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FOOD QUALITY AND FUELWOOD CONSERVATION OF SELECTED COMMON BEAN (PHASEOLUS VULGARIS L.), CULTIVARS AND LANDRACES IN RWANDA

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FOOD QUALITY AND FUELWOOD CONSERVATION OF SELECTED COMMON BEAN (PHASEOLUS VULGARIS L.), CULTIVARS AND LANDRACES IN RWANDA

By

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ABSTRACT

FOOD QUALITY AND FUELWOOD CONSERVATION OF
SELECTED COMMON BEAN (PHASEOLUS VULGARIS L.)
CULTIVARS AND LANDRACES IN RWANDA

By

Krista C. Shellie

The cooking time and protein content of common bean are important in Rwanda because fuelwood is scarce and common bean is the major dietary staple. Common bean is cultivated and consumed in Rwanda as a mixture of genetic components (landrace). The purpose of this research was to identify ecologically sound technologies that promote nutritional well-being through sustained dry bean consumption.

The potential of reducing bean cooking time and enhancing protein content through genetic manipulation was investigated by estimating the magnitude of the genetic and environmental variance components. Ten cultivars were grown at three locations during five consecutive harvests. The genotypic variance component for cooking time was large, but no genotypic effect was observed for seed protein content. The most efficient allocation of resources for evaluating cooking time was four field replications over two harvests at two locations.

The impact of fast and slow cooking dry bean cultivars and novel bean cooking methods on firewood conservation was evaluated at 15 homesteads in Rwanda. 'Calima' (fast cooking), 'Rubona 5' (slow cooking), and landraces were cooked with a measured quantity of firewood by the women of the households. The open wood fire cooking method was compared to cooking after overnight soaking and cooking in a haybasket cooker. 'Calima' required 16% less firewood and 8% less time to cook

than 'Rubona 5'. The haybasket cooker used 40% less firewood than the traditional open fire cooking method.

The distribution of food quality traits in landraces was investigated in purchased landraces from 10 farms in Rwanda. One thousand seeds were selected at random from each landrace and sorted according to their seed color and seed size. The seed types comprising the largest percentage of each landrace were evaluated for cooking time and incidence of hard seed. The observed range in cooking time among landraces suggested that some farmers selected cultivars according to their cooking performance and were developing fast cooking landraces. Low genetic variability for the hard seed coat trait indicated that selection against this trait has been successful.

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INTRODUCTION

Crops are modern day artifacts made and molded over the last 10,000 years by only 6% of the humans who have ever lived out a life span on earth. Crop plants evolved from their wild progenitors under human selection pressure for desirable agronomic and food quality traits. Extant variability in the wild progenitor of common bean was of sufficient magnitude to permit early agriculturists to select for desirable traits, such as consistent and reliable yield, indehiscent pods, large seed size, preferred seed color, and palatable cooked texture. Domestication has resulted in larger seed size (20 - 60 gm per 100 seed), myriad seed colors, and faster cooking seeds.

Common bean is cultivated and consumed in the countries comprising the Great Lakes region of Central Africa (Rwanda, Burundi, and Kivu, Zaire) as a genotypic mixture of pure-line cultivars. Annual per capita consumption of common bean in Rwanda is the highest in the world (50 kg). Dry beans provide more than one-half of the dietary protein and at least one-quarter of the energy in the Rwandan diet. Common bean is cooked over an open wood fire in Rwanda, and the length of time required to render the grains palatable determines household wood fuel needs. Increasing land pressure has resulted in a scarcity of wood for fuel, and current fuelwood demands far exceed the supply. A reduction in the amount of fuelwood required to cook beans and an increase in the amount of nutrients supplied by beans in the Rwandan diet would have a positive impact on the environment and enhance nutritional well-being of consumers.

The research presented herein on food quality and fuelwood conservation of improved common bean cultivars was divided into three manuscript style chapters. Each chapter addressed a distinct aspect of food quality and fuelwood conservation. The first chapter evaluated the potential for reducing bean cooking time and enhancing protein content through genetic manipulation by estimating the magnitude of the genetic and environmental variance components of 10 high yielding cultivars. The research presented in Chapter 2 estimated the impact on fuelwood conservation of a slow and fast cooking cultivar, and novel bean cooking methods. The fast ('Calima') and slow ('Rubona 5') cooking cultivars evaluated for fuelwood conservation in chapter 2, were selected among the 10 cultivars studied in chapter 1. The last chapter explored how seed types with varying cooking times and incidence of hard seed are distributed among modern day, farmer managed landraces.

The research approach presented in this dissertation is a model example of the transfer of basic research to applied technology and extension. The basic research results in Chapter 1 were tested under actual conditions in Chapter 2. Potential technologies were evaluated for their environmental soundness and impact on nutritional well-being within existing household contraints. The survey of landraces presented in chapter 3 acknowledged the plant breeding skills of traditional farmers and identified fast cooking cultivars that could be distributed immediately to other areas of Rwanda. The ecologically sustainable technologies identified in this research illustrated a role agricultural research can play in alleviation of world hunger and protection of the environment.

LITERATURE REVIEW

Common bean (*Phaseolus vulgaris* L.) originated in the Americas, but is currently grown and consumed around the world. The dry seeds of common bean are an important dietary staple throughout Central and South America, and Central and Eastern Africa (CIAT, 1981). Africa produces approximately 10% of world dry bean production, with nearly 60% produced in Uganda, Rwanda, Burundi, Tanzania, and Kenya. Mean per capita consumption of dry bean in these African countries (31.4 kg/capita) is approximately 1.4 times greater than Latin American bean consumption (13.3 kg/capita). Animal protein is limited and expensive in Rwanda, and common bean provides up to 60% of protein needs and 25% of calories in the diet (MINIPLAN, 1988). In addition to consumption of its mature seeds, *P. vulgaris* is cultivated for its immature fruit and leaves. Common bean is also an important source of iron, calcium, thiamine, and niacin.

Freshly harvested dry beans require a longer period of time to cook than most other foodstuffs. The degree to which prolonged cooking time is considered a constraint depends upon the cooking method employed and fuel availability. Bean cooking time is less of a constraint in areas where pressure cookers are used, such as many regions of Latin America, and more of a constraint where firewood is scarce, such as in Central Africa and Guatemala. Common bean is also subject to some well documented cooking defects. Normal seed softening during cooking occurs through the conversion of insoluble Ca++/Mg++ pectate in the middle lamella to soluble Na+/K+ pectate (Muller, 1967). The hard-to-cook defect and the hard seed coat trait impair normal seed softening during cooking, but their mechanisms, inheritance, and the environmental conditions under which they develop are different.

The cooking time and protein content of recently harvested dry seeds has both a genetic and environmental component and, thus, is influenced by season, site, and various possible interactions of these effects (Ghaderi et al., 1984; Hosfield et al., 1980). Interactions involving seasonal effects warrant different considerations than interactions containing location terms (Allard and Bradshaw, 1964). This is because genotype x season interaction effects are more unpredictable than genotype x location interactions. Environmental influences can often be altered by soil and crop management changes in the case of genotype x location interaction effects.

Although heritability estimates for cooking time are not available, extant genetic variability has been reported for the cooked texture of recently harvested dry beans. Heritability estimates for quantitative differences in seed protein percentage range from 0.10 to 0.85 depending on the type of estimates and the populations (Leleji et al., 1972; Kelly and Bliss, 1975; Evans and Gridley, 1979). Despite the availability of genetic variation, there have been few attempts to breed for increased protein percentage or reduced cooking time (Bliss and Brown, 1983.)

Hard Seed Coat Trait

Hard seed coat, or hardshell, is a condition of seed dormancy where the seed coat becomes impermeable to water. Since these viable seeds do not imbibe water normally, they require a long cooking and germination period. While an impermeable seed coat is a valuable survival mechanism of the plant under adverse environmental conditions, cultivars that contain a high percentage of seeds with this condition have an objectionable, nonuniform cooked texture.

The development of hard seed is genetically and environmentally controlled (Gloyer, 1928; Stanley and Aguilera, 1985; Rolston, 1978). The incidence of hard seed coat increases as seed moisture content decreases, such as during low relative humidity storage. Plant breeding experiments to study the inheritance of hard seed coat were begun as early as 1918 (Gloyer, 1928). Gloyer found that by proper crossing and selection, hard seed coat could be eliminated. Hard seed coat has been found by most researchers to be highly heritable (Copeland, 1976), with relatively few genes involved (Rolston, 1978; Lebedeff, 1947). In a cross between a hard-seeded Great Northern and a nonhard-seeded Red Mexican cultivar, Kyle and Randall (1963) showed the hard seed coat character to be controlled by a single recessive allele.

Seeds with hard seed coat tend to be the smallest 20% in a bean sample (Bourne, 1967). Although Gloyer reported no relationship between the tendency to develop hard seed and seed coat color, Kyle and Randall (1963) found a close association between white seed coat color and the hard seed character.

Hard seed coat can be reversed, or softened, using various treatments such as an acid soak, scarification, radiation, and blanching (Rolston, 1978). Natural reversibility under high relative humidity also occurs.

Hard-To-Cook Phenomenon

The inheritance and genetic variability of the hard-to-cook defect has not been determined. Storage under high temperature (above 21 C) and relative humidity is one of the key factors which initiates the irreversible hard-to-cook defect (Jones and Boulter, 1983; Jackson and Varriano-Marston, 1981). Seeds with the hard-to-cook defect imbibe water, but do not soften during cooking (Burr et al., 1968). Beans below 10% seed moisture content could be stored at 25 C for 2 years, whereas storage above 13% moisture content at 25 C for six months resulted in reduced cookability.

The mechanism by which the hard-to-cook defect develops is still not clearly understood. A theory is that an enzymatic and a nonenzymatic process is responsible for the reduced rate of cell separation. High moisture beans produced more CO_2 and used more O_2 than low moisture seed during storage, indicating that high moisture seeds had an elevated metabolic rate (Morris and Wood, 1956). The enzymatic process, the middle lamella-cation phytase theory, postulates that high relative humidity and temperature during storage permit restricted metabolism and allow an excess of bivalent cations (Mg^{++} and Ca^{++}) to accumulate from the hydrolysis of phytin. These ions are free to combine with pectin in the middle lamella and form insoluble pectates (Rolston, 1978; Jones and Boulter, 1983a and 1983b). Moscoso et al. (1984) noted an alteration in the ratio of monovalent to bivalent cations in the seed tissue, supporting this theory.

A nonenzymatic process was recognized when the hard-to-cook defect was observed after control for enzymatic degradation with heat treatments (Molina et al., 1976). A high correlation was found between cooked bean hardness value and the lignified protein content of the cotyledon. Lignification appears to involve phenolic compounds, possibly explaining the seed color darkening observed by Burr et al. (1968) and Morris and Wood (1956). In highly colored beans, hardening occurs even if severe heat treatment has been employed.

Protein Digestibility and Antinutritional Factors

One of the most important nutritional problems of dry beans is low protein digestibility. Apparent protein digestibility values of different colored beans are low (48%-62%) compared with animal protein digestibilities for meat (82%-86%). Possible factors that influence the protein digestibility of cooked beans include residual heat labile factors, (trypsin inhibitors and hemagglutinin compounds), and heat stable compounds, (tannins or proanthocyanidins). The tertiary structure of protein bodies may also prevent proteolytic enzymes from acting effectively. Considerable extant genetic variability has been reported for protein digestibility. Breeding to eliminate or reduce the effects of antinutritional factors may contribute to increased protein utilization.

Heat labile antinutritional factors in common bean consist mainly of trypsin inhibitors (protease inhibitors) and lectins (phytohemagglutinins). Both protease inhibitors and lectins are usually denatured during cooking, however some authors report residual activity in cooked beans (Bender and Reaidi, 1982). Little is known about the levels of protease inhibitors in bean, although they appear to be lower than in some other legumes, such as soybean.

Lectins are glycoproteins, and account for up to 10% of total protein in bean seeds. The toxicity caused by lectins is due to the lectins combining with epithelial cells of the small intestine, interfering with their intestinal enzyme activity, and damaging the intestinal epithelial surfaces (Kim et al., 1976; Rouanet and Resancon, 1979; King et al., 1980a and 1980b). About 10% of common bean accessions are lectin-free or have very low levels of lectin. The absence of most of the detectable seed lectins in beans is controlled as a single recessive trait (Brucher, 1968; Brown et al., 1982). A large number of electrophoretic variants of the seed lectin(s) have been described and they appear to form a multiple allele series (Brown et al., 1982). The amount of lectin in a bean seed is related to its lectin pattern and presents an inverse relationship with the amount of phaseolin (Osborn et al., 1985). Bean cultivars have been classified into groups according to the specific blood cell agglutinating properties of their lectins (Brown et al., 1982). The effect of reducing the amount of seed lectin on plant growth traits are not obvious. Since the lectins can be deleterious to humans if not completely inactivated by heating, lectin-deficient lines may be beneficial when cooking time is reduced due to inadequate fuel supplies. Boiling for a minimum of 10-12 minutes is necessary to adequately detoxify lectins (Bender and Reaidi, 1982). In addition, presoaking greatly improves elimination of toxicity (Bender and Reaidi, 1982; Grant et al., 1982; Coffey et al., 1985). Proanthocyanidins, or tannins, are plant polyphenolic compounds which precipitate proteins, and form a complex that is difficult to digest (Griffiths and Mosely, 1980; Aw and Swanson, 1985; Elias et al., 1979; Reddy et al., 1985). The amount of tannins (located mainly in the testae) of dry bean ranges from 0 to 283 mg/100g of whole bean depending on the cultivar and color of the seed coat (Reddy et al., 1985). The presence of tannins is associated with a 7-10% reduction in protein digestibility (Bressani et al., 1982; Norton et al., 1985).

The quantitative variability for tannin content within grain classes has not been extensively investigated. Dark-colored seeds tended to contain the highest amount, but there was not a strong relationship between tannin content and seed color. Varying levels of tannins have been found in the different colored seeded types (Ma and Bliss, 1978). A high broad sense heritability for tannin content was revealed by analyzing four populations resulting from crosses between parents that differed in testa color and tannin content. In three of the four F_2 populations, the segregation patterns were similar, and few genes seemed to be responsible for genetic differences. Seeds with black testae contained the most tannin, but recombinant types with black and other colors were identified with relatively low tannin.

Bean cultivars with low tannin content may be obtained by either selecting among existing pure lines or by crossing and selecting for desirable recombinants. A major difficulty encountered in breeding for lower tannin content is lack of a reliable assay for measuring tannin content (L. Telek, personal communication, 1985). Also, it is unknown whether the presence of the polyphenolic compounds imparts desirable effects, such as disease and insect resistance that may be important in well-adapted cultivars. The relationships (if any) of the various polyphenolic compounds in the seed coat to seed aging and the hard-to-cook phenomenon should also be explored.

Priorities and Objectives of Genetic Improvement

Survey results from major bean producing and consuming countries imply that insufficient supply due to low productivity per unit area is the major limiting factor for increasing bean consumption. Introduction of high-yielding cultivars will not increase bean consumption unless the agronomically superior cultivars also meet the food quality criteria of consumers. For example, a high-yielding, black seeded cultivar ('Wulma') was selected for distribution by the Rwandan National Program in the 1960s. Wulma had very limited adoption by farmers because its black seed coat stained companion foods an unappealing gray color. The nutritional impact of high-lysine, 'Opaque 2' maize developed in 1964, has yet to be realized because of its poor milling quality and inferior yields (Bressani, 1973).

A high and reliable yield should be the primary consideration in a breeding program, but important consideration should be placed upon consumer acceptability characteristics such as grain type, ease of cooking, and storage life. Breeding for improved protein utilization including digestibility, quality, quantity, and antinutritional factors should be of tertiary importance after consideration for yield and consumer acceptability. The introduction of a high-yielding, low-protein cultivar with high consumer acceptability may have a greater nutritional impact than introduction of a less acceptable, low-yielding, high-protein cultivar. A high-yielding, acceptable, low-protein cultivar may have greater nutritional impact because the increase in yield may offset the lower protein content, and the more acceptable cultivar has a higher probability of being consumed.

Genetic improvement of bean protein for human utilization is important in regions where beans are the staple food or the staple food is low in protein, such as in Central Africa. When beans are commonly consumed with a cereal staple, such as in Latin America, genetic improvement of the lysine content in common bean is justified. In cereal based diets, dry bean provides a smaller proportion of the total protein than cereals, and their major contribution to the cereal protein is their lysine content. Genetic enhancement of bean protein digestibility would make more total protein available and, thus, simultaneously improve protein quality.

Substantial genetic variability exists in the gene pool of common bean for many of the traits that affect food quality. Genetic improvement of food quality-enhancing traits is possible if selection criteria in breeding programs address yield and quality factors. Concomitant selection for quality and yield can be achieved by maintaining agronomically promising populations through recurrent backcrossing while selecting strongly for quality components, or maintaining a prescribed level of quality through periodic crossing to a known acceptable standard while selecting for agronomic factors (Adams and Bedford, 1973). When there is inadequate knowledge of the biological mechanisms responsible for quality traits, such as the hard-to-cook phenomenon, modification through breeding is likely to be difficult and long-term.

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CHAPTER ONE

GENOTYPE X ENVIRONMENTAL EFFECTS ON FOOD QUALITY OF COMMON BEAN: RESOURCE EFFICIENT TESTING PROCEDURES

ABSTRACT

Fast cooking, high protein bean (*Phaseolus vulgaris* L.) cultivars are desirable when dry bean is the dietary staple and firewood is the main fuel source. This study was conducted to estimate the magnitude of genotype x environment variance components for cooking time, water absorption and protein content, and identify the most efficient allocation of resources for their evaluation. Genotypic and environmental interactions were estimated on the three traits from data of 10 cultivars grown at three locations in Rwanda, Africa, during five consecutive harvests. The genotypic variance component was larger than genotype x environment variance components for the cooking time index and percent water absorption. No significant genotypic effect was observed for seed protein content. The correlation (-.37) between the cooking time index and percent water absorption indicated that these traits are weakly associated but that water absorption should not be used to select indirectly for cooking time. The most efficient allocation of resources for selection of cooking time with the 25-pin bar-drop cooker was four field replications over two harvests at two locations. Water absorption is evaluated most efficiently with four field replications over two harvests at a single location.

INTRODUCTION

The protein content and cooking time of common bean (*Phaseolus vulgaris* L.) is important in many countries in Africa and Latin America where the dry seeds are a dietary staple and firewood is the main fuel source used for cooking (Shellie-Dessert and Bliss, 1990). Dry bean is an important protein and calorie source in the Rwandan diet (MINIPLAN, 1988). Rwandan households use approximately 1.300 Mg of firewood annually for cooking (Shellie-Dessert and Hosfield, 1990). Rwandan household fuel-wood requirements are largely determined by the frequency in which beans are cooked, and the cooking time duration required to render the beans palatable. The rate of deforestation in Rwanda currently exceeds that of forest replacement through afforestation programs (Sirven, 1981). An annual savings of 150,000 Mg of wood was estimated for Rwanda if the country's 1.1 million rural households were to adopt cultivars that cooked faster than those currently produced and consumed for food (Shellie-Dessert and Hosfield, 1990). The development of fast cooking dry bean cultivars with relatively high protein content are worthwhile breeding objectives to maintain sufficient nutrients in the diet and conserve fuel-wood.

A wide array of local cultivars are grown throughout Rwanda, each reflecting local consumer preferences and natural selection for types that are relatively successful under variable and often unfavorable conditions (Shellie-Dessert and Hosfield, 1990). The culinary and nutritional quality traits of the dry seeds of *P. vulgaris* can be manipulated by breeders if extant genotypic variability is significant with respect to environmental effects, and if a useful screening method is available for selection of the traits. Variability in culinary and nutritional traits of beans has been reported (Hosfield and Uebersax, 1980; Hosfield et al., 1984). However, information is scarce regarding the heritability of food quality traits over a range of grain types.

Variance components have been used to estimate the most efficient allocation of locations, years, and replications necessary for testing and selecting genotypes with improved plant characteristics. Fernandez and Chen (1989) used variance components to ascertain efficient resource allocation for mungbean (*Vigna radiata* L.) yield trials. Variance components were used by Campbell and Kern (1982) to establish an efficient quality testing program for sugarbeet (*Beta vulgaris* L.).

Evaluation of common bean genotypes for cooking time at the International Center for Tropical Agriculture (CIAT) in Cali, Colombia is based on a cooking time index derived from a bar-drop cooker (Jackson and Varriano-Marston, 1981). Although screening common bean for cooking time with a bar-drop cooker is useful and produces reliable data, the technique is laborious and time consuming for a large number of samples. It has been suggested that the amount of water dry beans absorb during soaking prior to cooking may be indicative of the amount of time required to render them soft enough to eat. Hence, the water absorption of a genotype may be a more useful and rapid indirect selection method to screen germplasm for cooking time.

The current research was undertaken in view of the lack of information on testing procedures for common bean nutritional and cooking quality. The specific objectives of the research were to: (1) investigate the usefulness of water absorption as a rapid, indirect method of screening for cooking time, (2) estimate genotype and genotype x environmental components of variance for cooking time, protein content, and water absorption, and (3) use variance component estimates to determine the most efficient temporal and spatial allocation of resources for testing dry bean food quality.

MATERIALS AND METHODS

Ten high-yielding cultivars representing several grain types, were used as the experimental materials in the study. The grain types; Black ('Kibobo' and 'Ikinimba'), Creme/Red Mottled ('Rubona 5', 'Calima', 'Mutiki 2', 'Var 11', and 'Nyrakizungu'), Red Kidney ('Kilyumukwe'), Pinto ('Nsizebashonje 4'), and Cranberry type ('GLPX-1124') were tropically adapted and obtained from the Institut Scientific de Recherche Agronomique au Rwanda (ISAR). The 10 cultivars were unselected for protein content, and culinary quality traits.

Field experiments were conducted at the ISAR research stations at Rubona (1700 masl), Karama (1400 masl), and Rwerere (2300 masl) in Rwanda during the first and second harvests (September to January; March to June, respectively), in 1984, 1985, and the first harvest of 1986. Annual precipitation (1200 mm, 10-yr avg.) and edaphic factors (ultisols, pH 5.5, 3% organic matter) were similar at the Rubona and Rwerere stations. Karama received less precipitation (811 mm, 10-yr avg.), and had different edaphic conditions (pH 5.0, oxisols, 1.5% organic matter). Average annual temperature (10-yr avg.) varied inversely with elevation (Rwerere 16 C, Rubona 19 C, Karama 22 C). The cultivars were planted in single-row, 4 m plots and arranged in a randomized complete block design with three replications. Rows were spaced 45 cm apart, and the within row spacing was 10 cm.

The traits studied were seed protein content, cooking time, and the amount of water absorbed during overnight soaking prior to cooking. The moisture content of the seeds was equilibrated to approximately 11% before protein analysis. Nitrogen determinations were performed on triplicate samples from each field replication in each of three locations after the first season of 1984, and the first season of 1985. Seeds were ground in a hammermill to approximately 40 μ particle size and the percent nitrogen was determined on the bean flour by an automated microkjeldahl method (Kelly and Bliss, 1975). Percent protein was calculated by multiplying g nitrogen by 6.25.

The moisture content of the dry bean samples were equilibrated to each other prior to analysis of water absorption and cooking time by storing them for two weeks in sealed plastic buckets at ambient (20 C) temperatures and relative humidity (70%). The percent water absorption of dry beans was determined by first soaking 30 seeds for 16 h in deionized water at room temperature and dividing the difference in weight before and after soaking by the dry weight of the 30 seed sample. Water absorption determinations were expressed in percentages and made on duplicate samples from each field replication per location in 1985 and 1986. Bean cooking time was estimated from the cooking time index determined with a 25 seed bar-drop cooker (Jackson and Varriano-Marston, 1981). The 25 seed bar-drop cooker is a miniaturization and modification of the experimental laboratory bean cooker designed by Mattson (1946) and modified by Burr et al. (1968). Twenty-five seeds that did not possess the hard seed coat defect (Gloyer, 1928) were selected from the imbibed, 30 seed sample used for water absorption determinations. Elimination of hard seed from the seed samples evaluated for cooking time controlled for cooking time and water absorption bias caused by the hard seed coat trait. The cooking time index was calculated as the elapsed time from initiation of cooking until 13 of the 25 penetrating bars had dropped and perforated seeds in the cooker. Cooking time determinations were made on a single sample from each field replication per location for the first season of 1984, and from duplicate samples from each field replication per location in 1985 and 1986.

Statistical analysis. All data were subjected to analyses of variance (ANOVA) appropriate to a randomized complete block design. A combined analysis of variance following the outline of Miller et al. (1959) was used to calculate variance components. Replications, harvests and locations were considered to be random effects in the mathematical model. Since the ten entries were selected because of their yield and adaptation, genotypes were fixed. The form of the ANOVA and the expected composition of the mean squares of interest are presented in Table 1. An approximate F test, (Satterthwaite, 1946) was used to test the genotypic main effect. The least significant difference (LSD) test criterion was used to evaluate differences between genotypic means. Separate estimates of the components of variance were obtained to evaluate the relative magnitude of the different effects by algebraic manipulation of terms comprising the expected mean squares. The standard error of variance components was computed according to

Table 1. Analysis of variance for 10 cultivars grown at 3 locations during 5 harvests in Rwanda.

Source of Variation	df†	MS	Mean Square Expectation‡
Harvest (H)	(h-1)		
Location (L)	(l-1)		
H x L	(h-1)(l-1)		
Rep/(H x L)	(r-1)hl		
Genotype (G)	(g-1)	M_5	$\sigma^2_e + r\sigma^2_{ghl} + rh\sigma^2_{gl} + rl\sigma^2_{gh} + rhlK_g$
G x H	(g-1)(h-1)	M_4	$\sigma^2_e + r\sigma^2_{ghl} + rl\sigma^2_{gh}$
G x L	(g-1)(l-1)	M_3	$\sigma^2_e + r\sigma^2_{ghl} + rh\sigma^2_{gl}$
G x L x H	(g-1)(l-1)(h-1)	M_2	$\sigma^2_e + r\sigma^2_{ghl}$
Error	(g-1)(r-1)hl	M_1	σ^2_e

† h, l, g, and r are numbers of harvests, locations, genotypes, and replicates, respectively; harvests and locations are random variables and genotypes are fixed in the model.
‡ σ^2_e = error variance; σ^2_{ghl} = variance due to interaction of genotypes, harvests, and locations; etc.

Christie et al. (1988). Variance component estimates were used to calculate the theoretical variance of a genotypic mean (G_x) for different combinations of harvests (1 to 5), locations (1 to 5), and replications (2 to 5) using the following equation:

$$G_x=[(\sigma^2_{gh}/h) + (\sigma^2_{gl}/l) + (\sigma^2_{ghl}/hl) + (\sigma^2/rlh)]$$

where h, l, and r are the number of harvests, locations, and replications, respectively. Pearson correlation coefficients for water absorption and cooking time were calculated based on 270 observations using the software program SAS (SAS, 1985).

RESULTS AND DISCUSSION

Genotype X Environment Interactions

The second harvest in 1984 was eliminated from the analysis because drought caused a loss of over 30% of the trial. Genotypic mean squares from the combined analysis of variance for cooking time and water absorption were highly significant despite significant environmental effects (Table 2). The variance components for genotypes accounted for 25 and 52 percent of the total variance for cooking time and water absorption, respectively (Table 3). Broad sense heritabilities for cooking time and water absorption were 33 and 59 percent, respectively. The genotypic effect for protein content was not significant (Table 2), and the genotypic variance component was 0 (Table 3). Environmental effects were unique for each of the culinary and nutritional traits measured.

Cooking Time. The genotypic variance component exceeded that of the genotype x location and genotype x harvest interaction components (Table 2). Genotype x location and genotype x harvest variance components accounted for only 0 and 7 percent of total variance, respectively (Table 3). The significant second order interaction of genotypes, locations, and harvests (19% of total variance) demonstrated that the rank among cultivars for cooking time changed significantly from one harvest and one location to another (Table 2, 3). Since the genotypic variance component exceeded that of first and second order interaction variance components, general recommendations can be made from the data for the region and future harvests.

Table 2. Mean squares from the combined analyses of variance for 10 dry bean cultivars grown at 3 locations during 5 harvests in Rwanda.

Source	Cooking time df	Cooking time MS	Water absorption df	Water absorption MS	Protein content df	Protein content MS
H	3	1829.95*	2	68.05	1	117.86
L	2	1151.46	2	2103.52*	2	319.62
H x L	6	259.81**	4	316.47	2	28.38**
R/(L x H)	24	66.86	18	156.97	12	2.81
G†	9	646.92**	9	4521.41**	9	5.15
G x L	18	59.69	18	154.09	18	2.74
G x H	27	102.89	18	337.27**	9	7.83**
G x L x H	54	66.15**	36	138.76	18	2.17**
Error	216	30.50	162	105.17	108	.86

*,** Significant at the 5% and 1% probability levels, respectively.
† Significance determined by Satterthwaite's (1946) quasi F'ratio.

Table 3. Estimates of variance components scaled to sum to 100 for quality traits of 10 dry bean cultivars grown in Rwanda at 3 locations over multiple harvests.

Trait	Component† g	gl	gh	ghl	e	Total
Cooking Time	25§	0‡	7	19§	49	61.75
Water Absorption	52§	1	8	4	36	294.53
Protein content	0‡	5	31	22	42	2.03

† g-genotype, l-location, h-harvest, e-error
‡ Small negative values or zero estimates of variance components.
§ Variance component estimate equal to or greater than twice the SE of the estimate.

A 12 minute range among cultivars for the cooking time index wasobserved (Table 4). The cooking time of common bean is important because of the effect it has on energy use. Shellie (Chapter 2) showed the relationship between cooking time and fuel-wood requirements by evaluating the firewood usage of Rwandan households when they cooked a slow ('Rubona 5') and a fast ('Calima') cooking cultivar. 'Calima' cooked to eating softness 15 minutes faster than 'Rubona 5', and required an average of 1.3 kg less fuel-wood than Rubona 5. Fuel-wood conservation is urgently needed to reduce the serious deforestation in many developing countries. The 12 minute range in the cooking time index observed in this study indicated that extant variability for

Table 4. Mean performances of 10 dry bean cultivars grown in Rwanda for three food quality traits evaluated in three locations during multiple seasons.

Cultivar	Cooking† time index (min)	Water‡ absorption (g/kg^{-1})	Protein§ (g/kg^{-1})
Kibobo	46	765	211
Rubona 5	45	1068	214
Ikinimba	44	677	214
Kilyumukwe	41	1025	215
Nsizebashonje 4	40	899	203
GLPX-1124	39	934	200
Mutiki 2	36	1000	217
Var 11	36	988	208
Nyrakizungu	35	1035	208
Calima	34	1043	211
LSD (0.05)=	5	107	NS

† Cooking time index determinations are based on four seasons (1984a, 1985a, 1985b, 1986a).
‡ Water absorption based on three seasons (1985a, 1985b, 1986a).
§ Protein determinations based on two seasons (1984a, 1985a).

cooking time was of sufficient magnitude that fast cooking cultivars could be bred and their use could lead to fuel-wood conservation.

Water Absorption. The location main effect for water absorption was significant (Table 2), and the amount of water absorbed corresponded with the average mean temperature and precipitation of a particular location (data not shown). Seed grown at Karama, the driest and warmest location, absorbed the largest amount of water; and seed from Rwerere, the coolest, moistest location, absorbed the least. Morris et al. (1950) found that the amount of water absorbed after overnight soaking was similar in samples stored at low humidities to samples stored at higher humidities. This finding suggested that the location effect on water absorption was due to some factors intrinsic to the seed and not related to the moisture content of the seed at the beginning of this experiment.

The genotype x harvest interaction for water absorption was significant (Table 2) although the variance component only accounted for 8% of the total variance (Table 3). Since the genotypic variance component was 52 and 7 times as large as the g x l and g x h component, respectively, it is reasonable to make general cultivar recommendations for water absorption and harvests for the region.

Relationship between Cooking time index and Water absorption. The highly significant ($p<0.01$), negative correlation (-.37) between the cooking time index and percent water absorption (270 observations) indicated that slow cooking beans tended to imbibe less water than fast cooking beans. Since the seeds that did not imbibe water after overnight soaking (hard seed) were eliminated from the cooking evaluation, the negative correlation between water absorption and cooking time observed in this study may have been larger if the hard seed coat trait had not been selected against. However, the hard seed coat trait biases the assessment of the genetic potential of a cultivar's cooking time. The genetic potential for cooking time and for the hard seed coat trait are unique quality characteristics and require independent evaluation.

When beans are cooked, native protopectin within the middle lamella forms a soluble pectin which depolymerizes rapidly during heating and allows water to quickly enter and migrate throughout cotyledonary cells (Stanley and Aguilera, 1985). A high state of cellular hydration and heating thus allows cells to soften and separate. Reduced imbibition and/or compositional differences in pectins could be major factors affecting cooking time.

Since seeds that expressed the hard seed coat trait were eliminated from the water absorption evaluations in this experiment, the variability in water absorption among cultivars was due to other genetically controlled factors. For example, Agbo et al. (1987) found differences among bean genotypes for bean seed micropyle orafice dimension, the presence and number of seed coat pores, and microstructure that were related to seed coat water uptake. The microstructural differences were related to water imbibition and textural characteristics of cooked bean genotypes.

Water absorption explained only 14% of the variability in cooking time (R^2=0.137), thus, the correlation (-.37) between water absorption and the cooking time index was too low to justify the use of percent water absorption as an estimate of cooking time. For example, the average water absorption for the five slowest cooking cultivars was 887 g/kg^{-1}, whereas the five fastest cultivars absorbed 100 g/kg^{-1} of their dry weight (Table 4). If selection for fast cooking was made on the basis of water absorption, Rubona 5, the second longest cooking cultivar, would have been selected with Calima, the fastest cooking cultivar. Kibobo and Rubona 5 had an average cooking time of 45.5 min and water absorptions of 765 g/kg^{-1} and 1068 g/kg^{-1}, respectively. A similar overlap with a fast and slow cooking cultivar for water absorption was noted for Kilyumukwe, a bean with an intermediate cooking time (41 min). Rubona 5, Kilyumukwe, and Calima all had similar water absorptions, yet they differed significantly in cooking time.

Protein Content. There were no significant differences noted among cultivars for protein content; however, significant genotype x environment interactions were observed (Table 2). The effect of environmental influences on protein content in this study agrees with other reports of genotype x environment interactions on protein content in the literature (Rutger, 1970; Leleji, et al., 1972; and Kelly and Bliss, 1975). Seed protein of beans has been reported to vary from a low of 19% (Rutger, 1970) to a high of 34% (Woolfe and Hamblin, 1974). The mean and range of protein content among the cultivars used in this study (Table 4) were similar to observations reported by Rutger (1970), but we were surprised that the range in protein content was not greater given the diversity of grain types and cultivars used.

According to Rwandan production and population data, and data on the composition of dry bean, beans provide about 45% of the daily protein and 21% of calories consumed in the country (Graf and Dessert, 1986). Per capita daily protein and calorie availability is 60 g and 2074 kcal, respectively. The Food and Agriculture Organization and the National Research Council recommended dietary allowances for protein and calories is 56 g and 2200 kcal, respectively. These figures indicate that per capita protein and calorie availability is marginal in Rwanda, especially considering these estimates do not take into account production losses due to storage, seed requirements, or transport. The large environmental influences on bean seed protein indicate that selection for high protein will be difficult. A more useful goal may be to maintain an acceptable level of seed protein (20 - 22%) while selecting for agronomically superior, fast cooking cultivars. If the per capita supply of beans was inferior to per capita demand, then an increase in common bean yield would increase calorie and protein availability if the protein content was maintained at its current level.

Resource Efficient Testing Procedures

Variance component estimates of genotypic means for water absorption and the cooking time index showed that the expected variance of a cultivar mean decreased as the number of locations, harvests, and replications increased (Figure 1). The decrease was plotted (Figure 1) until it reached a point beyond which additional locations, harvests, and replications had no further pronounced effect on reduction of the variance. It is desirable to select the minimum number of replications, locations, and harvests needed to obtain a reasonable level of precision, yet remain within the resource constraints of a crop improvement program.

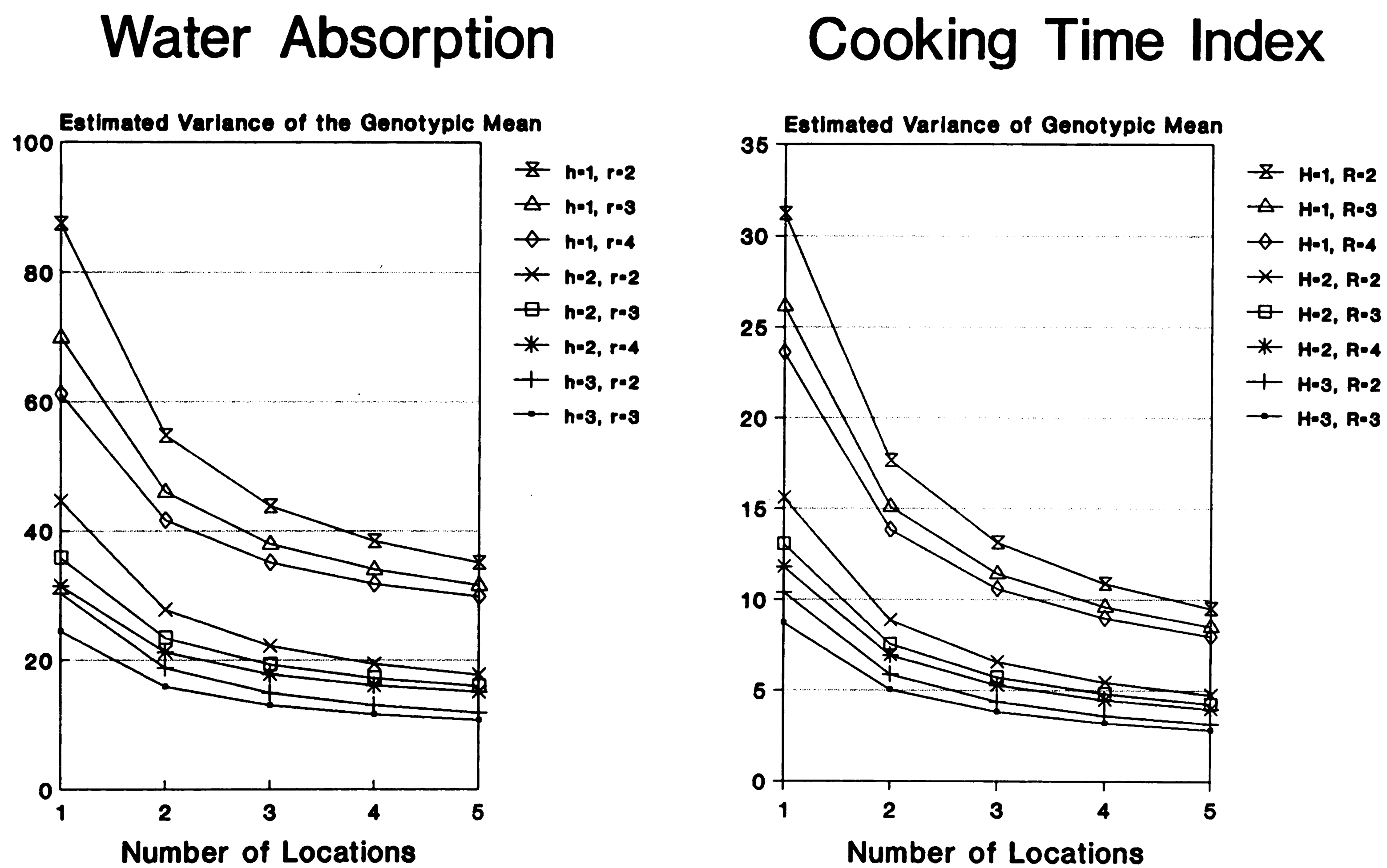

Figure 1. Expected variance of a genotypic mean for water absorption and cooking time.

The evaluation of cultivars for percent water absorption over two instead of one harvest when the number of replications and locations were kept constant at four and one, respectively (Figure 1, ◇ vs *), increased precision approximately 50% (61 σ^2 to 32 σ^2). Evaluation of water absorption over three harvests (Figure 1, * vs –), did not increase precision of sufficient magnitude to warrant the additional required resources. When the number of locations and harvests was kept constant at one and two respectively, the reduction in variance due to increasing the number of replications from two to three was approximately 20% (45 σ^2 to 36 σ^2). The addition of a fourth replication increased precision only 11% (36 σ^2 to 32 σ^2). A four-replication experiment for the evaluation of water absorption would be advantageous from the standpoint of ensuring that an experimenter obtained data from at least three replications. Unpredictable conditions and climatic factors in many tropical environments often lead to missing data. A four-replication experiment would ensure the salvage of three replications, and a sufficient degree of experimental precision to warrant reliable conclusions. When the number of locations was increased from one to two, with two harvests and four replications, the increased precision for evaluating the water absorption trait was approximately 15% (36 σ^2 to 21 σ^2). This indicated that additional replication increased precision more efficiently than an additional location because adding a replication to a study is less costly than adding a test site.

The substantial genotype x harvest x location interaction for the cooking time index indicated that it is best to evaluate the cooking time of cultivars over a minimum of two harvests, and two locations. When the replication number was kept constant at four, the reduction in variance due to increasing the number of harvests and locations from one to two was 50% (24 σ^2 to 12 σ^2) and 42% (24 $\sigma^2$to 14 σ^2), respectively. The increased precision for cooking time index with four vs. three replications was small, but similar to the water absorption trait, four replications are recommended as a safety factor for field plot procedures.

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CHAPTER TWO

IMPLICATIONS OF GENETIC VARIABILITY FOR DRY BEAN COOKING TIME AND NOVEL COOKING METHODS FOR FUELWOOD CONSERVATION IN RWANDA

ABSTRACT

This study was conducted to determine how fast and slow cooking dry bean cultivars and novel cooking methods affected firewood use, cooking time, and cooked bean texture among 15 homesteads in southern Rwanda. Cooking was done on the homestead by the women of the household with a known quantity of firewood. 'Calima' and 'Rubona 5' were evaluated as pure lines and as components of market mixtures. The open wood fire cooking method was compared to cooking beans after soaking them overnight and cooking beans in a haybasket cooker. Results indicated that the use of the haybasket cooker and 'Calima' (fast-cooking), significantly reduced fuelwood consumption and the amount of labor needed to prepare beans for eating. 'Calima' required 16% less firewood and 8% less time to cook than the slower cooking cultivar 'Rubona 5'. The haybasket cooker used 40% less firewood than the traditional open fire cooking method.

INTRODUCTION

The dry seeds of common bean (*Phaseolus vulgaris* L.) are an important source of protein and calories for middle and low income families in many developing countries. Nearly 60% of Africa's dry bean production is in the Eastern and Central countries of Uganda (13%), Kenya (11.9%), Burundi (12%), Rwanda (13%), and Tanzania (11%) (CIAT, 1981). The most common method of cooking beans in much of Africa is over an open wood fire built on the ground (Poulsen, 1980). An open wood fire is not fuel efficient because the rate of burning cannot be well controlled and much of the heat is dissipated into the surrounding atmosphere. Dry beans require a long cooking time to render the grains palatable, inactivate heat labile antinutrients, and permit the digestion of starch and protein (Jaffe, 1973). Since dry beans require more time than most other foodstuffs to cook to a palatable texture, their cooking time determines household fuelwood needs. The important contribution of beans to human nutrition and the large amount of fuelwood required to prepare them for consumption illustrate a strong link between nutritional well-being and adequate fuel supply in Central Africa.

If beans are available, people will find a way to cook them, but at a cost in terms of human and physical resources. Deforestation and soil degradation have become critical in parts of Central Africa where the demand for fuelwood far exceeds the supply (Howe et al., 1980; Bart, 1981). Fuelwood supply also affects the amount of time women have available for income-generating activities. For example, forests in Nepal have been pushed so far back from rural populations that it now requires a woman an average of 1.4 additional hours daily to collect firewood than it did a decade ago (Kumar and Hotchkiss, 1988). In addition to the labor involved with the acquisition of wood for fuel, the relatively long cooking time of beans requires labor for tending the cooking fire throughout the cooking period.

The scarcity of firewood in Central Africa has made the reduction in resources required to prepare beans for eating an important economic consideration. Major fuelwood savings have been reported by using stoves that enclose the fuel source rather than allowing it to burn openly and be exposed to the environment. However, no details of controlled tests to measure savings are available (Howe and Gulick, 1980).

Bean cultivars that cook faster than the cultivars currently grown for consumption may also be a means to conserve firewood. Bean cultivars that cook quickly to a palatable texture have been reported (CIAT, 1986; Dessert, K. 1986). Texture affects the perceived stimulus for chewing and, hence, acceptance of a food (Kramer, 1964). It is known that cooked bean texture is under genetic control and can be changed through selection (Hosfield et al., 1980; Wassimi et al., 1990).

The present study was undertaken in view of the economic need to conserve the fuelwood and labor required to prepare beans for eating in Eastern and Central Africa. Specific objectives were to: 1) determine cooking time and fuelwood savings of bean cultivars with variable cooking times, and 2) ascertain the cooking time, fuelwood usage and acceptability of novel, and fuel efficient bean-cooking methods.

MATERIALS AND METHODS

Background. The study was conducted in Rwanda, a small (26,338 km^2), mountainous country in Central Africa. About 95% of the population of Rwanda is rural, and live on small (1.3 hectare) homesteads throughout the countryside (MINAGRI, 1985). Rwanda's population density is the highest in sub-saharan Africa, 246 people per sq. km. (World Bank, 1989). This demographic pressure has made land availability an important constraint on household income and food security. The land allocated to forests from which fuelwood is obtained is in competition with household agricultural production needs. Fuelwood constitutes 96% of the total energy used in Rwanda (Howe, 1980), and afforestation does not meet domestic demand (Sirven, 1981).

The contribution of beans to total protein intake in Rwanda is one of the highest in the world (Pachico, 1984), and is more than all animal products combined. In Rwanda, dry beans provide more than one-half of the dietary protein and at least one-quarter of the energy requirements (Vis, 1975; MINIPLAN, 1988).

Although Rwandans consume beans daily, beans are usually cooked three or four times a week (CIAT, 1986), and require 14 fires per week for cooking and reheating the food. Rwandans usually prepare about 3 kg of beans in a single cooking, which is enough to provide a 2 day food supply for the household. Beans are not soaked prior to cooking and require about 3 h to render the seeds palatable. When beans are nearly soft enough to eat, a raw, starchy accompaniment, such as sweet potato (*Ipomoea batatas*), banana (*Musa paradisiaca*), or cassava (*Manihot* *esculenta*), is cooked with the beans. Beans and accompaniments are consumed together. Current bean preparation methods require enough fuelwood to keep an active fire burning for 9-12 h per wk (CIAT, 1986).

Common bean is a self-pollinated species, and genetic strains of the crop are usually pure lines with each plant within a given strain having a similar genetic constitution. In Rwanda, beans are produced and consumed as mixtures of genetic components each of which is a distinct pure line (CIAT, 1984). Beans are usually intercropped with bananas, sorghum (*Sorghum bicolor* Monsch), and maize (*Zea mays* L.), and grown in small plots during the two rainy seasons (October to January, and April to June) with no chemical inputs.

Most of the household food supply in Rwanda is produced on the homestead, and 97% of the homesteads cultivated beans (MINAGRI, 1985). Women are principally responsible for producing beans as well as for other agricultural and household chores. Since agricultural activities are accomplished exclusively with manual labor, labor shortages are common during periods of planting, weeding and harvest.

Experimental materials. 'Calima' and 'Rubona 5' were fast and slow cooking, pure-line cultivars, respectively. Seeds of both cultivars were beige, mottled with red. The similarity in seed color of the two cultivars was expected to eliminate bias from study participants' preference scores. The two cultivars were grown for three consecutive seasons (March-June, June-September, September-January) in 1987 on the research stations of the Institut des Sciences Agronomiques du Burundi (ISABU) at Mosso, and the Institut des Sciences Agronomiques du Rwanda (ISAR) at Rubona.

Mixtures of beans (hereafter referred to as market mixtures) with unknown genetic constitutions were used in the study and purchased each season shortly after harvest at a local market. Since the market mixtures were purchased from a different source each season, the ratio and composition of the various genotypes comprising the mixtures were different in each experiment.

The firewood used in the study was cut from eucalyptus trees (*Eucalyptus* sp.) of similar age on the ISAR station at Rubona. The wood was cut into 60 x 10 x 10 cm sections and weighed. A 100 kg bundle was delivered to each participating household.

The haybasket cooker, employed in Experiment 2 of the study, was a modified crock pot consisting of a round basket, a thin flat stone, and dry insulation material (Figure 1).

Description of Survey Participants. The experiment was conducted in 15 households, selected over a distance of 15 km in southern Rwanda, near the city of Butare. The households selected were 1) accessible by road to facilitate the transport of firewood, 2) included women with young, teenage, and adult children, and 3) constituted thatch-roofed adobe, metal-roofed adobe, and tile-roof brick houses. Homestead accessibility may have biased the sample because of different constraints in accessible versus nonaccessible households. Nevertheless, the selected households represented a range of age, economic, and social status.

Figure 1
The haybasket cooker employed in Experiment 2. The round clay pot containing beans and accompaniments was left to cook on top of a flat stone, surrounded by dry insulation material inside the round basket (80 cm high, 50 cm diameter) for 4 hours after the initial cooking over an open wood fire.

Procedures. In the 3 complementary experiments that comprised this study, beans were evaluated by household participants the season immediately following production to minimize influences of storage time (Jones, et al., 1983). In all experiments, beans were cooked at the homestead by the woman of the household using a predetermined weight of firewood provided by the experimenter. When the women determined that beans were cooked, the fire was immediately extinguished and the remaining unburned wood was collected and weighed. Bean cooking time was determined as the interval of time from when the clay pot containing the beans was placed on the open wood fire until it was removed from the fire. Texture was determined with a penetrometer (Chatillon Model DPP, John Chatillon and Sons, Inc. 83-30 Kew Gardens Road, Kew Gardens, New York 11415-1999) on a sample of 100 cooked beans drawn at random from the cooking vessel. Immediately after cooking each treatment, the gm force required to puncture a seed was recorded. Women and family members evaluated the beans immediately after each experimental treatment and rendered judgments as to bean color, amount of swelling during cooking, cooking time, and the amount of wood used for cooking the sample. Respondent judgements for each character were compared to judgements of the household bean mixture. Judgements equal to the household mixture for a character were given a score of 3. The judgments were scored on a 5 point scale, with 1 and 5 representing the most desirable and least desirable expression of the character, respectively. Informal results prior to conducting the tests indicated that use of the household mixture as a midpoint (3-score) in scoring resulted in greater reliability. Comparison to the household mixture provided a decision-making framework for each respondent which reflected their unique cooking experiences.

During the course of the study, cooking sessions were arranged with each household 2 to 3 times per week. Three kg of seed was cooked per treatment. The frequency of cooking sessions and the amount of beans cooked per session were commensurate with each household's normal consumption pattern.

Experiment 1. Five of the 15 households chosen for the study were selected for Experiment 1 (Table 1). The household was the experimental unit and formed the basis of replication. The experimental treatments were 'Calima' and 'Rubona 5' cooked over an open wood fire by two preparation methods. One preparation method was traditional cooking, where beans were not soaked prior to cooking. The other cooking method investigated the effect of soaking beans overnight in household water prior to cooking. For this treatment, the soak water was discarded, and fresh water was added to the hydrated (soaked) beans before cooking them. Data were collected on the two cooking methods and the two cultivars for the amount of wood used (kg), cooking time (min.), and cooked texture (ddp/gm), and were subjected to an analysis of variance appropriate for a randomized complete block design (Steel and Torrie, 1980). The cooking treatments (soaked vs not soaked) were split over cultivars ('Calima' and 'Rubona 5') in a 2 x 2 factorial arrangement of treatments. The least significance difference (LSD) test criterion was used to ascertain mean differences for the traits showing significant F ratios.

Table 1. Description of Experiments 1, 2, and 3 with 15 households in Rwanda, Central Africa.

Experiment	Experimental Unit	Rep.†	Treatment‡,§	Levels
1	Household	5	Cultivars	1)Rubona 5 2)Calima
			Cooking methods	1)Unsoaked,fire 2)Soaked,fire
2	Household	10	1)Rubona 5 (Pure line) 2)Calima (Pure line) 3)Rubona 5, 30% of mixture 4)Calima, 30% of mixture 5) Mixture, unsoaked, open fire 6) Mixture, soaked, open fire 7) Mixture, Haybasket	
3	Block of 3 households	3	Cultivars	1)Rubona 5 2)Calima
			Genetic Types	1) Mixed 2) Pure line

† Replications in the statistical sense.

‡ Experiment 2, treatments 1-4, were unsoaked, cooked over an open wood fire.

§ Experiment 2, treatments 3 and 4, Rubona 5 and Calima comprised 30% by weight, respectively of the market mixture.

Experiment 2. The experimental treatments included a new set of households, bean mixtures, and the haybasket cooker (Figure 1, Table 1). Each of the 10 households that had not participated in Experiment 1 comprised the experimental unit. 'Calima' and 'Rubona 5' were cooked over an open wood fire without prior soaking (traditional method) as a pure line and also as a component (30% by weight) of a market mixture. The effect of novel cooking methods on firewood usage, cooking time, and texture was evaluated by: 1) soaking the market mixture prior to cooking over the wood fire, and 2) cooking the market mixture in a haybasket without prior soaking. Beans were cooked in the haybasket by first boiling (96 C) them in household water in a clay pot over an open wood fire until the bean cotyledons acquired a floury, granular texture (about 90 minutes). A flat stone was heated concomitantly in the fire as the beans boiled (Figure 2). When the bean cotyledons appeared granular, a sufficient quantity of raw sweet potatoes, green banana, or cassava were added to the clay pot. The headspace between the top of the pot and the level of the food in the pot was less than 10 cm. Beans and the added foodstuffs were brought to a boil and the clay pot was covered with a banana leaf and removed from the fire. The heated stone was removed from the fire, and placed in sand at the bottom of the haybasket. The clay pot containing the beans was placed on top of the hot stone in the basket. The basket was insulated with dry grass or bean straw (Figure 1), and securely covered to conserve heat. Beans and added foodstuff were cooked for 4 hours on top of the hot rock inside the haybasket.

Boiling the beans for 90 minutes and subsequent cooking at a

Figure 2
Thin, flat stone (indicated by arrow) is heated in an open wood fire during the initial cooking of beans. The stone is used to supply heat to the bean pot during the 4 hour cooking period inside the haybasket.

minimum of 79 C for 4 h in the haybasket was sufficient to inactivate phytohemagglutinins (Coffey et al., 1985). The dimension of the basket (80 cm high, 50 cm diameter), thickness and width of the heating stone (4 cm thick, 20 cm diameter), amount of headspace in the pot containing the food (10 cm maximum), and quantity of material used to insulate the basket was standardized so as not to affect the amount of heat retained.

Data were subjected to an analysis of variance appropriate to a randomized block design. The treatments were in a 10 x 7 factorial arrangement. Orthogonal contrasts were used to partition the treatment sums of squares into relevant comparisons. Three contrasts were performed: 1) the cooking performance of 'Rubona 5' and 'Calima' as pure lines and as components of the market mixture contrasted to the market mixture <u>per se</u>, 2) 'Rubona 5' contrasted to 'Calima', and 3) the market mixture <u>per se</u> soaked prior to cooking and cooked in the haybasket cooker contrasted to the market mixture <u>per se</u> cooked traditionally over an open wood fire. The LSD test criterion was used to ascertain mean differences for the traits showing significant F ratios.

<u>Experiment 3</u>. Experiment 3 was designed to ascertain whether fast-cooking beans had the same cooked texture as long cooking beans once the study participants became familiar with the short cooking attribute. The 3 households in Experiments 1 and 2 that were most similar in their firewood management techniques and cooked bean texture perceptions were selected. Households were assigned to treatments in a randomized block design with the blocks replicated 3 times over a 2 wk time interval (Table 1). The treatments evaluated were 'Calima' and 'Rubona 5' cooked traditionally over an open wood fire as a pure line and as a component

(30% by weight) of a market mixture. Data were subjected to an analysis of variance appropriate for a randomized block design with cooking sessions, seed type (mixed or pure line), and variety ('Calima' or 'Rubona 5') in a 3 x 2 x 2 factorial arrangement. The LSD test criterion was used to ascertain mean differences for the traits showing significant F ratios.

Post-experiment Haybasket Survey. After completion of Experiment 2, weekly visits were made to the 10 homesteads for a 7 wk period to identify those households that continued to use the haybasket cooker. The woman of the household indicated how frequently they used the haybasket, the types of foods cooked in the haybasket, and the problems encountered.

Post-experiment Group evaluation of Treatments. A group discussion of treatments with the 15 women participants was conducted on the research station after completion of Experiment 2. The women were questioned concerning the advantages and disadvantages of the experimental treatments in the study.

RESULTS

Experiment 1. Analyses of variance revealed significant cultivar differences for texture and differences between cooking methods for firewood usage, cooking time, and cooked bean texture (Table 2). No significant interaction was observed between cultivars and cooking method. This indicated that soaking beans prior to cooking affected both cultivars in a similar fashion.

The study participants cooked 'Calima' (fast-cooking) and 'Rubona 5' (slow-cooking) for approximately the same length of time (190 vs 204 min, respectively) using about the same quantity of firewood (8.0 and 9.2 kg, respectively, Table 3). However, the cooked texture of 'Calima' was 341 ddp/gm compared to 442 ddp/gm for 'Rubona 5' ($p<0.01$, Table 3).

Beans soaked prior to cooking were cooked for 143 min. and required 4.4 kg of firewood (Table 3). Beans that were not soaked prior to cooking required 8.6 kg of firewood and took 197 min. to reach a palatable texture (Table 3). Beans soaked prior to cooking were significantly firmer (455 ddp/gm) than beans that were not soaked prior to cooking (391 ddp/gm).

The preference scores of household participants for cooking time and firewood used for the experimental treatments agreed with the data presented in Table 3 and, hence, are not presented. Beans soaked prior to cooking were judged significantly poorer in taste than beans prepared without prior soaking (scale rating scores not shown).

Experiment 2. Statistically significant differences in cooking time, the amount of firewood used, and cooked bean texture were detected between treatments (Table 4). When 'Calima' and 'Rubona 5' were contrasted to the market mixture as pure lines and as genetic constituents of the market mixture (orthogonal contrast 1), no statistical differences in cooking time, firewood usage, or cooked bean texture were detected. Orthogonal contrast 2, revealed significant cultivar differences in cooking time, firewood requirements, and cooked texture. Orthogonal contrast 3, indicated that the novel bean

Table 2. Experiment 1. Mean squares from analysis of variance of 5 households in Rwanda for Calima and Rubona 5 soaked and unsoaked prior to cooking over an open fire.

Source†	df	Wood‡ Used	Cooking‡ Time	Texture‡
Household	4	7.35	458.43	5178.97**
Cultivar	1	1.80	352.80	49554.99**
Error (a)	4	4.02	328.18	226.43
Cooking Method	1	88.20**	14472.20**	20544.05**
Method x Cultivar	1	1.80	135.20	17.79
Error (b)	8	4.28	362.45	193.63

† A 2^2 factorial arrangement of treatments with the cooking methods split over cultivars.
‡ **, significant at the 0.01 probability level.

Table 3. Experiment 1. Mean values from 5 households in Rwanda for Calima and Rubona 5 prepared by soaking and not soaking prior to cooking over an open fire.

Treatment		Wood Use† (kg)	Cooking Time† (min.)	Texture† (ddp/gm)
<u>Cultivar</u>				
Rubona 5		9.2 a	204 a	442 a
Calima		8.0 a	190 a	341 b
	LSD=	2.5	23	19
<u>Open wood fire</u>				
Soaked		4.4 a	143 a	455 a
Not soaked		8.6 b	197 b	391 b
	LSD=	2.1	20	41

† Identical letters in the same column indicate no significant difference at the 0.05 probability level.

preparation methods had a significant effect on cooking time and firewood usage compared to the traditional open wood fire method. 'Calima' (fast-cooking) cooked in 24 min. less time and required 1.6 kg less firewood than 'Rubona 5' (Table 5). 'Calima' also had a softer cooked texture (316 ddp/gm) than 'Rubona 5' (488 ddp/gm). The cooked texture of the market mixture containing 'Calima' was softer (335 ddp/gm) than the market mixture containing 'Rubona 5' (407 ddp/gm, Table 5). The haybasket method required 4.4 kg of firewood to cook the market mixture to a palatable texture compared to 7.4 kg for the traditional open wood fire method. The beans were cooked over an open fire for 102 min. in the haybasket method, compared to 185 min. for the traditional open wood fire method and 169 min. for beans soaked before cooking on an open fire. Soaking the market mixture overnight before cooking over an open wood fire did not significantly reduce firewood needs or cooking time, and resulted in a cooked texture similar to the market mixture cooked over an open fire with no prior soaking.

Preference scores of the household participants for cooking time and the amount of firewood needed to cook 'Calima' and 'Rubona 5' (Table 6) were consistent with the mean values presented in Table 5. 'Calima' was rated subjectively by the participants as having a more favorable cooking time and requiring less firewood than 'Rubona 5' (2.3 vs 3.2 and 2.2 vs. 2.7, respectively). The larger seed size of 'Calima' was perceived by the household participants as more acceptable ($P<0.01$) than the smaller seeded 'Rubona 5' (1.2 vs. 2.9, respectively).

The participant evaluations of cooking methods also agreed with

Table 4. Experiment 2. Mean squares from analyses of variance of 10 households in Rwanda and orthogonal contrasts between treatments. †,‡

Source†	df	Wood Used‡ (kg)	Cooking Time‡ (min.)	Texture‡ (ddp/gm)
Household	9	9.53**	736.13	10249.08*
Treatment	6	13.00**	12206.92**	39015.45**
Contrast 1	1	0.47	691.92	6190.51
Contrast 2	1	11.55**	3001.25*	148023.22**
Contrast 3	1	15.50**	16566.82**	1077.98
Error	54	1.46	687.90	4695.57

† The experiment consisted of a 10 x 7 factorial arrangement of treatments with 3 orthogonal contrasts.

Contrast 1– Rubona 5 and Calima, as pure lines and components of a mixture of bean genotypes cooked traditionally over an open wood fire contrasted to the mixture cooked traditionally over an open wood fire.

Contrast 2– Rubona 5 contrasted to Calima, cooked traditionally over an open wood fire.

Contrast 3– Mixture of bean genotypes soaked prior to cooking over an open wood fire and the mixture cooked in the haybasket contrasted to the mixture cooked traditionally over an open wood fire.

‡*, ** significant at the 0.05 and 0.01 probability levels, respectively.

Table 5. Experiment 2. Mean values from 10 households in Rwanda for pure-line cultivars, bean mixtures, and cooking methods.

Treatment	Wood Used† (kg)	Cooking Time† (min.)	Cooked Texture† (ddp/gm)
Rubona 5	7.9 a	207 a	488 a
Calima	6.3 b	183 b	316 b
Rubona 5 + Mixture	7.1 ab	197 ab	407 c
Calima + Mixture	7.1 ab	192 ab	335 b
LSD=	1.1	24	62
<u>Cooking Method</u>			
Open fire, unsoaked	7.4 a	185 a	415 a
Open fire, soaked	7.3 a	169 a	390 a
Haybasket	4.4 b	102 b	464 a
LSD=	1.1	24	62

† Identical letters in the same column indicate no significant difference at the 0.05 probability level.

‡ The cooking method treatment involved cooking a traditional market mixture without any adulteration with Calima or Rubona 5.

data presented in Table 5. Study participants judged the haybasket cooker as the most firewood efficient cooking method evaluated in the study (Table 7). However, participants perceived the total preparation time using the haybasket cooking method as significantly inferior to the traditional open wood fire method (4.8 vs 2.9, Table 7). The eating quality of the market mixture cooked in the haybasket cooker was as acceptable to consumers as the market mixture cooked traditionally over an open wood fire. When the market mixture was soaked prior to cooking over an open wood fire, it was perceived as significantly inferior (high scores) to the mixture not soaked before cooking for color, swelling during cooking, and overall eating preference (Table 7).

Experiment 3. The market mixtures took significantly longer (187 min.) to cook than the pure-line cultivars (171 min.) (Table 8). Analyses of variance mean squares for the amount of firewood required to cook market mixtures compared to pure-line cultivars were nonsignificant, but the tendency was for a higher firewood requirement to cook the market mixtures. Pure lines did not significantly differ in the amount of time or firewood required for cooking, but 'Calima' required less firewood and cooking time than 'Rubona 5'.

Study participants modified the amount of time they cooked 'Calima' and 'Rubona 5' after repeated cooking experiences, although the difference was not statistically significant. Examination of the means from the various cooking sessions with 'Calima' and 'Rubona 5' showed that participants tended to cook 'Calima' for a shorter period of time than 'Rubona 5' (Table 9). By the third cooking experience with

Table 6. Experiment 2. Mean preference scores of women in 10 Rwandan households for Calima and Rubona 5.

Treatment	Wood†‡ Used	Cooking†‡ Time	Seed†‡ Size	Overall†‡ Preference
Calima	2.2 a	2.3 a	1.2 a	2.0 a
Rubona 5	2.7 b	3.2 b	2.9 b	2.1 a
LSD=	0.5	0.6	0.4	0.8

† Preference scores are based on a 5 point scale with 1 and 5 representing the most favorable and least favorable perception of a trait, respectively.

‡Identical letters in the same column indicate no significant difference at the 0.05 probability level.

Table 7. Experiment 2. Mean preference scores of women in 10 Rwandan households for the market mixture prepared under different cooking methods.

Cooking Method	Wood Used†‡	Preparation Time†‡	Color†‡	Water Swelling†‡	Eating Preference†‡
Open fire, unsoaked	2.6 a	2.9 a	2.6 a	2.8 a	2.3 a
Open fire, soaked	2.3 a	2.6 a	3.5 b	3.7 b	3.6 b
Haybasket	1.1 b	4.8 b	2.9 a	3.0 a	2.9 ab
LSD=	0.5	0.6	0.5	0.5	0.8

†Preference scores are based on a 5 point scale with 1 and 5 representing the most favorable and least favorable perception of a trait, respectively.

‡Identical letters in the same column indicate no significant difference at the 0.05 probability level.

'Calima', participants used 6% less firewood (i.e., a reduction from 5.3 to 5.0 kg)and required 4% less time (i.e., a reduction from 168 min. to 161 min.) than the initial cooking experience.

Post-experiment Haybasket Survey. A total of 63 weekly interviews were conducted with 11 households over a 7 wk period. Household participants used the haybasket cooker as little as 33% and as much as 100% of the times beans were cooked. Participants in 6 of 11 households used the haybasket 50 to 75% of the times that beans were cooked. In 84% (53 of 63) of the responses, the haybasket was used at least once during the week. The haybasket cooker was the sole method used to cook beans in 54% (34 of 63) of the responses. The frequency of haybasket use did not change during the 7 wk period.

Participants cooked other foods together with beans in the haybasket cooker 83% (44 of 53) of the time the haybasket was used. The most common foods cooked in the haybasket with beans were cassava (57%) and taro (*Colocasia esculenta*, 27%).

Study participants encountered problems 27% (12 of 44) of the times the haybasket was used. Long total preparation time was the major disadvantage of the haybasket because beans were not available for children to eat during the day.

Post-experiment Group Evaluation. The group evaluation of seed types and cooking methods supported the individual participant evaluations of Experiments 1 and 2. The women associated certain seed characteristics with agronomic performance traits, and these associations influenced the participants' overall evaluation of the bean cultivars and mixtures.

Table 8. Experiment 3. Mean values from 3 Rwandan households of Rubona 5, Calima, and the market mixture.

Seed	Wood Used† (kg)	Cooking Time† (min.)
Pure line cultivars	5.7 a	171 a
Market mixtures	6.1 a	187 b
Rubona 5	6.2 a	174 a
Calima	5.2 a	168 a
LSD=	1.3	17

† Means are based on 9 cooking sessions, 3 sessions with each household at biweekly intervals.

‡ Identical letters in the same column indicate no significant difference at the 0.05 probability level.

Table 9. Experiment 3. Mean values from 3 Rwandan households per cooking session for Rubona 5 and Calima *per se* and mixed 30% with a market mixture.

Seed	Wood Used (kg)† Cooking Session			Cooking Time (min.)† Cooking Session		
	1	2	3	1	2	3
Rubona 5						
Pure	5.7	6.7	6.3	177	173	172
Mixed 30%	6.0	5.8	6.3	177	188	203
Calima						
Pure	5.3	5.3	5.0	168	175	161
Mixed 30%	6.0	6.0	6.7	180	183	188

† Differences between means were not significant at the 0.05 probability level.

Yield was the most important criterion the women used to select the beans they planted. Although cooking quality affected cultivar selection, it was a secondary consideration. Eleven of 12 respondents preferred a mixture of bean genotypes over a pure line cultivar because they perceived mixture yields as being more stable to harsh environments. All women surveyed in the study stated that large-seeded beans cook faster but require more fertile soils than small-seeded cultivars. The women preferred 'Rubona 5' over 'Calima' because they thought that the larger grain size of 'Calima' compared to 'Rubona 5' indicated that 'Calima' would yield poorly on less fertile soil. 'Rubona 5' was the least preferred of the seed treatment types because its cooked texture was too firm. However 11 of 12 respondents felt a mixture of bean cultivars containing a long cooking cultivar such as 'Rubona 5' would be acceptable as long as it had a stable yield.

All households indicated that firewood availability was the most important constraint to cooking beans, and that it was difficult to acquire enough firewood to meet household needs. The labor required to collect firewood and cook beans was also a constraint because these activities took time away from agricultural chores. The questioning of study participants revealed that firewood was rarely purchased, and usually gathered by children from areas surrounding the homestead. Collection of firewood usually required one to two h each time beans were cooked. In households headed by an older woman without young children, the woman usually gathered the firewood, and gathering time competed with her agricultural duties as well as transport of water for household use.

DISCUSSION

Results of the present study indicated that the haybasket cooker (Figure 1) and a fast-cooking bean cultivar significantly conserved fuelwood compared to the traditional cooking method and use of market mixtures. The traditional cooking regime required a fire to be established in the morning to cook the beans and a second fire in the evening to reheat them; hence, two fires per day were needed to cook or reheat food. The haybasket cooker required one less fire than the traditional cooking method because the food was still warm after 4 h in the haybasket, and reheating for mealtime was unnecessary. The use of the haybasket to cook beans 3 times per week would require 11 instead of 14 fires to be built. The fuelwood savings for 3 less fires is substantial because a large amount of wood is needed to establish a fire.

Greater fuelwood savings than that observed in this study would have accrued for the fast-cooking cultivar if the criterion for judging beans eating soft was determined with the penetrometer rather than perceived cooking time. For example, it was noted during the cooking process that most study participants perceived that 'Calima' was sufficiently cooked by the time they made their first evaluation of the sample for palatability. At this point, 'Calima' was softer in texture than the market mixture (Table 3, Table 5). The cooked texture of the open fire, unsoaked market mixture (415 ddp/gm, Table 5) was considered optimal for eating. Therefore, the cooked texture of 'Calima' (316 ddp/gm) indicated that 'Calima' was overcooked when it was cooked the same amount of time as the market mixture (Table 5). Overcooking beans is not a fuel efficient practice. In Experiment 3, the participants realized some fuelwood savings (nonsignificant, p = 0.05) with 'Calima' by cooking this cultivar less as they became accustomed to its quick cooking nature (Table 9).

The 5.7 h preparation time for the haybasket method, and its poor participant evaluation (4.8 vs 2.9, Table 7) compared to the traditional open fire method, did not deter participants from accepting (Table 7) and adopting (Post-experiment Haybasket Survey) the haybasket cooking method. The inconvenience associated with not having food available for children to eat while beans are cooking in the haybasket can be overcome. First, the haybasket cooker is most useful to a household during periods of peak agricultural field activity because the method reduces the amount of time during the day that must be devoted to firewood gathering and tending the fire for bean preparation. During these periods of high demand for field labor, children usually accompany their mothers to the work site for the day, and food is needed for both mother and child. Sweet potatoes, or similar fast-cooking foods, could be cooked in the morning before leaving for the field by using the fire established for the haybasket. The cooked food could be taken to the field for consumption at mid-day while beans and accompaniments are left cooking in the haybasket throughout the day at the homestead. A complete, warm meal of beans and accompaniments would be ready for consumption in the evening. Secondly, foodstuffs could also be cooked overnight in the haybasket, providing ample food throughout the day for children.

All the components of the haybasket cooker can be acquired or manufactured locally at minimum cost. Basket-making is a traditional handicraft in Rwanda. Therefore, demand for haybaskets could support an existing cottage industry. Successful cooking in the haybasket is dependent upon the basket dimension, amount of headspace in the pot, the degree to which the beans are cooked prior to being placed in the haybasket, and adequate insulation. Continued and successful use of the haybasket cooking method requires that users understand all the necessary components of the basket. The haybasket should be easily adopted for cooking beans by the inhabitants of rural households in Rwanda because this technology satisfies the acceptability requirements of household consumers.

Soaking beans overnight in household water prior to cooking was ineffective in reducing the amount of time and firewood required to obtain a palatable cooked bean texture. We were surprised at this observation because Uebersax et al. (1980) reported a reduction in cooking time after overnight soaking in distilled water. However, Quast and da Silva (1977) did not observe a reduction in cooking time when beans were soaked overnight in tap water.

The quality of the household water used for soaking beans may explain why soaking did not reduce cooking time in this study. As beans soak, they gain or lose minerals depending on the composition of the soaking solution (Deshpande and Cheryan, 1983), and ions are redistributed within the middle lamella of adjoining cell walls (Varriano-Marston et al., 1979). Uebersax et al. (1980) reported increased bean firmness with increasing calcium ion concentration in the soaking medium, and attributed the increased firmness to the formation of insoluble pectin-calcium complexes. Each household in this study drew water from the closest stream or river to the homestead. The ion concentration of the local water used in this study was not evaluated, but the soils in the area were predominantly oxisols with characteristically low cation exchange capacity. This may result in leaching of calcium or other divalent cations into the soil solution, and eventually into rivers and streams. It was noted during Experiment 1 that study participants expected beans to cook fast after the soaking treatment, and this bias may explain why beans with a firm texture were judged as sufficiently cooked.

Water soluble seed pigments (e.g. anthocyanins) leach from beans during soaking, and often cause beans to become pale in appearance, especially if beans are not cooked in the soak water. In this study it was not possible to cook beans in the soak water because a disagreeable froth formed during the overnight soak. Frothing was most likely due to microbial fermentation because the soak water was not chemically treated or boiled prior to soaking beans. Soaking beans prior to cooking may not be common in this region of Rwanda because the quality of the local water impairs rather than improves cooking characteristics.

The cultivation of bean mixtures versus pure-line cultivars should be encouraged because it is an ecologically sound agricultural practice that maintains genetic diversity while enhancing food security (CIAT, 1986). In the Post-experiment Group Evaluation of the present study, the participants continued to prefer mixtures despite research results that pure lines ('Calima' and 'Rubona 5') cook faster and require less fuelwood to become palatable than market mixtures. Conservation of fuelwood is possible using bean mixtures. For example, mixtures of beans chould be introduced that are comprised of fast-cooking genotypes such as 'Calima' , or fast-cooking cultivars could be incorporated into existing market mixtures.

Fast-cooking cultivars must be acceptable by consumers as mixture components. A fast-cooking cultivar that meets producer and consumer expectations for yield and culinary quality could be selected by first testing it as a pure line and then evaluating it as a component of a market mixture. It would be worthwhile for breeders in national programs where beans are a staple food and firewood is the major fuel source to select beans with decreased cooking time in addition to yield and pest resistance.

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CHAPTER THREE

COOKING TIME, HARD SEED COAT, AND SEED TYPE VARIABILITY IN RWANDAN LANDRACES OF PHASEOLUS VULGARIS

ABSTRACT

Common bean (*Phaseolus vulgaris* L.) is cultivated and consumed in Rwanda as a landrace-a diverse population of individuals maintained by human selection. The purpose of this study was to investigate the relationship between the distribution of predominant seed types in a landrace and their cooking time and incidence of hard seed coat. A 5 kg sample of bean landraces was purchased from each of 10 farms in the prefecture of Butare, and 1000 seeds from each landrace were sorted according to their seed color and size. The seed types comprising the largest percentage of each landrace were evaluated for cooking time and incidence of hard seed. Sixty-one predominant seed types were obtained from the 10 landraces. The 30 distinct seed types among the 61 samples consisted of 16 unique color combinations of small, medium, and large seeded beans. Six out of 10 landraces were comprised of seed types that differed significantly among each other for cooking time. Predominant lines that cooked significantly different than all other lines in the landrace comprised less than 10% of the landrace. If more than one predominant line cooked differently, a blending trend was observed whereby cooking times were graduated within the landrace. The observed range in cooking time among landraces suggested that some farmers have selected cultivars based upon their cooking performance and were

developing fast cooking landraces. Expression of the hard seed coat trait appeared to be genetically independent of cooking time. The small amount of genetic variability for the hard seed coat trait observed in this study indicated that selection against this trait during the domestication of common bean has been successful.

INTRODUCTION

The dry seed of common bean (*Phaseolus vulgaris* L.) is an important dietary staple in Rwanda. Beans provide up to one quarter of the calories and one half of the protein in the Rwandan diet. Wood is the main fuel used for cooking in Rwanda, and it constitutes 96% of total energy used in Rwanda (Howe, 1980). Afforestation programs in Rwanda have not kept pace with domestic demand for wood fuel (Sirven, 1981). The cooking time of dry beans is under genetic control and can be changed through selection (Shellie, Chapter 1). The amount of time and firewood required to prepare dry bean cultivars for consumption varies according to the genotypic composition of a cultivar (Shellie-Dessert and Hosfield, 1990).

Hard seed coat is a heritable condition of seed dormancy that is common in the wild progenitor of common bean (Gentry, 1969). Seeds possessing the hard seed coat trait are identified by their failure to imbibe water after a 24 hr soaking period (Gloyer, 1928). An impermeable seed coat is a valuable survival mechanism under adverse environmental conditions, but cultivars possessing a high percentage of grains with the hard seed coat trait have an objectionable, non-uniform cooked texture and uneven germination in the field.

Humans began to select for diverse seed types and against the hard seed coat trait approximately 8000 yr B.P. during early domestication of the wild common bean progenitor (Berglund-Brucher and Brucher, 1976). The rich diversity of cultivated seed types were selected from the small (5 mm long, 4 mm wide, and 2 mm thick), gray or brown mottled average seed type of wild common bean progenitors (Gentry, 1969). The *P. vulgaris* biotypes cultivated in Africa during the last few centuries represent only a sample of the Latin American germplasm that had already undergone selection for seed type and hard seed coat. The first reports by the Spanish about European bean introductions indicated that the hard seed coat trait was present in the 16th century. Beans were probably taken from Europe to the coastal areas of eastern Africa in the 1600's by the Portuguese, and carried inland by Arab traders (Martin and Adams, 1987). The dry bean biotypes growing in Rwanda are artifacts of Latin American, European, and African selection efforts.

Common bean was initially and is still cultivated in eastern and central Africa as a landrace comprised of perceptually distinct lines. Each genotypic mixture maintained by a farmer at a particular site is phenologically, morphologically, and qualitatively heterogenous (Martin and Adams, 1987). When multiple generations of landraces are sown without human selection, environmental factors encourage dominance of certain pure-line constituents, resulting in less genetic diversity (Suneson, 1956). Thus, the preferences which guide human selection play an important role in the distribution of pure-line components maintained in a landrace. The tendency of common bean to self-pollinate cleistogamously helps to maintain seed type diversity.

The relationship between the distribution of seed type, cooking time, and the hard seed coat trait of pure-line biotypes in Rwandan landraces has not been explored. The purpose of this study was to investigate the relationship between the cooking time and incidence of hard seed coat of predominant seed types within a landrace and their composition in the landrace. The distribution of food quality traits and their relationship with seed type in farmer managed landraces may be insightful to establish acceptability criteria for Rwandan bean improvement programs.

MATERIALS AND METHODS

A 5 kg sample of a bean landrace was purchased from each of 10 farms in the prefecture of Butare. The farms were randomly selected in the region over a range of 15 km. A one thousand seed sample was randomly selected from each 5 kg landrace. The 1000 seeds were sorted according to the color, color pattern, shape and size of the dry seed. The seed color, seed size, and number of dry seeds in each seed type classified was recorded. The seed color was classified as monochrome cream, yellow, brown, rose, red, purple, green, or black; or as background and patterned color combinations of these colors. The seed size classification used was small (< 25 gm/100 seed), medium, and large (> 40 gm/100 seed).

The predominant seed types of each landrace were identified by selecting the seed types possessing the greatest number of seeds until at least 50% of the 5 kg landrace sample was represented. Hence, each landrace could be represented by a different number of predominant seed types. The seed types comprising the largest percentage of each landrace are hereafter referred to as predominant seed types.

One hundred seeds of each predominant seed type, in each landrace, were randomly selected for evaluation of hard seed coat and cooking time. The moisture content of the samples was equilibrated for 2 weeks in sealed plastic buckets at ambient (24 C) temperatures and relative humidity (70%) prior to analysis. Seeds were soaked overnight in distilled water, and evaluated the following day for the presence of hardseed by recording the number of seeds that had not imbibed water. Cooking time was determined with a 25 seed bar-drop cooker (Jackson and Varriano-Marston, 1981) by cooking imbibed seeds in distilled water in a glass beaker over a gas stove. The cooking time of seeds expressing the hard seed coat trait was not evaluated. Laboratory samples were analyzed in a randomized block design with 4 replications. Time formed the basis of replication. Data on cooking time and incidence of hardseed coat of the predominant seed types within each landrace was subjected to separate analyses of variance (ANOVA) appropriate for a randomized block design for each landrace. Duncans multiple range test was used to ascertain mean differences for cooking time and hardseed coat among the predominant seed types of a landrace in those instances where significant differences occurred. The software program MSTAT was used for statistical procedures.

RESULTS AND DISCUSSION

Seed size and color. Each of the landraces studied was comprised of lines with different seed types (Table 1). This finding indicated that

Table 1. Distribution of seed type in 10 Rwandan landraces, and quality traits among predominant seed types.

		Predominant Seed Types		
Landrace	Seed Types no.	Distribution†	Cooking Time Index Weighted avg.‡ (min)	Hard Seed Weighted avg.‡ (%)
1	45	8 (51)	43**	2
2	48	5 (57)	43*	3**
3	18	3 (78)	44**	0
4	28	7 (62)	41**	3**
5	32	4 (66)	40	3*
6	28	8 (72)	40	0
7	34	9 (73)	39**	2
8	65	8 (58)	39	3
9	19	3 (75)	39	2
10	20	6 (79)	34*	0

† Actual number; percentage of landrace in ().
‡ **, * significantly different between selected seed types within a landrace at $p<0.01$ and 0.05, respectively.

a large amount of variability for seed characteristics was present in these Rwandan landraces. The number of unique seed types within a landrace ranged from 18 in landrace three to 65 in landrace eight (Table 1). Sixty-one samples of predominant seed types were selected for study from the 10 landraces. The predominant seed types sampled represented from 51% (landrace one) to 79% (landrace ten), of the landrace from which they were selected. The number of predominant seed types that were sampled in each landrace ranged from 3 (landrace three) to 9 (landrace seven).

There were 30 unique seed types among the 61 samples of predominant seed types. The 30 seed types were comprised of small,

Table 2. Distribution by seed size and seed color of the 61 predominant seed types comprising 10 Rwandan landraces.

Trait	Landraces with trait	Predominant Seed Types		
		Distribution†	Avg. Cooking Time Index (min)	Avg. Hard Seed (%)
Seed Size				
Small	10	44 (27)	37	3
Medium	10	30 (21)	44	2
Large	10	26 (13)	39	1
Seed Color				
Cream	2	14 (3)	41	0
Yellow	8	23 (13)	45	0
Brown	3	10 (4)	41	6
Rose	2	10 (2)	40	4
Red	7	10 (7)	37	0
Purple	3	11 (3)	35	0
Green	1	13 (1)	41	0
Black	8	17 (9)	35	2
White/black	5	11 (7)	45	6
White/red	5	8 (5)	37	4
Yellow/black	2	6 (2)	47	3
Red/Purple	1	10 (1)	40	3
Creme/Brown	1	9 (1)	44	2
Creme/green	1	10 (1)	37	2
White/black/pur.	1	9 (1)	37	0
Brown/Rose	1	5 (1)	36	0

† Percent; actual numbers in ().

medium, or large seeds with 16 unique color combinations (Table 2). All 10 landraces contained small, medium, and large seeded lines. When seed size was averaged over the 10 landraces, small seeded types tended to predominateand accounted for 44% of the total. Large seeded types comprised approximately 26% and intermediate seeded types (0.25 - 0.40 g/seed) comprised 30% of the total types evaluated. However, the distribution of predominant lines of each seed size was quite variable among landraces (data not shown). For example, one landrace was comprised of 8% small seeded lines, while another was comprised of 86% small seeded lines. Large seeded types predominated in only 2 out of 10 landraces.

The most ubiquitous colors of predominant seed types were yellow, black and red (Table 2). Yellow and black seeded lines were observed in 8 of 10 landraces, and comprised 23 and 17% of the landrace, respectively. Red seeded lines were encountered in 7 out of 10 landraces, and comprised 15% of the landrace. Bicolored, white with black and white with red colored seed types were observed in 5 out of 10 landraces, and comprised 11 and 8% of the landrace, respectively. Monochrome cream, purple, and brown colored seeds were less widely distributed among landraces, but when present, comprised 14, 11, and 10 percent of the landrace. The predominance of yellow and red seeded types in this region of Rwanda was also observed by Lamb and Hardman (1987).

The variability for seed type maintained in the Rwandan landraces is similar to the large variability observed in Malawian landraces (Martin and Adams, 1987a). Large standard deviations for seed size and seed color among and within landraces suggested that particular needs and preferences of a farmer maintaining a landrace influenced selection, and that farmers selected for traits in addition to seed type. For example, the distribution of small versus large seeded types in a particular landrace may reflect the particular microenvironment and needs of the farmer maintaining the landrace. Large seed size is preferred and commands a premium market price, however, growers associate large seed size with poor stability on infertile soil (Lamb and Hardman, 1985). Lamb and Hardman, 1987, reported that 81% of small seeded types in Rwandan landraces were considered by Rwandan farmers to be high yielding. Tolerance to infertile soil and resistance to diseases were traits reported to be associated with small seededness. Predominantly small seeded cultivars may be maintained in a landrace when yield is the primary constraint, and predominantly larger seeded types maintained when there is adequate or surplus production.

The wide array of seed color and size selected and maintained in modern day landraces may serve as a perceptually distinct genetic marker to ensure diversity for less readily perceived use or survival traits (Kaplan, 1981; Boster, 1984). A model of selection for perceptual distinctiveness based upon observation of traditional manioc (*Manihot esculenta*) cultivation (Bolster, 1984) can be applied to bean landraces. A perceptual marker possesses high, continuous, and independent variation for a nonadaptive taxonomic character. The bean seed color and size observed in 10 Rwandan landraces shows high, continuous variability, but no intrinsic survival value.

Historical and empirical evidence suggests that cultivation of genetically diverse germplasm has advantages over cultivation of pure-line cultivars. Archaeological evidence from at least 1,000 B.P. indicated that common bean was cultivated in its centers of origin in Latin America as a landrace comprised of 4-6 perceptually distinct cultivars (Kaplan, 1981). Specific preferences in Latin America for various combinations of size and color of seeds, and the cultivation of commercial grain classes evolved after approximately 7000 years of cultivation and selection from a genetically diverse germplasm. Common bean has only a few centuries of history as a crop in Africa, and it is still cultivated in many parts of Africa the same way it was cultivated during the early days of domestication in Latin America.

The population buffering provided by cultivation of landraces has specific advantages (Allard and Hansche, 1964). Phenological diversity may reduce the risk of total crop loss during short periods of drought, and morphological diversity may offer differential tolerance to pests, diseases, or certain growing conditions. Yield increases superior to yields of pure-line cultivars developed by conventional breeding methods have been reported for self-pollinating populations after 15 generations of natural selection (Suneson, 1956).

Cooking time. Significant differences in cooking time of the predominant lines within a landrace were observed for 6 out of the 10 landraces evaluated (Table 1). In addition to cooking time differences among predominant seed types within a landrace, the weighted average of the cooking time indexes of the landraces ranged from 34 min (landrace ten) to 44 min (landraces one and two). The range in cooking time among landraces observed in this study suggested that some farmers had selected cultivars based upon their cooking performance and were developing fast cooking landraces.

The cooking time of the 61 predominant seed types according to their seed color and seed size revealed some trends. Medium seeded types tended to require a longer amount of time to cook (44 min) than small and large seeded types (37 and 39 min, respectively; Table 2). The average cooking time index ranged from 35 min for nine predominant black seeded types, and 3 predominant purple colored types to 47 minutes for two multicolored yellow with black seeded types.

The range in the cooking time index observed in this study appears to be of sufficient magnitude to aid fuelwood conservation. Shellie-Dessert and Hosfield, 1990 reported a fuel-wood saving of 1.3 kg per cooking session between treatments with a 15 min difference in cooking time. The 9 minute range in the cooking time index observed among landraces and the 12 minute range observed among seed colors suggested that the fast cooking landraces and seed types observed in this study conserved fuelwood.

The slower cooking landraces tended to be comprised of predominant seed types that cooked significantly differently from each other (Table 1). Landrace ten was an exception to this trend because it was the fastest cooking landrace but was comprised of predominant seed types that required significantly different amounts of time to cook. The significance of the cooking time index within a landrace was not related to the number of predominant seed types in a landrace or the percentage of the landrace represented. There was an average of 6.3 predominant seed types in landraces one, two, three, four, seven, and ten; and an average of 5.8 predominant seed types in landraces five, six, eight, and nine. Predominant seed types accounted for 67% of landraces one, two, three, four, seven and ten; and 67% of landraces five, six, eight, and nine.

Some trends were apparent between the distribution of a predominant seed type in a landrace and its cooking time index (Table 3). Predominant seed types that cooked significantly faster or slower than all other types in the landrace comprised less than 10% of the landrace. If more than one predominant type cooked differently, a blending trend was observed whereby cooking times were graduated within the landrace. For example, in landraces one, three, and ten, one predominant type cooked significantly different than all other types in the landrace, and it comprised 7, 8, and 8 percent of the landrace, respectively. In landrace one, slow cooking predominant seed types (columns b, c, and d) were each blended into the landrace at 9 percent. The fast cooking types (columns e and f) comprised 25 and 26 percent of the landrace, respectively. The blending trend of overlapping, evenly distributed fast and long cooking seed types within a landrace was apparent in landraces two, four, and seven. In landrace two, the predominant lines with identical letters in the same column comprised 31, 26, and 37 percent of the landrace, respectively. The same trend was apparent in landraces four and seven where predominant lines with identical letters in the same column comprised 15, 39, and 47; and 30, 18, 29, and 28 percent of the landrace, respectively. This blending trend could be due to a random assortment of a highly variable trait, but it could also be due to farmer selection for uniform cooked texture and fuelwood conservation.

Hard seed coat trait. Extant genetic variability for the hard seed coat trait in the 10 observed landraces was small (Table 1). The mean percentage of predominant lines within a landrace that expressed the hard seed coat trait ranged from 0% in landraces three, six, and ten, to 3% in landraces two, four, five, and eight. Significant differences among the predominant seed types of a landrace were apparent in only 3 of the 7 landraces that contained hard seed. The low amount of genetic variability for the hard seed coat trait observed in this study may indicate that selection against this trait during the domestication of common bean has been successful.

Landraces two, four, and 5 each contained one predominant seed type that expressed a significantly higher incidence of hard seed coat (Table 1). A medium sized, white with black seed expressed 17% incidence of hard seed in landrace two (Table 3). The seed color of the predominant seed type in landrace four that expressed a 20% incidence of hardseed was also white and black, but the seed size was small instead of medium. A small, brown seeded bean expressed 9% incidence of hardseed in landrace five (data not shown).

Expression of the hard seed coat trait appeared to be independent of cooking time. Landrace three had the longest average cooking time and did not contain any predominant seed types that expressed the hard seed trait (Table 1). Landraces seven, eight, and nine were relatively fast cooking and contained predominant seed types with 2, 3, and 2

Table 3. Mean values of predominant seed types in landraces containing significant differences.

Landrace	Predominant seed type: Distribution (%)	Cooking time index† (min)	Hard seed coat† (%)
1	7	59 a	0 a
	5	52 b	0 a
	4	48 bc	2 a
	5	44 cd	3 a
	4	41 de	8 a
	14	36 ef	0 a
	7	36 ef	0 a
	5	35 f	4 a
2	12	55 a	0 a
	8	50 ab	17 b
	11	42 abc	0 a
	7	39 bc	3 a
	19	34 c	0 a
3	48	44 a	0 a
	22	45 a	0 a
	8	37 b	0 a
4	8	53 a	20 b
	7	46 ab	0 a
	5	40 bc	3 a
	17	40 bc	0 a
	10	39 bc	0 a
	6	38 c	0 a
	9	35 c	0 a
7	8	47 a	3 a
	9	47 a	0 a
	10	46 a	0 a
	3	44 ab	0 a
	8	37 bc	7 a
	7	37 bc	0 a
	4	35 cd	11 a
	10	34 cd	0 a
	14	29 d	2 a
10	6	39 a	0 a
	7	37 a	0 a
	26	35 a	0 a
	23	34 a	0 a
	9	34 a	0 a
	8	25 b	4 a

† Identical letters in the same column indicate no significant different at the 0.05 probability level using Duncans multiple range test.

percent expression of the hard seed coat trait, respectively. The average cooking time index of predominant seed types expressing the hard seed coat trait was the same as the grand mean of the 61 predominant seed types in the study (40 min).

It has been suggested that the amount of water dry beans absorb during soaking prior to cooking is indicative of the amount of time required to render them eating soft, and that water absorption be used as an indirect selection criteria for cooking time in a crop improvement program. The amount of water absorbed after overnight soaking in the absence of hard seed was determined to be a genetic trait that was independent of cooking time (Shellie, Chapter 1). The cooking time of seeds with the hard seed coat trait is prolonged due to impaired water imbibition, but once the seed imbibes water, cooking proceeds normally. If selection for cooking time was based upon water imbibition, the hard seed coat trait would mask the genetic potential of a cultivar's cooking time and water absorption. Results from this study suggest that the genetic potential for cooking time and for the hard seed coat trait are unique quality characteristics that require independent evaluation.

The apparent preference for and advantages of indigenous landraces should be recognized by cultivar improvement programs in east Africa, and deployment strategies developed whereby improved cultivars are evaluated according to their potential contribution as a component of an intraspecific polyculture. Results from this study indicate that seed type per se will not limit the acceptability of an improved cultivar as a component of a landrace. The slight dominance of small seeded types in landraces indicated that small and medium seeded improved cultivars may be incorporated into a landrace at a higher percentage than a large seeded cultivar. One could therefore anticipate greater impact on bean production from a small to medium sized cultivar than a large seeded cultivar. Improved, long cooking cultivars will most likely be incorporated into a landrace at less than 10 percent, and will require other lines to blend their firm texture into a palatable product. Therefore, the incorporation of a new, long cooking cultivar into a landrace would require the presence of other long cooking lines in the landrace. The net effect would be to prolong the cooking time of the landrace and utilize more fuelwood to prepare the landrace for consumption. Fuelwood conservation and deforestation are important constraints in Rwanda; hence, the screening and selection of improved cultivars with moderate or fast cooking times should be a major objective of cultivar improvement programs for dry bean.

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