HERITABILITY OF COOKING TIME AND WATER ABSORPTION TRAITS IN DRY BEANS *(PHASEOLUS VULGARIS L.)* USING A NORTH CAROLINA DESIGN II MATING SCHEME

FM Elia
University of Dar es Salaam, Department of Botany
P.O. Box 35060, Dar es salaam, Tanzania

Received June 2002: Accepted: 27 December 2002

ABSTRACT

Estimation of genetic variances, heritabilities and estimations of response to selection of the cooking time and water absorption traits of Andean gene pool of dry bean seed Phaseolus vulgaris L. were done. General combining ability (GCA) i.e. GCA males and GCA females, and Specific combining ability (SCA) were estimated. The parents were crossed in a North Carolina mating design II and genetic analysis was made on the F_3 and F_4. Both male and female effectations within sets for the cooking trait in F_3 and F_4 were highly significant for the traits studied. Variances due to General combining ability (GCA) and Specific combining ability (SCA) were significant for the traits. It was observed that quick cooking parental genotypes produced progenies that were rapid cooking. This suggests that it is possible to select superior cooking progenies from crosses involving quick cooking parents due to the preponderance of the additive genetic variance in both F_3 and F_4. The high heritability and large magnitude in the range of the means of the cooking time trait indicates that population improvement is possible through recurrent selection. Estimation of response to selection indicated that genetic gain in selection was achievable.

Partitioning among the entry source of variance for the water absorption into male and female effects within sets, their interactions, and the environment main effect indicated that the values were highly significant in both F_3 and F_4. The GCA male and GCA female effects had a much larger component of variance than the SCA. This indicates that additive genetic variances were important. The large magnitude in the heritability and the range in the mean of water absorption, and the estimated high response to selection indicate that the population can be improved through selection as shown by the presence of genetic gain in selection for the trait. It appears from the results obtained in this study that soaking dry beans before cooking is indicative of the amount of time required to render them eating soft. Hence water absorption can be used as a secondary selection index or indirect selection criteria for cooking time in a crop improvement program. In both traits studied, narrow sense heritability estimates were high (76% to 85 %).

INTRODUCTION

In East and Central Africa, dry bean *(Phaseolus vulgaris L.)* is an important source of protein and carbohydrates in diets of many people. One of the main constraints to increased bean utilization is the prolonged cooking time required for beans leading to excessive use of fuel wood thereby exacerbating deforestation.

Bean cultivars that cook fairly quickly to a palatable texture have been reported (CIAT 1986, Dessert 1986, Shellie 1990, Shellie-Dessert and Bliss 1990). In addition to fast cooking, beans that are preferred in Africa have protein contents >20%, mature within three months, and have 100-seed weights between 35 and 45 g. (van Schoonhoven and Voysest 1993).

The presence of genetic variability is a prerequisite for making genetic improvement of metric traits in a crop. Selection in segregating generations following hybridization is the current practice in making genetic advance for metric traits in dry bean. However, the efficacy of selection for a trait depends on the knowledge of its genetic control and the degree to which the environment influences the expression of traits. Information is available on genetic variability for cooking time of dry bean (Shellie-Dessert and Hosfield 1991) but information on the inheritance of this trait is scanty.

Knowledge of the heritability (H^2) of a trait is important because it can aid the breeder in successfully changing the characteristics of populations. Thus the H^2 of a metric character is one of its most important properties. Heritability in its broad sense is the proportion of the phenotypic expression of a trait that is due to genetic causes and is defined as H^2 = genotypic variance/phenotypic variance. Since H^2 is that proportion of the total variation in a trait's expression attributable to the average effects of genes, it has a major impact on the methods chosen for population improvement. For this reason, H^2 enters into most formulae concerned with plant breeding theory and methods, and, in the practical sense, its magnitude determines the effectiveness of improvement strategies within a given environment. This is because H^2 is not constant and varies with different environments.

In many studies involving cooking of dry beans, the seeds are often soaked in water to improve the hydration characteristics of the seeds for uniform cooking. The amount of water absorbed by beans during soaking prior to cooking may be indicative of the amount of time required to render them eating soft; hence provide a rapid indirect method for screening genotypes for cookability.

This study was undertaken in an attempt to develop fast cooking beans. Specific objectives were to: (1) determine mechanisms of genetic control of cooking time and estimate the heritability for this trait, (2) estimate the selection differential and the gain expected from selection, and (3) examine the correlation between cooking time and water absorption trait to ascertain the ease of selecting several traits simultaneously.

MATERIALS AND METHODS

Genetic material

Except for 'Sierra', the parents were representative of the Andean geographic race of *P. vulgaris* and considered a random sample of the useful Andean gene pool (Table 1). 'Sierra' was representative of the Meso-American geographic race with medium sized seed (average about 30g /100 seeds).
Although all the genotypes were adapted to the bean production areas of East and Central Africa, the lines differed in yield, seed weight, growth habit, seed coat characteristics (color and shape), and tropical stresses namely drought, pests and diseases.

Procedures

The 16 genotypes were crossed in the greenhouse using a North Carolina Design II mating scheme where eight genotypes were randomly chosen as male parents and the remaining eight genotypes were used as female parents. Each of the eight male parent was crossed to four females. The genotype used as

male parents were not crossed to each other nor were the genotypes used as females crossed to each other. To reduce the number of matings required two sets were formed. Within each set, each male parent was crossed to four females, resulting in a total of 16 crosses per set. Thus a total of 32 progeny resulted from this crossing procedure.

The field arrangement of entries was based on the assignment of the eight male groups to each of the two sets. Four male groups were assigned to set one, and the remaining four male groups were assigned to set 2. Although the male groups were assigned to each set at random, the integrity of each set was maintained at each location in each growing season. Eight of the 16 parents corresponding to the males and females within a particular set were also included in that set. The two sets were planted in a randomized complete block design with three replications at the Crop Museum farm (530 masl) and Morning site (~1000 masl) at SUA. Seeds were hand planted into four row plots. Rows were 4 m long and spaced 0.5 m apart. Within row spacing was 0.1 m. Standard practices for herbicide, pesticide and fertilizer applications were followed. Mature plants were harvested by hand from the middle two rows of individual plots when the pods had attained physiological maturity (when about 90% of the pods in a plot had changed from green to pale yellow or brown).

Character evaluation

The freshly harvested seeds from each plot were sun dried for two weeks and stored in tight-fitting plastic buckets at 20^0c and 70% RH until sample preparation and analysis. In order to determine the percent water absorption of the genotypes, triplicate samples of a known weight of 75 seeds from each plot were soaked in distilled water for twelve hours. The amount of water absorbed was taken as the difference in weight before and after soaking divided by the difference in the weight of un-soaked seeds. Results were expressed as percent water absorption. Once the bean water absorption determinations were made, seeds of each entry were evaluated for cooking time which was determined on 25 seeds with a bar-drop cooker described by Jackson and Varriano-Marston (1981). The time required to cook at least 50% of the sample (i.e., when 13 of the 25 pin drop bars had penetrated through the seeds) was considered as the cooking time index for the sample. Values were recorded in triplicate for each field replication at each location.

Statistical analysis

An all-random-effects model was used for analyses of variance (ANOVA) (Searle 1971). In the Design II ANOVA (Table 2), variability due to progeny was broken out as variation due to males within sets, females within sets, and males x females interaction within sets (Hallauer and Miranda 1988). In the present study, variation due to males within sets, females within sets and male x females within sets will be referred to interchangeably as GCA males, GCA females, and SCA variation, respectively. The F-tests were straightforward for all sources of variation in the ANOVA except for male and female components. Approximate F-tests (Satterthwaite 1946) were constructed based on the mean square expectations and used to test the male and female effects.

Estimates of the variance components were calculated by equating terms comprising the expected mean squares to the corresponding observed mean square and solving by appropriate algebraic manipulations (Comstock and Robinson1948, Hallauer and Miranda 1988). The components of genetic variance were estimated according to expectations provided by Cockerham (1956) as:

$s^2_m = s^2_f = \text{Cov HS} = (1/4)\, s^2_A$, and

$s^2_{mf} = \text{Cov FS} - \text{Cov HS}_m - \text{Cov Hs}_f = (1/4)s^2_D$.

manipulations (Comstock and Robinson1948, Hallauer and Miranda 1988). The components of genetic variance were estimated according to expectations provided by Cockerham (1956) as:

$s^2_m = s^2_f = \text{Cov HS} = (1/4)\, s^2_A$, and

$s^2_{mf} = \text{Cov FS} - \text{Cov HS}_m - \text{Cov Hs}_f = (1/4)s^2_D$.

Where: s^2_A, and s^2_D are the additive and dominance variances, and s^2_m, s^2_f, s^2_{mf} are the variance due to GCA males, GCA females, and SCA respectively. The Cov HS and Cov FS are the covariances of half-sib and full-sib progeny.

The degree of dominance governing the genes for trait expression was estimated by: $d = (2s^2_{mf} / s^2_m)^{1/2}$ where d = degree of dominance.

Narrow-sense heritability was estimated from:

$$H^2_N = s^2_A / s^2_{ph}$$

The approximate standard error of the narrow -sense heritability estimate was calculated as $SE(H^2) = SE(S^2_f)/S^2_{pfm}$; where S^2_f is the variance components due to progeny and S^2_{pfm} is the total phenotypic variance of progeny estimated from variance components (GENSTAT 5, program) (Anon,1989).

Table 1: Name, mean values and other seed characteristics of the 16 dry bean entries used in the study at Sokoine University of Agriculture, Morogoro, Tanzania

No.	Entry	Grain Type	Seed coat characteristics	100 Seed Wt(g)	Cook Time	Water adsortion
1.	Var 11	kidney	Red mottled	35.7	25.5	1061.0
2.	Nyiraki- zungu	kidney	Red mottled	40.3	30.5	941.0
3.	Lyamungu 85	kidney	Deep red mottling	34.6	41.5	786.0
4.	Kilyumukwe	kidney	Red kidney	47.4	46.5	699.0
5.	Yellow-eye	yellow	yellow ventral white dorsal	36.9	6.3	819.0
6.	UAC 221	-	Grayish pink	45.3	52.3	542.5
7.	TMO 959	kidney	Purple and speckled	36.9	43.5	765.0
8.	Kalima	calima	Cream/red mottled	45.3	28.3	991.5
9.	3005	Khaki colored		36.8	49.8	588.5
10.	605621	kidney	Brown speckle	47.9	28.3	1030.0
11.	GLPX 1125	cranberry	Cream and speckled	44.7	49.0	649.0
12.	Jacob's cattle	Heirloom	Black/white patched	46.3	33.5	818.0
13.	Montcalm	-	Cream/light brown	44.2	47.3	675.0
14.	NY 99	-	Pinkish brown	33.1	45.5	732.5
15.	Sierra	pinto	Cream/dark patched	28.6	35.5	860.0
16.	Diacol Calima	calima	Red mottled	45.3	37.0	805.0

Table 2: Form of the analysis of variance used of a design II experiment repeated over environments

Source	df†	Mean square	Expected mean squares ‡¨
Site(E)	e-1		
Sets(S)	s-1		
S x E	(e-1)(s-1)		
R/S/E	es(r-1)		
M/S	s(m-1)	M7	$s^2 + r\,s^2_{fme} + rfs^2_{me} + res^2_{mf} + refs^2_{m}$
F/S	s(f-1)	M6	$s^2 + rs^2_{fme} + rms^2_{fe} + re\,s^2_{mf} + rems^2_{f}$
M x F/S	s(m-1)(f-1)	M5	$s^2 + rs^2_{fme} + res^2_{mf}$
M/S x E	s(m-1)(e-1)	M4	$s^2 + rs^2_{fme} + rfs^2_{me}$
F/S x E	s(f-1)(e-1)	M3	$s^2 + rs^2_{fme} + rms^2_{fe}$
M x F/ S x E	s(m-1)(f-1)(e-1)	M2	$s^2 + rs^2_{fme}$
Pooled error	es(r-1)(mf-1)	M1	s^2
Total esrmf-1			

†e, s, r, m, and f refer to the number of environments or locations, sets within an environment, replications, males, and females, respectively.

‡ s2 = pooled error variance; s^2_{fme} = variance due to the interaction of males and females and environment.

RESULTS AND DISCUSSION

Mean squares for males within sets and females within sets were highly significant for the cooking time index and water absorption (Table 3). The set mean square was significant for cooking time index in F_3 and for water absorption in both F_3 and F_4. The mean square for environment was also significant for water absorption in both F_3 and F_4. The significant mean square corresponding environments led to no interactions involving this source of variability. On the other hand, the SCA was significant for water absorption in F_3 and F_4 and for the cooking time index in F_4. These interactions indicated that non-additive gene action was important in the populations because the male x female variance component, estimated from the mean square contains one fourth of the dominance genetic variance. The absence of interactions involving environment indicated that the rankings of the entries were fairly consistent at the two locations of crop museum farm and morning site although these environments differed in altitude by about 500 m.

The GCA males and GCA females for cooking time index in F_3 and F_4 accounted for 17% and 51% of the total variance, respectively (Table 4). The variance components for water absorption accounted for 78% and 77% of the total variance in F_3 and F_4 respectively, indicating that it remained fairly consistent in the two seasons. The genetic variance influencing cooking time index was essentially all additive in F_3 and F_4 but a small amount of non additive (s^2_D) was noted in F_4 (Table 5). The genetic variance influencing water absorption was predominantly additive with this type of variance overshadowing the non-additive variance (slightly greater than 3 to 1) in F_3 and F_4. The additive and non-additive variance components for water absorption were in good agreement between F_3 and F_4. The additive variance is the chief determinant of the resemblance between relatives and therefore the main genetic property of a population that responds to selection.

Table 3: Mean squares from the analyses of variance for cooking time and water absorption traits of dry beans grown at two locations at SUA Morogoro, Tanzania

Source of Var.	DF	Cooking Time		Water absorption	
		F3	F4	F3	F4
E	1	278	213	383*	275*
S	1	1117*	1281	2663*	2770*
S/E	1	0	5	1	1
R/S/E	8	3.5	1	1	2
M/S †	6	62**	114**	315**	322**
F/S †	6	21**	248**	1358**	1310**
M x F/S	18	1	5**	23**	24**
M/S x E	6	4	1	0	1
F/S x E	6	0	2	1	0
E/S/M/F	18	1	1	1	1
Error	120	2	2	1	1
Total	191				

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

Table 4: Estimates of variance components scaled to sum to 100 for the cooking time and water absorption traits of dry beans grown at two locations at SUA, Morogoro, Tanzania

Source of variation	Trait			
	Cooking time in minutes		Water absorption g.kg-1	
	F_3	F_4	F_3	F_4
Environments (E)	15.0	7.5	4.6	3.3
Sets (S)	56.0	33.3	12.1	14.1
SxE	0.0	0.3	0.01	0.0
Reps/S/E	0.5	0.0	0.0	0.1
Males/S	12.3	15.7	14.0	14.4
Females/S	4.4	35.0	63.7	62.6
Males x Females/S	0.4	2.3	4.1	4.4
Males/SxE	1.5	0.1	0.0	0.04
Females/sets x E	0.0	0.3	0.01	0.0
Males x Females/S x E	0.0	0.0	0.0	0.0
Pooled error	10.0	5.5	1.6	0.1
Total variance	100.0	100.0	100.0	100.0

Table 5: Estimates of additive and dominance variance, and broad and narrow sense heritability for the cooking time and water absorption traits in the F_3 and F_4 generation of 32 half-sib families grown in two environments at SUA, Morogoro, Tanzania.

Character	A_v		D_v		H^2_B		H^2_N		Degree of dominance	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
Cooking time index	9.5	18.1	0.3	2.7	0.8	0.9	0.9	0.9	0.2	0.6
Water absorption	48.9	49.6	14.5	15.2	0.9 5	0.96	0.8	0.8	0.8	0.8

A_V, D_V, H^2_B, and H^2_N = the additive and dominance genetic variance and the broad and narrow sense heritabilities respectively.

Knowledge of the genetic variance influencing a metric trait is important because it allows one to estimate its relative importance to that of the environment (Falconer 1981). The ratio of the genetic variance to total variance of a trait is an expression of the trait's heritability. The broad sense heritabilities for the cooking time index were 0.8 and 0.9 in F_3 and F_4 respectively; and narrow sense heritability of 0.9 and 0.9 in F_3 and F_4 respectively (Table 5). The respective heritabilities for water absorption were 0.95 and 0.8 in the F_3 and 0.96 and 0.8 in the F_4 (Table 5). It is acknowledged that these H^2 estimates may be biased by confounding effects of the dominance variance components and those between years and segregation effects. The concept of H^2 is important in understanding how to successfully change the characteristics of populations because its magnitude determines the effectiveness of improvement strategies. The degree of dominance (Table 5) of the cooking time index was 0.2 and 0.6 in F_3 and F_4, respectively and 0.8 in both F_3 and F_4, for the water absorption trait. A degree of dominance greater than 0.5 but less than 1.0 indicated that traits were governed by genes with the quality of partial dominance.

Means of the 32 entries for cooking time index in F_3 and F_4 were essentially equivalent (Table 6); however the range in cooking time was greater in the F_4 (16 min) versus the F_3 (9.5). These ranges in cooking time in the F_3 and F_4 while not of a great magnitude should be sufficient enough to significantly assist in the effort to conserve fuel wood in improved lines developed by selection from this population.

Shellie-Dessert and Hosfield (1990) showed an average fuel wood savings of 1.3 kg per cooking session associated with a 15-min reduction in bean cooking time. Consumers of beans in most bean producing East African countries build 14 fires per week for cooking and reheating the food (Shellie-Dessert and Hosfield 1990). Given a 1.3 kg fuel wood savings per cooking session for beans, the annual fuel savings would be 949 kg which is slightly less than 1 MT. Since the cooking time of dry beans is of critical importance to energy use and the overall preservation of fuel wood in Tanzania and other bean growing regions of Eastern Africa, even a small reduction of bean cooking time should lead to a greater consumption and thus improve nutritional well-being. While the development of high yielding cultivars of beans that have a shorter cooking time remains an important objective to reduce

costs and increase their utilization, there is need to look at alternative ways to estimate the cooking time index.

A number of cookability studies in dry beans have shown a relationship between cooking time and water absorption (Mora 1982, Moscoso *et al.* 1984; Hernandenz-Unzon and Ortega-Delgado 1987, Paredes-Lopez *et al.* 1989, Edmister *et al.* 1990).

Table 6: Mean performance of F_3 and F_4 progenies of dry beans evaluated for the cooking time and water absorption traits in two locations at SUA, Morogoro, Tanzania

	Cooking time (min.)	Water absorption (g.kg-1)
Mean		
F_3	38.4	817.6
F_4	38.0	822.6
Range		
F_3	33.0 - 42.5 (9.5)	648.3 -955.0 (306.7)
F_4	30.5 - 46.5 (16.0)	676.7 -975.0 (298.3)
LSD		
F_3	2.4	28.2
F_4	1.5	11.2

Table 7: Correlation coefficients between ooking time and water absorption traits for F_3 and F_4 generations of dry beans grown at Morogoro, Tanzania.

Trait	Generation	Water absorption
Cooking	F_3	-0.871*
Time	F_4	-0.781*

*Correlations significant at $p < 0.005$)

The phenotypic correlations between the cooking time index and water absorption for 192 observations were fairly consistent between the F_3 and F_4 (-0.871* and -0.781* respectively). The sign but not the magnitude of the correlation between these two traits agreed with the correlation between cooking time index and water absorption reported by Shellie-Dessert and Hosfield (1991). These researchers found a -0.37 phenotypic correlation between the traits after examining data from 270 observations. Shellie-Dessert and Hosfield (1991) had no family structure in their experiments, hence, their data was representative of the correlations among data taken on 10 cultivars *per se*. The negative correlation found in the present study indicates that slow cooking beans imbibe less water than fast cooking beans. The magnitude of the correlations between cooking time and water absorption found in this study suggest that the percent water absorption trait should be useful to predict or estimate cooking time in beans. The method of using water absorption for estimating cooking time as opposed to measuring the cooking time per se can save considerable time and energy resources.

Breeding implications

Significant variation in the cooking time index and water absorption traits in the present study indicated that these traits can be effectively

changed by selection. The high magnitude of GCA to SCA indicates that progress can be realized. The genetic gain from controlling both parents is twice that expected when only the female parent is selected. A downside of this procedure is that two seasons are required to complete a cycle of selection; however, the use of winter nurseries (in non-tropical regions) or a bimodal rainfall as occurs at Morogoro, in which selection can be practiced, would reduce the time required to complete a selection cycle. A combination of early generation selection or pedigree selection may be used. Should a combination of inbreeding method be used for trait improvement, the breeder could select the best F_2-derived F_4 lines and evaluate these on a row basis for water uptake and cooking time. Since the two traits exhibited high heritability, pedigree selection could be continued between selected $F_{2:4}$ lines derived from the second selection cycle.

The estimated gain in selection for cooking time was of the magnitude of about two minutes per cycle while that of water absorption trait was 63 $g.kg^{-1}$ per cycle (Table 8). This indicates that perhaps at least two cycles of selection may be needed for population improvement of the two traits to attain economic benefit. Since the interactions due to males and females x environment were non significant and characterized by high heritabilities, the effectiveness of selection of superior genotypes for recombination was improved thereby increasing the genetic gain per cycle. Knowledge of genetic gain per cycle can therefore be used by bean breeders to evaluate resource allocation when evaluating genotypes for release as new lines or cultivars

Table 8: Estimation of response to selection for cooking time and water absorption traits of dry beans studied at SUA, Morogoro, Tanzania

Trait	x_P	x_S	H^2_N	SD	$_DG$
Cooking time	40.70	38.70	0.85	2.00	-1.80
Water Absorption	743.90	822.60	0.76	78.7	63.00

x_P mean of the population; x_s mean of the individuals for selection; H^2_N narrow sense heritability; **SD** selection differential; $_DG$ genetic gain in selection.

ACKNOWLEDGEMENT

The author is grateful to the Crop Science Department, Sokoine University of Agriculture, Morogoro, for availing the necessary space, material and technical assistance, and for the financial support by Rockefeller Foundation.

REFERENCES

Anon 1989 GENSTAT as a statistical software program from Rothamsted Experimental Station, Harpenden, Hertfordshire AL5 2JQ.

CIAT (Centro Internacional de Agricultura Tropical) 1986 *Bean program annual report CIAT* Cali, Colombia. p. 248.

Cockerham C C 1956 Analysis of quantitative gene action. Brookhaven_*Symposia in Biology* **9**: 53-68

Cockerham C C 1963 Estimation of genetic variances. In Hanson W D and Robinson H F (eds.) *Nat. Acad. Sci. Nat. Res. Coun. Pub.* **982**: 53-94

Comstock R E and Robinson H F 1948 The components of genetic variation in population of biparental progenies and their use in estimating average degree of dominance. *Biometrics* **4:**254-266.

Dessert K C 1986 Environmental influence study on cooking times and total protein content often *(Phaseolus vulgaris L.)* Varieties in Rwanda, Africa *Bean Improv. Coop.* **29**: 123

Edmister J A, Breene W. M and Serugendo A 1990 Influence of temperature, water activity and time on cookability and color of a stored Rwandan dry bean *(Phaseolus vulgaris L.)* J. *Stored Prod Res.* **26(3)**: 121-126.

Falconer D S 1981 *Introduction to quantitatve genetics* Longman Scientific and Technical

Hallauer A R and Miranda. J B 1988 *Quantitative genetics in maize breeding. Iowa State University Press/Ames.*

Hernandez-Unzon H Y and Ortega-Delgado M L 1987 Water absorption and cooking time in long stored common bean seeds *(Phaseolus vulgaris L.). Annu. Rept. Bean Improv. Coop.* **30**: 58-59.

Jackson G M and Varriano-Marston E 1981 Hard to cook phenomenon in beans: effect of accelerated storage on water absorption and cooking time *J. Food Sci.* **46**: 799-803.

Miller P A, Williams J C and Robinson H F 1959 Variety x environment interactions in cotton variety tests and their implications on testing methods. *Agron. J.* **51**: 132-134.

Mora M A 1982 The influence of different temperatures and moisture contents on the cooking time of beans *(phaseolus vulgaris L.)* stored during 18 months [storage conditions]. *Agro. Costarric.* **6(ý):**87-89

Moscoso W, Bourne M C and Hood L F 1984. Relationship between the hard to cook phenomenon in red kidney beans and water absorption, puncture force, pectin, phytic acid, and minerals. *J. Food Sci.* **49:**1577-1583

Paredes-Lopez O, Maza-Calvino E C and Gonzalez-Castaneda J 1989. Effect of the hardening phenomenon on some physico-chemical properties of common bean. *Food Chem.* **31(3)**: 225-236.

Satterthwaite F E 1946 An approximate distribution of estimates of variance components. *Biometrics* **2:**110-114.

Searle S R 1971 Topics in variance component estimation. *Biometrics* **27**: 1-74.

Shellie-Dessert K C and F A Bliss 1990 Genetic improvement of food quality factors. In: van Schoonhoven A and Voysest O (eds) *Common Beans: Research for Crop Improvement.* CIAT. Cali, Colombia.

Shellie-Desert K C 1990 *Food quality and fuelwood conservation of selected common bean (Phaseolus vulgaris L.) cultivars and land races in Rwanda.* Ph. D. Thesis. Michigan State University,. East Lansing.

Shellie-Dessert, K. C. and G. L. Hosfield. 1990. Implications of genetic variability for dry bean cooking time and novel cooking methods for fuel conservation in Rwanda. *Ecol. Food and Nutr.* **24**: 195-211

Shellie-Dessert K C and Hosfield G L 1991 Genotype x environmental effects on food quality of common bean: resource-efficient testing procedures. *J. Amer. Soc. Hort. Sci.* **116(4)**: 732-736.

Van Schoonhoven A. and Voysest O 1993. *Common Beans. Research for Crop Improvement* C. A. B. International in association with CIAT.