage time (> 6 months) at high temperature and low RH
Hard-to-cook defect	Failure of beans to soften even after absorbing water during boiling, leading to increased cooking time	Beans with a high moisture content subjected to extended storage at high temperature and high RH
Water related hardness	Firmness of beans and failure to disintegrate after boiling in hard water, leading to increased cooking time	Presence of calcium salts in the cooking water. The divalent cations, especially Ca, leach into the bean tissue to exchange for monovalent cations, forming Ca-pectinates in the middle lamella, thereby firming the bean tissues

beans upon storage can be a limitation to increasing their production and availability and can lead to economic losses. Fortunately, through crossing and selection, plant breeders can eliminate most hard-shell varieties of beans. Hard-shell can also be reversed by hydrothermal treatment or scarification (Vindiola *et al.* 1986).

Hard-to-Cook Defect. The hard-to-cook (HTC) defect is a condition whereby bean cotyledons absorb water but fail to soften during boiling (Stanley and Aguilera 1985; Ramcharran and Walker 1985; Paredes-Lopez *et al.* 1989; Hentges *et al.* 1991). The defect develops when cowpeas and other legumes with high moisture content (> 13%) are stored at high temperature and high relative humidity, resulting in changes in the middle lamella, which makes subsequent degradation difficult. In cowpeas, HTC defect has been studied by examining the texture and microstructure of the beans (Sefa-Dedeh *et al.* 1979). This poor cooking characteristic can result in extended cooking times in an effort to produce beans with an acceptable tenderness level. Hard-to-cook defect leads to increased consumption of cooking fuel that may be scarce and expensive in developing countries. This may limit utilization of cowpeas and other dry grain legumes for prevention of protein energy malnutrition in these countries. It also places people who rely on dry beans for dietary protein at a nutritional disadvantage. The HTC defect in dry beans can therefore affect acceptability by consumers in developing coun-

tries such as Nigeria. These consumers tend to prefer carbohydrate-rich tubers that cook in a few minutes to high-protein dry beans with HTC defect that take several hours and much fuel to cook. The HTC defect differs from hard-shell in that it is primarily chemical in nature, while hard-shell is physical. Agronomic factors, such as fertilizer levels and composition as well as storage conditions, affect HTC defect. Development of HTC defect is not well understood and various factors may cause the defect and lead to increased cooking time in beans. The most frequently advanced hypotheses for the explanation of the HTC defect are (a) the middle lamella-pectin-cation-phytate mechanism of Mattson (1946); (b) the dual enzyme (phytase + pectin methyl esterase) mechanism of Jones and Boulter (1983); (c) the cross-linking of phenolics and/or protein in the middle lamella theory as proposed by Hincks and Stanley (1987) and Vindiola *et al.* (1986); (d) the decreased solubility of starch and protein theory (Akinyele *et al.* 1986; Hentges *et al.* 1991).

Basically, phytic acid located in the protein bodies of bean cotyledons chelates divalent cations (Ca, Mg). At high temperature and high relative humidity conditions in legumes with high moisture content, there is increased metabolic activity, phytase activation and membrane degradation. Phytase hydrolyzes phytin in cotyledon cells to release bound Ca and Mg, which migrate from the cotyledon cells to the middle lamella. At the same time, pectin methyl esterase (PME) in the middle lamella hydrolyzes pectin to pectic acid, pectinic acid and methanol. The divalent cations that migrated to the middle lamella now react with the released pectinic acids, forming insoluble Ca or Mg-pectinates that firms the middle lamella and cements cells together. Decreased pectin solubility and low phytate content have been correlated to poor cookability in HTC beans (Vindiola *et al.* 1986). Starch and protein may also play some roles in the developent of HTC defect, since decreased starch and protein solubilities were observed in HTC beans (Hentges *et al.* 1991). Increased lignification of the middle lamella as well as cross-linking of polyphenols with proteins or other polyphenols can also cause the HTC defect (Hincks and Stanley 1987).

Sefa-Dedeh *et al.* (1979) observed that cowpeas stored at 29C showed little breakdown in the middle lamella after cooking in water for 90 min. Sefa-Dedeh *et al.* (1979) also established that after storage of cowpeas under unfavorable conditions, these legumes developed the HTC defect. Recent reports have shown that HTC defect in cowpeas and dry beans could be reversed after additional storage of such beans at low temperature (6.5C) and low RH (71%) (Hentges *et al.* 1990), leading to economic and nutritional benefits. Such beans can no longer be discarded or used only as animal feeds. Rather, they can be used as human food, and their shorter cooking time will lead to greater nutrient retention and use of less cooking fuel.

HTC beans can, however, be processed and utilized by disruption, dry or wet fractionation prior to further cooking as well as by extrusion cooking (Aguilera

and Stanley 1985). HTC beans can also be disintegrated, cooked and used for animal feeding (Aguilera and Stanley 1985).

Water Hardness. Potable waters are termed "hard" when they contain high levels of Ca and Mg salts. Hard water has the disadvantage of increasing the cooking time and leads to high consumption of cooking fuel. Water hardness also affects several quality characteristics of cooked legumes, such as water imbibition, texture, color, cooking time and nutrient composition (Wilson *et al.* 1973; Silva *et al.* 1981; Uzogara *et al.* 1992b). All these effects on the quality of the cooked legumes may affect the acceptability and utilization of such legumes as food.

The extended cooking time caused by water hardness is easier to overcome than that due to hard-shell or the HTC defect. This is because hard waters can be softened locally with baking soda and with natural alkaline salts. Industrially, water can be softened by distillation as well as by passing the water through sodium aluminum silicate (permutit), before use in the cooking process. Water hardness is widely accepted as a cause of long cooking time in dry beans but has not been properly researched.

PROCESSING OF COWPEAS

Processing of cowpeas and legumes in general is essential to make them nutritious, nontoxic, palatable and acceptable. The constraints to maximum utilization of cowpeas can be overcome by appropriate processing technology. Processing can be classified into domestic and industrial techniques. The domestic processing techniques that are practiced in villages in developing countries include dehulling, grinding, soaking, germination, fermentation, addition of salts, wet and dry heat treatments, cooking and roasting. These processes can also be achieved in the food industry. The industrial processing techniques that are not common in the villages include canning, toasting, extrusion cooking, formation of protein concentrates and isolates and texturized vegetable proteins. Processing can further be divided into primary and secondary processes. Primary processes yield storable products to be used as and when required and include soaking, dehulling, grinding or milling, fermentation and germination. Secondary processes are involved in the preparation of final consumer products from cowpeas and include various forms of heat treatment, such as boiling, steaming, cooking, alkaline treatment, roasting and deep fat frying.

Soaking

Soaking cowpeas prior to cooking softens the cotyledons and reduces the cooking time of cowpeas by over 30%. This can save an ample amount of cooking fuel,

which may be scarce in many developing countries. Soaking is an essential step in home cooking of many legumes, especially in high altitude areas where the boiling point of water is lower than 100C, thereby resulting in longer cooking time for beans (Abou-Samaha *et al.* 1985). Presoaking has been recommended to facilitate the cooking step, and bean hydration kinetics have been studied (Quast and Da-Silva 1977). The efficacy of soaking has been enhanced by use of special soaking solutions containing a combination of inorganic salts (Rockland and Metzler 1967); in local villages where pure inorganic salts are not available, natural rock salt or kanwa solutions (Edijala 1980a,b; Uzogara *et al.* 1988) or wood ash (Laurena *et al.* 1986) can be used in soaking. Soaking shortens the cooking time and saves energy (Rizley and Sistrunk 1979; Uzogara *et al.* 1988). Soaking itself is a long process, and ways to shorten the soaking time include increasing the rate of water imbibition through the vacuum infiltration principle (Rockland and Metzler 1967) or by increasing the temperature of the soak water which has the added advantage of reducing flatus-causing oligosaccharides (Calloway *et al.* 1971; Kon 1979; Ogun *et al.* 1989; Ofuya *et al.* 1989). However, it has been reported that high temperature soaking can adversely affect the flavor and texture of soaked beans (Al-Nouri and Siddiqui 1982), so room temperature soaking appears to be the best method for commercial and home preparation of beans using ordinary tap water. During soaking, organic phosphates are continuously hydrolyzed to inorganic phosphates by the action of phytase at low temperature, probably because of optimal temperature for phytase lies around 40C (Becker *et al.* 1974). Soaking also leads to loss of solids (Walker and Kochhar 1982). Components lost in soaking of cowpeas and other pulses include tannins, phytates, pectic acid, simple sugars, oligosaccharides, minerals, vitamins, and trypsin inhibitors. When cowpeas are soaked with their seed coats on, a little nutrient loss is incurred.

In some developing countries like Nigeria, cowpeas are usually soaked for a few minutes followed by rinsing to remove dirt and extraneous materials on the seed coat. Longer soaking times ($>$ 12 h) are not a common culinary practice in West Africa, as this may lead to bacterial contamination under tropical conditions as well as to loss of nutrients.

Dehulling

Dehulling or seed coat removal has the effect of reducing the dry matter of cowpeas and other legumes but leads to faster cooking times, increased digestibility, better texture and appearance. Dehulled beans or dhals are popular in India, Pakistan, Bangladesh and Africa. Dehulling can be achieved manually in homes by rubbing or stirring the wetted beans in a mortar and floating off the seed coats in water. This traditional method is laborious and time consuming, and efficiency can be improved by use of dehulling machines. This involves mechanical abrasion and needs a pretreatment consisting of wetting conditioning and drying

(Reichert *et al.* 1979; Hudda 1983). The advantages of dehulling lie in the removal of seed coat tannins, anthocyanins and trypsin inhibitors (Walker 1982), as these antinutrients can lower the protein quality by reducing the digestibility of the cowpea (Ogun *et al.* 1989). However, some dietary fiber, calcium, iron and proteins may be lost through dehulling.

In Nigeria, cowpeas are not usually dehulled before cooking unless they are intended for use in the preparation of cowpea flour or paste for later preparation of steamed or fried cowpea products. The cowpea testa removal is important because the colored hilum and tough seed coat interfere with the functional behavior of the paste or flour if not removed. Since the testa is not easily digestible, it should also be removed when preparing cowpea dishes for infants and children. However, the testa is a valuable animal feed. Some studies (Uwaegbute and Nnanyelugo 1989) have shown that cooked undehulled cowpeas induced diarrhea when fed to some children, while no diarrhea was experienced when the same subjects were fed the dehulled product.

Grinding or Milling

Cowpea can be partially milled into dry dehulled splits or dhal (Kurien 1987). Dhal is a good storable form of cowpea. It is not easily prone to insect infestation, since there is no room for the insect to hide in the split cotyledons. Dry milling can be done locally by breaking the split or whole seeds into smaller pieces using mortar and pestle or grinding stone. Afterwards, the flours are winnowed to remove the husk and later sieved to obtain fine flour for use in the preparation of various cowpea products. Whole or dehusked split cowpea can be ground into dry flour or ground wet into a batter for use in a number of sweet and savory preparations alone or in combination with cereals (Ningsanond and Ooraikul 1989a,b). The eating quality of milled cowpea products, particularly the texture, depends on the flour composition, degree of fineness of grinding and relative proportions of particles of different mesh grades and cooking conditions. Grinding into flours can promote beany flavor in cowpeas unless such flours are appropriately treated to inactivate lipoxygenase enzymes.

Fermentation

This is a food processing technique practiced by man for centuries in various parts of the world, especially the Orient and Africa. Various legumes can be fermented into nutritious products. For example, tempeh is traditionally obtained from fermented soybeans using various inocula. Fermented products like tempeh from cowpeas are not common in Nigeria and West Africa, but their production is being investigated to enhance their general utilization in the region (Djurtoft 1982). A yoghurt-like product has been produced from cowpea (Rao *et al.* 1988).

Fermentation has been reported to have caused a general improvement in the nutritional quality of cowpeas (Zamora and Fields 1979; Akpapunam and Achinewhu 1985). Fermentation of various legumes also leads to improved protein quality and availability, increased palatability, reduced phytic acid and flatulence-causing oligosaccharides, increased levels of B-vitamins, increased shelf-life and removal of toxic components (Hesseltine 1983; Bressani 1983). Fermentation of legume and cereal mixtures has attracted possibilities because the protein quality of fermented bean-cereal mixture is higher than that of the bean alone (Bressani 1983). Generally, most fermented legumes are prepared by initial cooking or soaking to soften the seed coat, then dehulling, grinding, cooking, draining and fermenting for 1–5 days using various microorganisms such as *Rhizopus oligosporus, Bacillus subtilis* and *Staphylococcus aureus*) or adventitious inocula. The fermented product can later be dried or cooked with other ingredients into savory dishes. Further research is needed to assess cowpeas potential in fermented foods.

Germination (Sprouting)

Use of germinated cowpeas in food is fast gaining popularity in Nigeria and other West African countries (Akpapunam and Achinewhu 1985; Ologhobo and Fetuga 1986; Obizoba 1989). Germination or sprouting improves proteins, carbohydrates, vitamins, minerals and overall nutritional values of legumes and leads to reduction in some toxicants (Vanderstoep 1981; Boralkar and Reddy 1985). Germination leads to an increase in enzymes (Nnanna and Phillips 1988) as well as free amino acids. Vitamins such as ascorbic acid, riboflavin, niacin, choline and biotin are increased by germination (Nnanna and Phillips 1989). However, thiamin and pantothenic acid do not change while folic acid is diminished by germination. Germination leads to a slight decrease in trypsin inhibitor activity, and ample decrease in starch and flatulence-causing oligosaccharides in cowpeas (Ologhobo and Fetuga 1986; Nnanna and Phillips 1988, 1990). During germination, reducing sugar content increases while polyphenol and phytate levels are reduced (Chen and Pan 1977). There is a general increase in nutritive value of germinated cooked cowpeas (Obizoba 1989).

Germination imparts a characteristic, agreeable flavor to cowpeas probably because of amides released during germination (Kurien 1987). The germinated cowpeas can be dried and cooked later into sweet savory dishes with good nutritional qualities.

Heat Treatment

Several heat treatments are employed in legume preparations before they can be consumed. These include boiling to an eating-soft condition (atmospheric boiling), pressure cooking, steaming, frying and roasting. Whole undercorticated

cowpeas are usually boiled because the testa removal and grinding process are laborious and time consuming; this is one of the constraints in increased cowpea consumption (Dovlo *et al.* 1976; Uzogara *et al.* 1988). Cooking under pressure appears to be the best method of reducing cooking time of cowpeas but pressure cookers are expensive in developing countries (Uzogara *et al.* 1988). Testa-free cowpea cotyledons can also be ground into dry flours or wet paste using mortar and pestle, grinding stones or village hammer mills. The paste product or rehydrated flours can be deep fat fried into bean balls (McWatters 1983) or steamed into moin-moin (Adeniji and Potter 1980; Lasekan *et al.* 1987).

The nutritional implications of heat processing of legumes have been extensively studied (Elias *et al.* 1976; Onayemi *et al.* 1976; Geervani and Theophilus 1980; Walker and Kocchar 1982; Bressani 1983; Kurien 1987). Heat treatment can affect the nutritional value of beans stored under various conditions before they are cooked. Fresh cowpeas have better *in vitro* carbohydrate digestibility than year-old seeds. After cooking, starch grains are gelatinized and lose their characteristic birefringence (Uzogara *et al.* 1988, 1992b; Sefa-Dedeh *et al.* 1978). Gelatinized starch is more readily digested by enzymes than ungelatinized starch. Heat treatment for specific optimum periods also improves protein quality of cowpeas and other legumes by improving protein digestibility and PER (Table 10). Heating also inactivates antienzyme factors (such as trypsin and amylase inhibitors), hemagglutinins, polyphenols and cyanogenic glycosides, which can influence protein utilization. Heat treatment can also produce acceptable flavors and colors with food legumes. However, extended cooking at higher temperatures and pressures lowers the nutritional quality of legumes.

The desirable effects of heating on legumes can be attributed to loss of toxicity of proteinaceous antinutrients and easier digestion of heated denatured globulins, which are normally resistant to denaturation and digestion in the native state. The initial rise in PER is due to rapid inactivation of the proteinaceous antinutrients (Bressani 1985). The loss of protein quality on prolonged heating may be related to the Maillard browning reaction in which lysine and other amino acids react with sugars making such amino acids biologically unavailable. There may also be complex reactions between these amino acids and phenolic pigments. Possible loss of protein quality under prolonged cooking may also be due to cross-linking of amino acids, forming compounds such as lysinoalanine and dehydroalanine, usually under alkaline conditions. All these adverse changes lead to reduction in digestibility and PER.

Alkaline Treatment

Boiling cowpeas can take a long time, consuming excessive fuel energy in many developing countries where there is energy shortage. Consequently, housewives

TABLE 10.
EFFECT OF COOKING ON PROTEIN QUALITY OF COWPEA

Legume	TIA ($\times 10^{-4}$ units/g)	% Digestibility Raw	% Digestibility Heated	PER Raw	PER Heated
Cowpea[a]	1.9	79	83	1.4	2.2
Cowpea[b]	N.D.	73.2	77.4[1]	1.21	1.33

Source: [a]Liener (1976); [b]Bressani (1985).
[12]Autoclaved at 15 psi, 15 m in, 121C.

(especially in Nigeria and Ghana) shorten the cooking time of beans by raising the pH of the cooking solution with an alkaline rocksalt known in West Africa as "kanwa" or trona (Ankra and Dovlo 1978; Edijala 1980b; Onwuka 1983; Oyeleke 1984; Uzogara *et al.* 1988). Sometimes sodium bicarbonate and wood ash may be used to substitute kanwa in raising the pH and thereby reduce the cooking time (Laurena *et al.* 1986; Uzogara *et al.* 1988). Kanwa is sometimes misnamed "potash" in Nigeria because of the erroneous belief that it is a complex potassium salt. The mineral however is a complex sodium salt ($Na_2CO_3.NaHCO_22H_2O$), sodium sesquicarbonate, an admixture of sodium carbonate and sodium bicarbonate. The salt is mined in several rocksalt deposits or quarries in various parts of West Africa. Use of these alkaline salts in cooking increased water uptake and cowpea tenderization, thereby reducing cooking time (Uzogara *et al.* 1988). Cooking cowpeas with the alkaline salts improved digestibility (Oyeleke *et al.* 1985) and reduced some antinutrients (Uzogara *et al.* 1990a,b); but B-vitamins, especially thiamin were decreased (Edijala 1980b; Uzogara *et al.* 1991a). Growth (weight gain) and protein quality (PER and NPR) were also reduced in rats fed kanwa-cooked cowpeas (Uzogara *et al.* 1991b). It was also observed that organoleptic quality of kanwa-cooked cowpea was decreased, especially when high levels of kanwa was used (Uzogara *et al.* 1988). Therefore, the level of kanwa used in cooking cowpea should be reduced in order to prevent reduction in organoleptic and protein quality while saving cooking fuel. Use of low level of alkaline salts is also recommended to prevent possible formation of lysinoalanine, a toxic amino acid capable of causing renal lesions when fed to laboratory animals (Struthers *et al.* 1977) and possibly humans.

POPULAR WAYS OF PREPARING COWPEA FOOD IN AFRICA AND OTHER DEVELOPING COUNTRIES

Cowpeas are widely consumed in Nigeria, as well as other African countries, North and Central America, South America and the Indian subcontinent (McFie 1967; Dovlo *et al.* 1976; King *et al.* 1985; Nnanyelugo *et al.* 1985; Bressani

1985; Kurien 1987). They are consumed as a boiled vegetable using fresh or rehydrated dry seeds, as roasted seeds used for snacks, as ingredients in soups, spreads, stews, porridges, breads, salads and casseroles and as steamed or fried dishes (Table 11). They are also consumed when cooked in combination with cereals, tubers, legumes, oil seeds and other staples such as plantain, banana and garri (Akpapunam and Markakis 1981; Okeiyi and Futrell 1983; Sanchez *et al.* 1972). The combination dishes are prepared by cooking the staple and cowpeas separately, then mixing them together with addition of vegetable oil, salt, onion, pepper, palm oil, ground shrimp or crayfish, or with pieces of smoked fish or meat. The mixture is then stewed together for some time before serving.

Many Nigerian households prepare cowpea dishes about twice a week in addition to cowpea food products purchased from street vendors (King *et al.* 1985). Cowpeas, therefore, play an important role in the diets of low income Nigerian families who depend on these beans as their major source of protein. Some popular cowpea dishes in Africa are described below.

Akara (Deep Fat-Fried Bean Balls)

Fried cowpea ball or akara is commonly consumed in Nigeria and other African countries because of its crisp and crunchy texture. It is usually consumed together with akamu (fermented corn starch gruel) or with eko (moulded akamu) as part of a family breakfast. It can also be bought from street vendors who sell akara as a popular snack food and as food for travellers.

Traditionally, akara can be prepared from cowpea paste made from wet ground cowpea. Modern method of akara preparation involve use of hydrated cowpea flour or cowpea meal (McWatters 1983; McWatters and Brantley 1982). The paste or rehydrated flour is mixed with some water and whipped or stirred in a mortar with pestle until enough air is incorporated. Then the whipped product is seasoned with pepper, salt, onions or crayfish, scooped with a wooden spoon and deep-fried in hot palm oil or other vegetable oil) until completely brown (McWatters and Flora 1980; McWatters 1983; McWatters *et al.* 1990a,b). By varying the amount of water as well as the whipping time during paste preparation, light or heavy akara may be obtained. The quality of akara is also affected by particle size, water-to-flour ratio, volume and viscosity of the foam produced when cowpea paste is whipped (McWatters 1985; Ngoddy *et al.* 1986). This fried product is known by various names (such as akara, koose, kosai, akla, accra) in different parts of Africa. Akara is one of the most extensively investigated cowpea foods (Dovlo *et al.* 1976; McWatters and Flora 1980; McWatters and Brantley 1982; McWatters 1983, 1990a,b; Ngoddy *et al.* 1986; Hung *et al.* 1988; Nnanna *et al.* 1989; Jung and McWatters 1990).

TABLE 11.
SOME FOOD USES OF COWPEA

Cowpea Food	Description	Uses
Akara	Fried cowpea ball	breakfast foods and snacks; food for travelers
Moin-moin	Steamed cowpea paste	lunch and dinner foods, foods for entertainment
Ewa-ibeji	Boiled whole cowpea seeds	lunch and dinner foods; foods for growing children
Danwake	Boiled dehulled cowpea seeds	lunch and dinner foods; foods for growing children
Gbegiri	Cowpea soup	appetizers; foods for infants, children and adults
Adayi	Cowpea puree	puree baby foods
Cowpea spread	Boiled, mashed cowpea mixed with fat and seasonings	spread on bread and yams
Roasted cowpea	Nutty flavored roasted cowpea seed	snack foods or appetizers
Cowpea bread	Local bread made with cereal flour and cowpea flour	breakfast, lunch and snack foods
Cowpea cake	Cowpea used as ingredient in cakes and pies	breakfast, snack and entertainment foods
Rice-and-beans-jollof	Combination dishes from boiled rice and boiled cowpea seeds	variety foods for infants, children and adults
Akidi-na-oka	Combination dish from boiled maize and boiled cowpea	variety foods for adults
Cowpea-sorghum dish	Combination dish from boiled cowpea and sorghum	variety foods for adults
Cowpea-plantain potage	Boiled cowpea and plantain	variety foods for infants, children and adults
Cowpea-yam potage	Combination dish from boiled yam and boiled cowpea	variety foods for infants, children and adults
Cowpea weaning foods	Dehulled, boiled cowpea supplemented to cereal-based infant foods	infant feeding

Akara prepared from commercial cowpea flour has a different texture and flavor from akara made from cowpea paste from wet-dehulled cowpea (Dovlo *et al.* 1976; McWatters 1983). Recent research has shown that akara is also acceptable in other regions besides Africa (McWatter *et al.* 1990a,b).

Other fried cowpea products include "awon" (fried cowpea ball with okro); "cowpea kakro" (fried plantain and cowpea); "sekesin" (fried cowpea cake with onions); "kengbe" (large akara ball fried in palm oil); as well as cowpea strips, crepes, croquettes, cutlets and scotch eggs (Dovlo *et al.* 1976).

Moin-Moin (Steamed Cowpea Paste)

Cowpea paste or rehyrated flour can be seasoned with onions, salt, pepper, crayfish and palm oil. The mixture is distributed in small portions into covered aluminium bowls greased with oil or into greased tin cans with covers or wrapped in greased aluminium foil or blanched green leaves (Musa, Sacrophrynum or Thaumatococcus spp). These green leaves give a characteristic pleasant flavor to the moin-moin and are therefore preferred by the local people. The cans or wrapped leaves are placed in steamers or deep pots lined with wooden sticks or leaves to facilitate steam cooking. The paste is steamed until appropriately cooked (Dovlo *et al.* 1976; Adeniji and Potter 1980; Ngoddy *et al.* 1976; Lasekan 1987). The steamed food is called by various names, such as "moin-moin," "olele," "alele," "mai-mai," and "tabani," in different West African Towns. Moin-moin is served with akamu as a popular breakfast food. It is also served as a main course meal together with rice, yam, or plantain at lunch, dinner or at parties. Research has led to production of canned moin-moin (Adeniji and Potter 1980), but this preserved product is not common in local African markets.

Ekuru is prepared from cowpea paste in a way similar to moin-moin except that the paste is whipped until very light, then hot water is added gradually to make a thin but not watery consistency before steaming. It is served as lunch or supper dish with boiled yam, bread or agidi.

Other steamed cowpea products include "jogi" (steamed cowpea cake with toasted melon seeds), "ikoko" (steamed cowpea cake with smoked fish or shrimp), "apapa" (steamed cake with bitter pepper), "kakro" (cowpea cake with fried plantain) and "yakayake" (steamed fluffy cowpea paste) (Dovlo *et al.* 1976).

Ewa-Ibeji (Boiled Cowpeas)

Cowpea can be rinsed and boiled without soaking or soaked for a few hours before boiling in order to reduce cooking time and save cooking fuel. Cooking to softness takes from 30–60 min, depending on the cowpea variety. The boiled cowpea is seasoned with salt, tomato, pepper, vegetable oil, crayfish or dry fish and served with eko, fried plantain or other staples. If boiled cowpea is not seasoned with oil and other ingredients, then it can be served with rice and stew. This dish is common all over West Africa. It is commonly referred to as "cowpea-dish-for-twins."

Awuje (Soft Boiled Cowpeas)

This food, which is popular in Western Nigeria, is prepared by preboiling cowpeas in water for a few minutes. The cook water is discarded and the beans covered again with water and brought to boil. After discarding the cooking water,

the beans are mixed with two parts of water, then salt or potash is added and the mixture is brought to boil. The heat is then lowered and beans allowed to simmer until the beans absorb all the water and become soft. More water is added and the cowpea boiled until it is mushy. It is served with stew, bread or agidi.

Danwake (Cowpea Dumplings)

This cowpea food is popular in Northern Nigeria. It is prepared by soaking dehulled cowpea seeds or flour in kanwa solution (1–10% w/v) for 15–20 min; then salt is added to taste and the mixture is stirred until a thick consistency is obtained. Spoonfuls of the cowpea mixture are dropped into rapidly boiling water until it cooks for 3–5 min. The water is drained and the cooked product is served with fish, meat broth, egusi or sesame oil. Dovlo *et al.* (1976) have reported that as much as 10% kanwa relative to weight of cowpea has been used in preparation of danwake in Northern Nigeria. Such foods are high in sodium and may also have altered organoleptic and nutritional properties (Uzogara *et al.* 1988). The high concentration of alkaline salts in such foods may lead to possible formation of lysinoalanine, a toxic amino acid (Struthers *et al.* 1977).

Gbegiri (Cowpea Soup)

This soup is prepared from cowpea by soaking the beans for a few hours in water. Later the beans are dehulled and the testa-free cowpea is boiled with about 1 g of potash (kanwa) and cooked at low heat until it softens. The beans are mashed, seasoned with onion, pepper, smoked fish, cooking oil and salt and cooked further for 20 min at low heat, stirring frequently to prevent scorching. Crayfish and grated okro are added and cooked for another 3 min. The soup is served with amala, garri or eko.

Other forms of soup from cowpea include cowpea flour soup, "epeza" soup (cowpea flour soup with dry fish), cowpea soup with beef and okro, "awuje" (cowpea soup with smoked fish), palm nut soup with cowpea, okro soup with cowpea leaves (Dovlo *et al.* 1976).

Cowpea Spread

Cowpea is soaked and testa is removed. It is boiled in water until very soft. Excess water is drained, the beans sieved and blended to a puree, seasoned with onions, margarine, salt and nutmeg and used as a spread on toast, yam or sandwich.

"Adayi" (cowpea puree baby food) is also prepared as above except that the amount of salt and nutmeg are reduced.

Roasted Cowpeas

Cowpeas can be soaked in salty water, drained and boiled with little water until all the water evaporates. Then it is stirred constantly, avoiding burning until the skin peels off, and a nutty flavored seed is produced. It is used as snacks.

Baked Cowpea Products

Cowpeas can be baked into cakes or pies and served on special occasions, like parties and weddings. Such cowpea dishes include cowpea "apiti" (baked cowpea paste with egg), cowpea tea-cake and cowpea pie. Local cereal flours are also mixed with varying proportions of cowpea flour and used in baking local breads.

Cowpea Combination Dishes

Beans-and-Rice Jollof. This cowpea-rice dish is prepared by first rinsing and partly cooking the cowpeas, then palm oil or other vegetable oils, salt, fish and seasonings are added and boiling continued. Rice is later rinsed and added to the mixture and the cooking continued until the rice is softened. This is served with meat or as prepared. The dish is very filling and is a favorite food of growing active children.

Akidi-Na-Oka. This is a cowpea-maize dish prepared by boiling separately cowpea and maize grains until both are tender. Potash may be added to the maize to increase its softness. The two components are mixed together with palm oil, crayfish or dry fish and seasoned with onions, pepper and salt and cooked further until appropriately tender. This food has a good nutritional property (Abbey *et al.* 1988).

Other cowpea maize dishes include roasted corn-cowpea porridge, "adalu," "agwa ibala" (cowpea-corn flour), "owowo" (maize-cowpea-groundnut mix), "ayibli" (brown cowpea-maize mix) (Dovlo *et al.* 1976). Maize can be substituted in the above dishes with millet or guinea corn where maize is not available.

Cowpea-Plantain Dish. Cowpeas are boiled until soft, then mixed with cooked ripe plantain cubes. The mixture is cooked again with seasonings such as onions, fresh pepper and dry fish until soft. The food is consumed as prepared or served with agidi or garri. Other cowpea-plantain combination dishes include cowpea stew with fried plantain, cowpea "kakro" (fried plantain and cowpea cake) and cowpea "ofam" (baked cowpea-plantain loaf) (Dovlo *et al.* 1976).

Frejon (Cowpea-Coconut Dish). This was formerly a Brazilian dish, which is now consumed in Lagos Nigeria and other West African countries. Cowpeas

are cooked until mushy, then mashed into a paste and made into a puree. Coconut milk is extracted from coconut and added to the cowpea puree, boiled until very thick, then its taste is enhanced by addition of salt or sugar. It is served with fish stew and dry garri or served as a dessert.

Igbalo (Steamed Cowpea Paste with Mellon Seeds). This is prepared by mixing two parts of cowpea paste with one part of ground egusi (shelled melon seeds) with seasonings such as salt, pepper and tomato. It is whipped with hot water added intermittently until the mixture is viscous. Then it is placed in aluminium bowls, covered and steamed until properly cooked. It can be served with stew, eko, bread or rice.

Jogi is also a cowpea-egusi mix prepared in a way similar to igbalo except that the amount of egusi added is greater than that of cowpeas. The steamed product is similar in consistency to an omelette and is very nutritious.

Novel Cowpea Products

Infant Weaning Foods. The high protein content of cowpeas has led to its incorporation into cereal based infant foods as a way of enhancing their protein quality. Blends of cooked decorticated cowpea with rice, corn, sorghum, and yam have been evaluated (Odum *et al.* 1981; Oyeleke *et al.* 1985; Akinyele and Adesina 1986; Akinyele and Akinlosotun 1987; Roman *et al.* 1987; Uwaegbute and Nnanyelugo 1989; Abbey *et al.* 1988; Malleshi *et al.* 1989; Uzogara *et al.* 1990b). Digestibility and low level of flatulence compounds are important factors to consider when feeding cowpeas to children. Most cowpea used for infant foods should be dehulled because cowpeas served as boiled beans without dehulling are unsuitable for children and can cause them diarrhea. The government of Nigeria is contemplating starting commercial preparations of cowpea-based infant formula. The success of such a product will depend on the price it will be sold to the public, since most low income mothers have low purchasing power. It will also depend on adequate subsidy from the government, good promotion by the media and relevant nutrition education to the public.

Extruded Cowpea Products. Extrusion cooking is an efficient technique for converting starch or proteinaceous raw materials into finished foods or into intermediates that require minimal further processing. Extruded cowpea products have been produced on experimental basis (Phillips *et al.* 1985; Phillips and Baker 1987; Akinyele *et al.* 1988). They are not yet available in local African and tropical markets. Protein isolates from cowpea are also produced on experimental basis, but these are not available in local tropical markets.

Fermented Cowpea Products. A yoghurt-like product from cowpea has been produced and used in the Indian subcontinent (Rao *et al.* 1988). A natto-like product has also been made from cowpea (Beuchat *et al.* 1985). Even tempeh has been made from cowpeas (Djurtoft 1982). Flours have also been produced from fermented cowpeas (Lu and Sanni-Osamo 1988). Fermentation besides making the product light makes it more easily digestible. Some of the fermentative changes such as breakdown of starch, protein and indigestible carbohydrate residue will be helpful in improving utilization of cowpeas. All these fermented cowpea products have an enhanced protein quality and need to be gradually introduced after appropriate sensory tests into the diets of the populations that consume cowpea foods.

Germinated Cowpeas. Germinated or malted cowpea seeds have been produced and evaluated (Obizoba 1989). These are consumed as salads or after cooking.

Ready-to-Eat Cowpea Foods. Canned moin-moin has been produced experimentally (Adeniji and Potter 1980). Functional properties of cowpea flours have also been investigated in order to facilitate production of convenience foods from cowpeas (Enwerre and Ngoddy 1986; Sefa-Dedeh and Giardom-Farkye 1988; Phillips *et al.* 1988; Abbey and Ibeh 1988; Sosulki *et al.* 1987; Padmashree *et al.* 1987; Bulgarelli and Beuchat 1990).

Effects of the Recipes

Not all the cited cowpea recipes are utilized in all developing countries. There are cultural differences in methods of utilization of cowpea in various countries. For example, while cowpea is grown mainly for seeds and pods in West Africa, it is grown for both seed and leaves in East Africa. In India and the Far East, cowpeas are puffed, toasted or sprouted before consumption (Kurien 1987), and wafer-like products from cowpeas are popular in India. The most popular cowpea foods in Africa and akara, moin-moin, beans-and-rice jollof, cowpea-yam pottage, cowpea-plantain pottage, and plain boiled beans. The combination dishes are preferred by people who perform strenuous jobs like construction and farm work requiring high energy expenditure. In Central America, wet cooking is the most common method of processing cowpea, which is later consumed as a side dish with soups, stews or other foods.

There is need for cooperation among countries who produce and use cowpea. Exchange of information among such countries and regions will be of mutual benefit for all concerned.

RECOMMENDATIONS

The acute shortage of meat and animal proteins in developing countries has made it necessary for consumers in these countries to rely heavily on proteins from legumes especially cowpeas. These beans, which are rich in proteins, minerals, B-vitamins and dietary fiber, are important in the diet of people in developing countries where malnutrition is a perennial problem. Although cowpea production has increased through development of high yielding varieties, constraints still exist in the processing and full utilization of this crop as food. Fortunately, through recent collaborative research (Phillips and McWatters 1991), flour production technology has been developed to facilitate cowpea usage in fried, steamed or baked foods thereby removing the drudgery, time and labor involved in dehulling and milling of cowpea for certain dishes. However dehulling machines and mills are not commonly available to most households because of their high cost and location in only a few centers.

Attention should now be directed to other areas of cowpea processing and utilization. More research should be conducted into ways of reducing the cooking time of undehulled beans, as this is an important factor preventing frequent use of cowpeas on these regions where cooking fuel is scarce and expensive. Such studies are necessary because, for customary or ethnic reasons, some people in Africa still prefer whole cowpea seeds in food to cowpea flour which are regarded as food for children and invalids. Traditional cowpea processing methods, such as use of native alkaline rocksalt (trona) in boiling cowpeas or use of cowpea in combination dish with other foods, should be reviewed and reevaluated with the aim of improving their efficiency and nutritional quality. Attention should now be directed at processing techniques that cause reduction of antinutrients (enzyme inhibitors, phytates, tannins, lectins, etc.) or of oligosaccharides, indigestible protein and starch that may contribute to the flatus problem. In particular the role of trona in flatus reduction requires further investigation. Research should also be conducted on digestibility of cowpea protein. The role of the seed coat and cooking broth should be studied further, as these are suspected to be the cause of diarrhea experienced by children who consume cowpeas. Acceptability and cooking quality characteristics of cowpeas processed in different methods deserve more attention. Control of storage-induced quality changes (insects, mold and hard cooking) should also be investigated further.

Novel and improved cowpea products should be developed. Such products should be more convenient, more stable, and more nutritious than traditional cowpea dishes, thereby expanding cowpea use and increasing the total market for the raw commodity. Several high protein composite flours based on cowpea-cereal or other foods should be developed for use as weaning foods, mixes for

school feeding programs and for nutritional rehabilitation centers for treatment of protein-energy malnutrition or other nutitional disorders. The cowpea flour, besides increasing protein and energy content, also balances the cereal or other foods with respect to lysine and tryptophan content and also improves flavor and removes monotony in the diet. More simple recipes should be formulated in addition to traditional recipes in a particular region, as diversifying cowpea use will benefit producers and consumers in the long run.

Cowpea has now assumed a wide global importance, being popular in Africa, Latin America, Asia, UK, Central and North America because of its cheapness, high nutritive value and health benefits. Further research and development activities are needed in order to realize the full potential of cowpeas for use in urban and rural areas. Such activities call for interdisciplinary, interinstitutional and international collaboration in various phases of research on cowpea. Regarding interdisciplinary collaboration, food scientists and technologists, nutritionists, home economists, biochemists, chemists, geneticists and plant breeders need to interact with each other to upgrade the nutritional potential of cowpea. Developed countries with their high capabilities in Science and technology can assist in research and development activities or in funding cowpea research through bilateral or multilateral programs.

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BOOK REVIEW

SENSORY EVALUATION TECHNIQUES, Second Edition. Morten C. Meilgaard, Gail Vance Civille and B. Thomas Carr. CRC Press, Inc., 354 pages.

The industrial or research food scientist often has the challenging task of establishing the sensory acceptability of a food or beverage product. Deciding what test to run and how to conduct it are two of the most common problems encountered in sensory testing. This book serves as a useful guide and handbook for resolving these issues. In it, the authors provide practical solutions to sensory problems using accepted methods and standard practices. Clear and detailed examples of the various methodologies are given in a direct, "cook-book" format. All aspects of the test design are considered from selection of the test, development of the ballot and choice of the appropriate number of panelists, to statistical treatment of the data and interpretation of results. Controversial material is not addressed, but basic information needed to conduct a sound sensory evaluation is presented in a simple, straight-forward style.

Chapters 1 and 2 provide brief overviews of the development of sensory testing and the workings of the human senses. These chapters are not intended to be theoretical and readers wanting more in-depth coverage of these topics must look elsewhere.

Variability and bias is inherent with the use of humans as sensory assessors and minimizing such factors is critical for obtaining good test results. Chapter 3 discusses ways to control the test environment, including design of the physical setting, sample presentation and panelist instructions. Physiological and psychological factors also influence sensory judgements and are discussed in Chapter 4. The appropriate use of scales to measure sensory responses is introduced in Chapter 5.

A large portion of the book is devoted to difference testing. Chapter 6.1 covers the common overall differences tests such as the triangle, duo-trio and difference-from-control test. A section on the application of similarity testing, i.e., establishing sensory equivalence rather than difference, is a welcome addition and is rarely covered in similar texts. Attribute difference tests are presented in Chapter 6.2 with emphasis on multi-sample tests and their statistical treatment. Threshold testing is discussed in Chapter 7.

The selection and training of panelists are discussed in detail in Chapter 8. The appendices to this chapter give useful examples of screening and interview questionnaires. Also included are a collection of standard terms describing appearance,

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flavor and oral texture characteristics for descriptive analysis as well as intensity scales for measuring basic tastes, aromatics and oral texture. The examples are based on the Spectrum™ method of descriptive analysis developed by the second author. Definitions and applications of the most popular forms of descriptive analysis techniques follow in Chapter 9. Two relatively new techiques, time-intensity scaling and free-choice profiling are also reviewed.

Effective consumer testing is discussed in Chapter 10. The bulk of the chapter discusses preference and acceptance testing, but qualitative testing which uses focus groups and panels to probe consumer attitudes and habits are also briefly mentioned. Examples of consumer questionnaires are also provided.

Statistical methods are presented in two chapters. Chapter 11 reviews the basic statistical methods including hypothesis testing, t-tests and analysis of variance. Chapter 12 introduces some of the more sophisticated statistical techniques such as principal component analysis and response surface methodology. Detailed discussions of these methods are beyond the scope of this volume and interested readers are referred to other texts.

The last two chapters are written as guidelines in easy-to-follow, tabular form. Chapter 13 compactly summarizes the bulk of the material in this book. It presents the standard problems encountered in sensory testing with areas of application for the various tests. Since the results of sensory testing are of little value unless effectively interpreted and communicated to associates or management, guidelines for report writing are presented in Chapter 14.

The information contained in this volume is up-to-date and comprehensive. Each chapter contains a table of contents for easy reference and a complete bibliography. Statistical tables are also provided. This edition includes material not found in the first edition such as psychophysical theory and separate intensity scales for describing semi-solid and solid oral texture. The chapters discussing statistical methods have also been significantly reorganized and expanded. The text is printed in large type with bold headings and subheadings which make this edition much easier to read than the previous edition.

With the exception of the chapter on advanced statistical methods which may be too advanced for the novice, this book can also find use as a textbook, suitable at the senior undergraduate level. This is notable since few current texts can fill this important need.

In summary, this book is a valuable resource to those exposed to sensory testing for the first time as well as to more experienced sensory practitioners. Even if one has other sensory texts on the reference shelf, the current edition of this volume is well worth the investment.

BEVERLY TEPPER

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PUBLICATIONS IN FOOD SCIENCE AND NUTRITION

Journals

JOURNAL OF RAPID METHODS AND AUTOMATION IN MICROBIOLOGY, D.Y.C. Fung and M.C. Goldschmidt
JOURNAL OF MUSCLE FOODS, N.G. Marriott and G.J. Flick, Jr.
JOURNAL OF SENSORY STUDIES, M.C. Gacula, Jr.
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JOURNAL OF TEXTURE STUDIES, M.C. Bourne and P. Sherman

Books

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DESIGN AND ANALYSIS OF SENSORY OPTIMIZATION, M.C. Gacula, Jr.
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GUIDE FOR AUTHORS

Typewritten manuscripts in triplicate should be submitted to the editorial office. The typing should be double-spaced throughout with one-inch margins on all sides.

Page one should contain: the title which should be concise and informative; the complete name(s) of the author(s); affiliation of the author(s); a running title of 40 characters or less; and the name and mail address to whom the correspondence should be sent.

Page two should contain an abstract of not more than 150 words. This abstract should be intelligible by itself.

The main text should begin on page three and will ordinarily have the following arrangement:

Introduction: This should be brief and state the reason for the work in relation to the field. It should indicate what new contribution is made by the work described.

Materials and Methods: Enough information should be provided to allow other investigators to repeat the work. Avoid repeating the details of procedures which have already been published elsewhere.

Results: The results should be presented as concisely as possible. Do not use tables *and* figures for presentation of the same data.

Discussion: The discussion section should be used for the interpretation of results. The results should not be repeated.

In some cases it might be desirable to combine results and discussion sections.

References: References should be given in the text by the surname of the authors and the year. *Et al.* should be used in the text when there are more than two authors. All authors should be given in the References section. In the Reference section the references should be listed alphabetically. See below for style to be used.

DEWALD, B., DULANEY, J.T. and TOUSTER, O. 1974. Solubilization and polyacrylamide gel electrophoresis of membrane enzymes with detergents. In *Methods in Enzymology*, Vol. xxxii, (S. Fleischer and L. Packer, eds.)pp. 82–91, Academic Press, New York.

HASSON, E.P. and LATIES, G.G. 1976. Separation and characterization of potato lipid acylhydrolases. Plant Physiol. *57*, 142–147.

ZABORSKY, O. 1973. *Immobilized Enzymes*, pp. 28–46, CRC Press, Cleveland, Ohio.

Journal abbreviations should follow those used in *Chemical Abstracts*. Responsibility for the accuracy of citations rests entirely with the author(s). References to papers in press should indicate the name of the journal and should only be used for papers that have been accepted for publication. Submitted papers should be referred to by such terms as "unpublished observations" or "private communication." However, these last should be used only when absolutely necessary.

Tables should be numbered consecutively with Arabic numerals. Type tables neatly and correctly as they are considered art and are not typeset. The title of the table should appear as below:

TABLE 1.
ACTIVITY OF POTATO ACYL-HYDROLASES ON NEUTRAL LIPIDS, GALACTOLIPIDS, AND PHOSPHOLIPIDS

Description of experimental work or explanation of symbols should go below the table proper.

Figures should be listed in order in the text using Arabic numbers. Figure legends should be typed on a separate page. Figures and tables should be intelligible without reference to the text. Authors should indicate where the tables and figures should be placed in the text. Photographs must be supplied as glossy black and white prints. Line diagrams should be drawn with black waterproof ink on white paper or board. The lettering should be of such a size that it is easily legible after reduction. Each diagram and photograph should be clearly labeled on the reverse side with the name(s) or author(s), and title of paper. When not obvious, each photograph and diagram should be labeled on the back to show the top of the photograph or diagram.

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Short notes will be published where the information is deemed sufficiently important to warrant rapid publication. The format for short papers may be similar to that for regular papers but more concisely written. Short notes may be of a less general nature and written principally for specialists in the particular area with which the manuscript is dealing. Manuscripts which do not meet the requirement of importance and necessity for rapid publication will, after notification of the author(s), be treated as regular papers. Regular papers may be very short.

Standard nomenclature as used in the biochemical literature should be followed. Avoid laboratory jargon. If abbreviations or trade names are used, define the material or compound the first time that it is mentioned.

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