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Research Article

Genetic Analysis of Cooking Time in Five Common Bean (*Phaseolus vulgaris* L.) Cultivars Grown in Cameroon

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Abstract: Long cooking time continues to be a major hindrance to the widespread consumption of beans. It is an important trait with implications for gender equity, energy utilization, and nutritional value of diets. In order to develop *Phaseolus vulgaris* genotype with faster cooking time, an experiment was conducted at Dang University of Ngaoundéré campus on five common bean cultivars and ten F_1 hybrids synthesized from 5 x 5 half diallel mating. Cooking time test was carried out on freshly harvested dry seeds (T=0) and 10 days stored seeds (T=10) using the standardized Mattson cooker method. Analysis of variance showed that, the differences among the five cultivars for cooking time were highly significant ($p< 0.001$) for fresh and stored seeds indicating the presence of wide genetic variability. Freshly harvested beans cook 3-4 times faster than beans stored for 10 days. High broad sense heritability and high narrow sense heritability values showed the preponderance of genetic variance and the additive gene action in the governing of cooking time. The ratio GCA/SCA was greater than unity, confirming the importance of additive genetic variance for this character. The fastest cooking lines PR and PB appeared also as the best general combiners. Among the crosses, F_1 hybrids PB x BI, PB x CT, PB x PR, PN x PR and BI x PR had positive and significant specific combining ability. Recessive alleles had positive effect for reducing cooking time and genotype PR had the maximum number of recessive genes. These results would help breeders to improve this trait in terms of initial parent selection and subsequent crossbred selection and breeding procedures.

Keywords: *Phaseolus vulgaris*, cooking time, hard-to-cook defect, diallel analysis, seed storage, genetic selection.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is a nutrient dense food and a dietary staple in several nations of Latin America, Africa, and Asia (Hnatusko-Konka *et al*., 2014). It is the second most important grain crop in next to maize in terms of production and consumption in Africa and especially in the Western Highlands of Cameroon (Broughton *et al*., 2003). Dry beans are rich source of protein, dietary fiber, iron, magnesium and folic acid (Osborn, 1988; Broughton *et al*., 2003; Hnatusko-Konka *et al*., 2014). Total protein of common bean ranges from 16 to 33% and salt-soluble globulins are the most abundant proteins in beans (Osborn, 1988). It is the second most important source of proteins and the third most important source of calories for people in rural and poor communities in developing countries (Buruchara *et al.*, 2011). Common bean consumption has reportedly reduced colon and breast cancer, and heart diseases (Buruchara *et al.*, 2011). Despite their high nutritional value, beans require long cooking time to become palatable (Wang and Daun, 2005; Wood, 2006). Pulses are commonly cooked prior to consumption normally by hydrothermal processes (boiling, pressure cooking, canning) or dry heat processes (puffing, roasting, oil frying) (Wood, 2006). In some cultures, beans are soaked in water overnight prior to cooking, and in other cultures, they are cooked without soaking (Parades-Lopez *et al*., 1991; Wood, 2006). The series of chemical changes that occur during hydrothermal cooking process include the water imbibition, heat transfer and dissolution, denaturation of enzymes, starch gelatinization between 60 and 95°C, denaturation of the major storage proteins and of the heat-resistant proteins (Wood, 2006). The gelatinization of the starch is the chemical change that signifies the change from a raw pulse to a cooked one (Wood, 2006). Cooked pulses become adequately soft and easy to chew, and possess the desired aroma, flavor and texture. Storage under adverse conditions of high temperature and high humidity renders beans susceptible to a hardening phenomenon called hard-to-cook defect (Parades-Lopez *et al*., 1989; Parades-Lopez *et al*., 1991; Reyes-Moreno and Parades-Lopez, 1993). One of the major factors limiting the utilization of common bean is the hard-to-cook phenomenon attributed to various mechanisms include cell wall thickness and pectin-phytate crosslinking (Parades-

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Lopez *et al*., 1991; Coelho *et al.*, 2007; Yousif *et al*., 2007; Nakelema, 2015). The hard-to-cook defect results in longer cooking time, which leads to increased energy consumption, and reduced textural quality of cooked beans affecting the sensory quality and the nutritional value (Coelho *et al*., 2007; Yousif *et al*., 2007; Mubaiwa *et al.*, 2017).

The cooking quality of beans is related to post-harvest handling and storage conditions (Mubaiwa *et al.*, 2017). Pulses that require long cooking times are less convenient, more energy consuming and, therefore less desirable for consumers and processors (Wood, 2006; Mubaiwa *et al.*, 2017). The time required to cook a product is an important quality attribute because longer cooking times are inconvenient and require more electricity or fuel and, therefore, are costly to consumers or processors (Wani *et al*., 2013). Globally about 76% of the population uses firewood and charcoal as their primary fuel used for cooking in Sub Saharan Africa (Maes & Verbist, 2012). About 7-11 kg of fuel wood are needed to cook one kg of beans, in contrast one kg of fuel wood is needed to cook one kg of maize flour (Adkins *et al*., 2010). Gathering of firewood is typically the responsibility of women and children (Wani *et al*., 2013). Thus, obtaining cultivars with shorter cooking time represents an improvement in terms of time, energy savings, gender issue, and better quality of the food (Pereira *et al.*, 2017). Traits related to commercial quality of seeds such as size, color and cooking time have been gaining importance in common bean breeding programs (Williams & Singh, 1987). Wide genetic variability for cooking time has been documented for dry beans (Nielsen *et al*., 1993; Elia *et al*., 1997; Cichy *et al.*, 2015; Nakelema, 2015; Kajiwara *et al*., 2017; Mughi Mukai, 2017; Pereira *et al.*, 2017; Cichy *et al.*, 2019). Recently, some reports (Cichy *et al.*, 2015; Mughi Mukai, 2017; Syombua Syanda, 2019) also revealed that, beans varieties were genetically and highly diverse for culinary traits. The genetic variability for cooking time is less understood than the environmental influences on cooking time (Cichy *et al.*, 2019). Cooking time is believed to be a heritable trait (Williams & Singh, 1987; Elia, 2003; Mughi Mukai, 2017) although environmental and storage conditions, cooking method and seed age are known to influence this trait (Mashi, 2006; Wood, 2006; Ozkan *et al*., 2012; Cichy *et al*., 2019). When beans are stored in unfavorable conditions, specifically at high temperature and high humidity, cooking time greatly increases (Coelho *et al*., 2007; Yousif *et al.*, 2007). Previously, Elia (2003) and Jacinto-Hernandez *et al*. (2003) demonstrated that, the short cooking time of dry beans was controlled by small number of genes. Efforts have been made to manufacture quick-cooking pulses (Sethi *et al*., 2011). However, few studies have been carried out on the genetics of cooking time in common bean in order to select fast-cooking genotypes. Thus the main objective of this research is to assess the genetic variability of cooking time in five common bean cultivars using freshly harvested seeds and 10 days stored seeds, and investigate on the genetic factors controlling this trait through 5 x 5 half diallel crosses analysis. The final aim of this research is to develop fast-cooking bean genotype.

MATERIALS AND METHODS

Study Site

The research was carried out during 2017 and 2018 at the University of Ngaoundéré campus (1113 m altitude, 7.28°N latitude and 13.34°E longitude), which is located at Dang, Ngaoundéré division in the Adamawa region, Cameroon. This region belongs to the high altitude Guinea savannah ecological zone previously described by **Noubissié *et al.*** (2012). The soil is ferruginous type, and the climate is characterized by two seasons with an average annual rainfall of 1480 mm that is fairly distributed over the rainy growing period (April to September). The average annual temperature is 22°C, while the annual hygrometry is about 70% (**Noubissié *et al.*,** 2012).

Samples

A subset of five popular common bean lines introduced in the Grassfields zone of Cameroon (Noubissié *et al.*, 2000) were selected based on their adoption rate by growers (Table 1). These genotypes were provided by the Institute of Agricultural Research for Development (IRAD, Dschang station, Cameroon). The five tested pure lines comprised: Pan magreta (PH 181, Bigarre, BI), Meko atsa (PH 114, Couleur Terre, CT), Merengue (PH 123, PR, Petit Rouge, PR), She meko (PH 460, PN, Petit Noir, PN), and Zizi fho meko (PB, Petit Blanc, PB) (Noubissié *et al.*, 2000).

The five selected pure lines were planted in pots from April to July 2017 for manual crossings. The 5 x 5 half-diallel mating scheme was thus obtained giving 15 entries consisting of five selected parents and 10 F_1 hybrids.

Table 1: Some characteristics of the five selected common bean cultivars

Cultivars (IRAD code)	Date	Growing area	Seed color	Seed index (g)
Meko Atsa (PH 114 / CT)	1960	Menoua	Maroon	40.33
Merengue (PH 123 / PR)	Local	West region	Red speckled	19.16
She Menko (PH 460 / PN)	Local	West region	Black	17.89
Pan Magreta (PH 181/BI)	1960	Grassfields	Brown spotted	31.26
Zizi fho meko (PB)	1960	West region	White	18.00

Date: Date of introduction in Cameroon; local varieties are those introduced during colonial period; IRAD: Institute of Agricultural Research for Development.

Field Experiment

During the rainy season 2018, all five pure lines and the 10 F_1 hybrids were conducted in field in a triplicated randomized complete block design (RCBD). Sowing took place on May 02, 2018, on an experimental surface of 240m^2 (16m length x 15m broad). Each plot unit consisted of one row of 4 m length x 0.5 m broad, spaced 40 cm apart. Dry beans seeds were sown at an intra-row spacing of 20 cm. Three seeds were dibbed per hole and after germination one healthy seedling was retained at each hole after thinning, 20 days after sowing (DAS). The plots were manually weeded at 20 DAS, 45 DAS and at 65 DAS. Strings were tied to the climbing genotypes to provide support. A maturity, harvesting was done at six-day intervals, when the pods were ready for picking.

Cooking Time Evaluation

Samples were fresh harvested dry seeds (T=0) and dry seeds stored during 10 days in steam room at 60°C and relative humidity of 60-70% (T=10). Seed samples were obtained on plot basis, thus each entry was replicated thrice. Seeds were cooked without pre-soaking. An automated Mattson pin drop cooker cooker (Matson 2T Cooker) was used to measure cooking times (Wood, 2006; Bitjoka *et al*., 2008). The base plate of the cooker contains 25 wells, and each well holds an individual bean seed. The Mattson bean cooker has potential as reference method if the seed coat resistance can be overcome and a more reliable cooked end-point defined. For each replication, 25 seeds were placed in the 25 cylindrical holes of the automated Mattson bean monitored by a computer. Individual beans were considered cooked when the piercing rods had passed through a seed. The cooking time was calculated when 80% of the beans are soft enough to be pierced through by the pin; this is an equivalent of when the 20th of the 25 pins of the cooker has penetrated the seeds (Bitjoka *et al*., 2008).

Statistical and Genetic Analysis

Data were subjected to analysis of variance (ANOVA) using Statgraphics Plus 15.1 software. The genotypic means were compared using Least Significant Difference at 5% level of probability (LSD 5%).

The diallel analysis was done using Dial 98 microcomputer package (Ukai, 2002). The Griffing's (1956) method 2 (excluding reciprocal F_1 crosses), model 1 (fixed effects) was used to analyze the general combining ability (GCA) of lines and the specific combining ability (SCA) of crosses, supplemented by the analysis of variance by Walters and Morton (1978). With this approach, the components of variation were partitioned into the additive effects (a) and the dominance effects (b) which were further sub-divided into b_1, b_2 and b_3 (Walters and Morton, 1978). The genetic parameters were estimated as per Hayman (1954). Heritability in broad sense (h^2) was measured as the proportion of genetic variance (δ^2g) in the phenotypic variance (δ^2p), while heritability in narrow sense (h^2_n) was calculated as the proportion of additive variance (δ^2_A) in the phenotypic variance (δ^2p) (Mather & Jinks, 1982). The simple additive-dominance model was tested by the regression of the covariance values between the parents and their offspring in the rth array (Wr) against variance values of the rth array (Vr) according to the assumption of Hayman (1954).The correlation between parental values (Pr) and recessive factor (Wr+Vr) indicated the gene action (Griffing, 1956).

RESULTS AND DISCUSSION

Analysis of variance for cooking time showed a significant difference ($p< 0.01$) between the five selected common bean lines (Table 1). For freshly harvested seeds (T=0), the cooking times of genotypes ranged from 49.28 min (PR) to 89.28 (PN) min with average of about 65 min. For T=0, fast cooking varieties were PR, PB and BI which cooked in less than one hour. After 10 days of storage (T=10), the cooking time improves significantly (average of about 195 min) with cultivar CT had the highest value (270.52 min) while variety PR showed the shortest value (128.38 min). After 10 days storage, fast cooking varieties were PR and BI which cooked in less than three hours.

Significant differences observed between these lines revealed that, there is sufficient genetic variability for this trait within studied beans germplasm. Some varieties have inherent longer cooking times than others. After storage, the hard-to-cook defect develops in dry beans regardless to the variety. Maryange *et al.* (2015) reported a significant difference in cooking time among 30 bean lines, with times ranging from 29 to 83 min using Mattson method. Pereira *et al.* (2015) also found genetic variability for cooking time and the average cooking time of about 30 min for Brazilian common beans cultivars. In a panel of 206 *P. vulgaris* accessions, Cichy *et al.* (2015) noted that five accessions cooked in less than 27 min, where the average cooking time was 37 min. Among 152 test genotypes East Africa, Mughi Mukai (2017) noted that cooking for fresh seeds ranged between 35 min and 100 min with an average of 56 min. In USA, Cichy *et al.* (2019) also noted that the cooking times of the 14 dry bean genotypes left unsoaked ranged from 77 to 381 min, with a mean cooking time of 113 min. Others studies also showed a large variability for this trait in various environments (Elia *et al*., 1997; Kajiwara *et al*., 2017; Syombua Syanda, 2019).

The studied Cameroonian cultivars showed relatively longer cooking time as compared previous reports (Wood, 2006). Cooking time of beans is greatly influenced by the storage time, the temperature and relative humidity of the storage environment, the seed

characteristics, the seed-coat properties, and whether the seed was presoaked or dehulled (Pereira et al., 2017). According to Coelho *et al.* (2007), freshly harvested beans cook 2-4 times faster than beans stored for 6 months. We recorded similar results with seeds stored for 10 days. A majority of calcium in the seeds is stored with phytate and during storage, phytate is broken down and free calcium is available to crosslink pectin in the cell wall, thereby strengthening cell wall and increasing cooking time (Nakelema, 2015; Mubaiwa *et al*., 2017). Studying the effects of post-harvest of adzuki beans for different storage time and under different conditions, Yousif *et al.* (2007) noted that storage under unfavorable conditions affects the quality of beans by reducing water uptake during cooking, which leads to poor cell separation, incomplete starch gelatinization, and protein denaturation. According to Nakalema (2015), there are two mechanisms by which storage hardens the beans namely pectin-phytate crosslinking in the cell walls and deposition of lignin-like material into cell walls from seed coat. This hardening of bean cell walls increases the bean's cooking time Nakalema (2015). Concerning the importance of seed type, Cichy *et al.* (2019) observed that white beans had the fastest cooking time while the red/purple mottled had the longest cooking time, and larger seed took longer to cook.

The cooking times of beans is greatly influenced by both physicochemical properties of the seeds and environmental factors as highlighted by Syombua Syanda (2019]. The interaction between genotypes and environments is important for cooking time in common bean (Pereira *et al*., 2017). Edaphic conditions, like soil mineral content, also affect seed characteristics and cooking time. Cooking time and seed hardness were increased by growing beans in a location with soils rich in calcium and magnesium and with higher average annual temperature (15–24°C) (Parades-Lopez *et al.*, 1991; Mubaiwa *et al*., 2017). Higher rainfall was associated with thinner seed coat and shorter cooking time (Stambolier *et al*., 1995). High water absorption rate is associated with faster cooking time (Elia, 2003). According to Jood *et al.* (1995), longer cooking times have been attributed to low seed coat permeability, increased physical hardness of the seed, chemical composition of the cell wall, composition of the seed coat and endosperm, and longer starch gelatinization time. Nakelema (2015) showed that seed coat thickness, starch content and total pectin content each was associated with cooking time in common bean. Cooking time also depends on seed weight and on the hydration and swelling capacity of the seed (Ozkan *et al*., 2012). Numerous studies have found a relationship between polyphenols in the seed coat and increased cooking time (Wood, 2006; Mubaiwa *et al*., 2017).

Table 2: Variability of the five common bean cultivars for seeds cooking time after sowing (T= 0) and after 10 days storage (T= 10)

Genotypes	**Cooking time (min)**	
	T= 0	**T= 10**
Bigarre (BI)	57.66 ± 1.07^{ab}	163.86 ± 6.51^{ab}
Couleur Terre (CT)	73.92 ± 1.54^{b}	270.54 ± 4.55^{d}
Petit Blanc (PB)	52.55 ± 1.97^{a}	191.41 ± 3.97^{bc}
Petit Rouge (PR)	49.28 ± 3.52^{a}	128.38 ± 3.06^{a}
Petit Noir (PN)	89.21 ± 3.47^{c}	222.99 ± 5.54^{c}
Mean	**64.52 ± 16.73**	**195.44 ± 54.56**
Probability	0.0001	0.0001
LSD (5%)	15.46	40.70

Means with the same subscript within the same column do not differ significantly at 5%. LSD: Least Significant Difference at 5%.

Based on Griffing (1956) fixed effect model I, method II, the analysis of variance showed significant effects ($p< 0.01$) of means squares for general combining ability (GCA) of the parents and specific combining ability (SCA) of crosses for cooking time of freshly seeds and 10 days stored seeds (Table 3). The GCA/SCA ratio was greater than one (3.74 for T= 0 and 3.69 for T= 10 days respectively) for this trait (Table 3).

The significance of both GCA and SCA showed that additive and non-additive gene effects contributed to the observed variations. This agrees with Mughi Mukai (2017) on cooking time inheritance in common bean. Mughi Mukai (2017) concluded that cooking time seem to be quantitative trait controlled majorly by additive gene effects, with considerable non-additive gene effects, so it would be more effective to conduct selection in latter generations. But the relative importance of GCA on SCA suggested the preponderance of additive gene action in the genetic control of cooking time of beans. Elia (2003) showed that the cooking time of beans is governed by multiple genes with partial dominance of short cooking time over long cooking time, and with cytoplasmic influences on the expression of cooking time. In this study, the GCA/SCA ratio strongly indicated the preponderance of additive gene effects although non-additive gene effects are of considerable importance.

Table 3: Mean squares for general and specific combining abilities in 5 × 5 half-diallel crosses for freshly harvested seeds (T= 0) and 10 days storage seeds (T=10) for cooking time

Source of variation	Degree of freedom	Mean squares for cooking time	
		T= 0	T= 10
GCA	4	737.48**	8125.36**
SCA	5	65.65**	733.26**
Error	18	0.53	0.52
δ^2 GCA/δ^2 SCA		3.74	3.69

GCA: General combining ability; SCA: Specific combining ability; **: indicates significance at 1%.

The ANOVA based on Walters and Morton (1978) method also revealed that both additive (a) and dominance (b) effects were significant ($p < 0.01$) for cooking time (Table 4). Within the dominance components (b_1, b_2 and b_3), the mean dominance effects (b_1) was highly significant, while the additional dominance effects due to the parents (b_2) and the residual dominance effects (b_3) were also strongly significant ($p < 0.01$) for T= 0 and T= 10 (Table 4)..

The significance of (a) and (b) items confirmed that, both additive and dominance effects of genes were involved in the inheritance of cooking time of dry beans. The significant b_1 mean dominance item suggested that, the dominance of the genes is predominantly in one direction. The value of b_1 showed that most of the dominant alleles tend to reduce or increase the cooking time. The significance of additional dominance deviation due to the parents (b_2) revealed that, some parents contain considerably more dominant genes than other. The significance of b_3 residual dominance item showed the importance of the specific combining ability.

Table 3: Mean squares for additive and dominance effects for cooking time of freshly harvested seeds (T= 0) and 10 days storage seeds (T=10)

Source of variation	Degree of freedom	Mean square for cooking time	
		T= 0	T= 10
Repetition	2	5.27^{ns}	0.53^{ns}
a	4	862.60**	9786.24**
b	10	326.88**	3629.67**
b_1	1	17.01**	154.71**
b_2	4	23.29**	469.17**
b_3	5	635.13**	6853.07**
Error	28	2.77	1.42

a = additive effects of genes; b = dominant effects of genes; b_1 = mean dominance effects; b_2 = additional dominance deviation due to the parents, b_3 = residual dominance effects, **: indicates significance at 1%.

For cooking time, the genetic parameters as well as the broad and narrow sense heritability values estimated for T= 0 and for T= 10 (Table 5). According to Hayman (1954) assumptions, the degree of dominance $(H_1/D)^{1/2}$ was less than unity (0.45 and 0.49), thus confirming partial dominance in the inheritance of this trait. The five tested parents had a moderate proportion of dominant genes (47% and 50%) for cooking time. The direction of dominance was positive, attesting that the dominance genes of the parents tend to increase the cooking time and the recessive genes act in the direction of reducing the cooking time.

The correlation between parental values (Pr) and recessive factors (Wr+Vr) was significant and negative (-0.50 and -0.90) showing that dominant alleles had positive effects for long cooking time. The performance of a genotype depends on the proportions of dominant genes. Genotypes with reduced cooking time possessed most recessive alleles for this trait.

The broad sense heritability for cooking time was high (h^2 = 0.90 and 0.95) indicating that the large proportion of the total variance was due to the genotype; hence it is possible to improve the cooking time of beans through selection. For this trait, Mughi Mukai (2017) also recorded a high value for the broad-sense coefficient of genetic determination (h^2= 0.94). This result was in agreement with Elia *et al.* (2015). Cichy *et al.* (2019) observed that the heritability of the presoaked cooking time was very high (98%) and moderately high for the unsoaked cooking time (~60%). In cowpea, Nielsen *et al.* (1993) also recorded 76% broad sense heritability of cooking time. The narrow sense heritability was also high (h^2_n = 0.71 and 0.74 representing 78.88 and 77.89 % of the broad-sense heritability) showing the preponderance of additive gene effects. Elia (2003) and Jacinto-Hernandez *et al.* (2003) also recorded 90% and 74% narrow sense heritability of cooking time in *Phaseolus vulgaris*. In contrast, Mughi Mukai (2017) reported low value of narrow sense heritability (47%) for cooking time in beans. The heritability values for cooking time as

observed in this study showed the preponderance of additive genes attesting that selection in early generations could be effective for this trait. But the association of fast-cooking with recessive genes might present some difficulties for selection during the early generations.

Table 4: Genetic components estimates and heritability values for cooking time of beans for freshly harvested seeds (T=0) and 10 days stored seeds (T=10) based on a 5 x 5 half diallel

Genetic parameters and heritability	Values for cooking time	
	T= 0	T= 10
Average degree of dominance $(H_1/D)^{1/2}$	0.45	0.49
Proportion of dominant genes kd/(kd+kr)	0.47	0.50
Direction of dominance (h)	0.71	6.29
(Pr, Wr+Vr) correlation coefficient	-0.50*	-0.90**
(Pr, Wr + Vr) regression	-1.61Pr + 339.93	-21.29Pr + 6767.01
Broad sense heritability (h^2)	0.90	0.95
Narrow sense heritability (h^2_n)	0.71	0.74
h^2_n / h^2 ratio (%)	78.88	77.89

r (Pr, Wr+Vr): Correlation coefficient between the degree of recessive genes (Wr+Vr) and the parental value (Pr), Vr the variance of the r^{th} array and Wr the covariance between the parents and their offspring in the r^{th} array; * and **: indicates significance at 5% and 1% respectively.

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Among the five studied cultivars, three genotypes namely PR, BI and PB genotypes had significant and negative GCA effects for cooking time while PN and CT showed significant and positive GCA effects for this trait (Table 5).

The genotypes PB, BI and PR exhibited negative and significant GCA effects are considered as good combiners and hence desirable genotypes for use in breeding programs to reduce cooking time (Jacinto-Hernandez *et al.*, 2003). These lines were also the shortest cooking parents. High GCA effects are attributable to additive or additive x additive gene interaction, which represent the fixable genetic components of heritable variance (Walters & Morton, 1978. Mughi Mukai, 2017). These results were in agreement with the findings of Elia (2003) and Mughi Mukai (2017) which reported an important GCA effects in beans cultivars.

Table 5: General combining ability effects (GCA) for cooking time of freshly harvested seeds (T=0) and 10 days stored seeds (T=10) of five common beans genotypes

Parents	GCA effects for cooking time	
	T= 0	T= 10
PB	-8.58*	-7.91*
CT	8.24*	48.57**
BI	-4.33**	-21.24*
PN	11.18**	6.89*
PR	-6.52*	-26.30*
Standard error (SE)	0.27	0.37

PB: Petit Blanc, CT: Couleur de Terre, BI: Bigarre, PN: Petit noir, PR: Petit Rouge, *: Significant at p = 0.05; **: Significant at p = 0.01.

Among the 10 F_1 crosses evaluated for T= 0 and T= 10 (Table 6), six combinations namely PB x PR, PB x BI, BI x PR, PB x CT, BI x CT and PR x PN showed significant and negative SCA effects for cooking time. Notably, these crosses were between short cooking parents (PR, PB and BI) or between short cooking varieties and long cooking lines (PN, CT). This indicates strong action of the negative GCA parents and probable dominance of short cooking time over long cooking time. These crosses could be considered for further advancement in breeding to reduce cooking time. The crosses CT x PN, CT x PR, BI x PN and PB x PN, showed significant and positive SCA effects. These crosses were between long cooking parents or between a long cooking parent and a short cooking parents. The low x low or low x moderate general combiners exhibiting high SCA effects suggested gene dispersion and genetic interaction between favourable alleles contributed by both parents. The SCA is considered to be the best criterion for selection of superior hybrid. Similar results were also obtained by Mughi Mukai (2017) from the estimates of SCA effects for this trait.

Table 6: Specific combining ability effects (SCA) of cooking time of freshly harvested seeds (T=0) and 10 days stored seeds (T=10) of ten F_1 crosses on 5 x 5 half-diallel

	SCA effects for cooking time	
F_1 crosses	**T= 0**	**T= 10**
PB x CT	-1.43*	-5.02**
PB x BI	-2.23**	-8.47**
PB x PN	2.52**	7.06**
PB x PR	-4.70**	-11.22**
CT x BI	-0.73^{ns}	-4.23*
CT x PN	2.61**	9.18**
CT x PR	7.38**	24.72**
BI x PN	2.26**	8.47**
BI x PR	-2.14**	-8.43**
PN x PR	-1.55*	-3.07*
Standard error	0.67	2.19

PB: Petit Blanc, CT: Couleur de Terre, BI: Bigarre, PN: Petit noir, PR: Petit Rouge, ns : not significant, *: Significant at p = 0.05; **: Significant at p = 0.01.

The Wr/Vr graphs for cooking time of freshly harvested seeds (T= 0) and 10 days stored seeds (T= 10) respectively (Figure 1A and 1B) revealed that, the estimated regression lines (Wr= 0.68Vr + 85.48 and Wr= 0.85Vr + 766.48) intercepted the Wr-axis above the point of origin. This also suggested that the inheritance of cooking time was governed by partial dominance (Hayman, 1954).

The Wr / Vr graphs showed that an additive-dominance model is verifying for cooking time as the coefficients of regression of Wr on Vr were not significantly different for unity. The relative distribution of the array points on the regression lines indicated that, for T= 0 and for T= 10 respectively, fast-cooking PR genotype possessed the maximum number of recessive gene, being nearest from the point M' whereas CT a long-cooking genotype located near the lower end of the regression line (near M), had the maximum number of dominant gene for cooking time. PB genotype, a good combiner, harbored some dominant genes contributing for long cooking time as BI and PN.

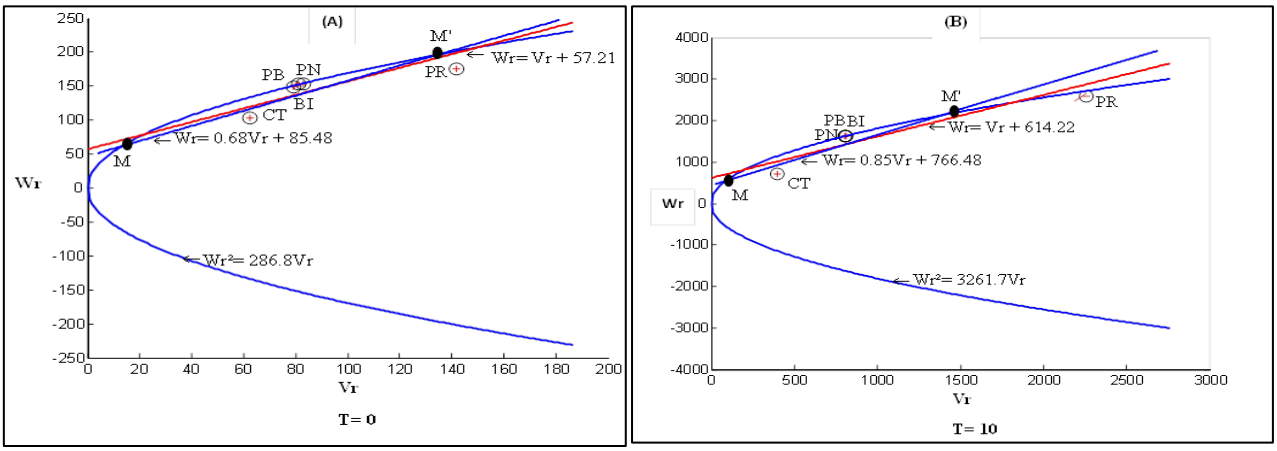

Figure 1: Wr/Vr graphs for cooking time of freshly harvested seeds (T= 0) (A) and of 10 days stored seeds (T= 10) (B). $Wr^2 = VrVp$: Limiting parabola where Vp is the variance of the parents; Vr the variance of the r^{th} array and Wr the covariance between the parents and their offspring in the r^{th} array. Solid line: tangent to the limiting parabola (Wr = 1Vr + b); red line: regression of Wr on Vr. PB: Petit Blanc, CT: Couleur de Terre, BI: Bigarre, PN: Petit noir, PR: Petit Rouge.

CONCLUSION

The studied cultivars were genetically highly diverse for cooking time. General combining ability effect gave greater proportion of variance than specific combining ability, suggesting the additive gene action was greatly involved in the inheritance of cooking time. PR genotype, a good combiner, harbored more recessive genes with positive effect for reducing cooking time. The preponderance of additive genetic variation indicates the effectiveness of selection in early generations but fast-cooking is due to recessive genes so the possibility of producing quick-cooking varieties through bulk or single seed/pod descent methods are suggested. As suggested by Sandhu *et al.,* (2018) improvement of cooking quality might include both conventional and biotechnological means. The identification of fast cooking germplasm from diverse

market classes through marker assisted selection has value in breeding. These improved varieties might achieve premiums in the marketplace because of convenience and reduced energy cost required.

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REFERENCES

1. Adkins, E., Tyler, E., Wang, J., Siriri, D., & Modi, V. (2010). Field testing and survey evaluation of household biomass cook stoves in rural sub-Saharan Africa. *Energy Sustainable Development*, *14*, 172–185.
2. Bitjoka, L., Teguia, J.B., & Mbofung, C.M.F. (2008). PC-based instrumentation system for the study of bean cooking kinetic. *Journal of Applied Sciences 8*(6), 1103-1107.
3. Broughton, W.J., Hernandez, G., Blair, M., Beebe, S., Gepts, P., & Vanderleyden, J. (2003). Beans (*Phaseolus* spp.) – model food legumes. *Journal of Plant and Soil Sciences*, *252*, 55–128.
4. Buruchara, R., Chirwa, R., Sperling, L. Mukankusi, C. Rubyogo, J.C., Muthoni, R., & Abang, M.M. (2011). Development and delivery of bean varieties in Africa: The Pan- Africa Bean Research Alliance (PABRA) model. *African Crop Science Journal*, *19*(4), 227–245.
5. Cichy, K.A., Wiesinger, J.A., & Mendoza, F.A. (2015). Genetic diversity and genome-wide association analysis of cooking time in dry bean (*Phaseolus vulgaris* L.). *Theor. Appl. Genet.*, *128*(8), 1555–1567.
6. Cichy, K.A., Wiesinger, J.A., Berry, M., Nchimbi-Msolla, S., Fourie, D., Porch, T.G., Ambechew, D., & Micklas, P.N. (2019). The role of genotype and production environment in determining the cooking time in dry beans (*Phaseolus vulgaris* L.). *Legume Science, e13*, 1–15.
7. Coelho, C.M.M., de Mattos Bellato, C., Santos, J.C.P., Ortega, E.M.M., & Tsai, S.M. (2007). Effect of phytate and storage conditions on the development of the hard-to-cook phenomenon in common beans. *J. Sci. Food Agric.*, *87*, 1237–1243.
8. Elia, F.M. (2003). Heritability of cooking time and water absorption traits in dry beans (*Phaseolus vulgaris* L.) using a North Carolina design II mating scheme. *Tanzanian J. Sci*., *29*(1), 25-34.
9. Elia, F.M., Hosfield, G.L., & Uebersax, M.A. (1997). Genetic analysis and interrelationships between traits for cooking time, water absorption, and protein and tannin content of Andean dry beans. *J. Am. Soc. Hort. Sci. 122*(4), 512-518.
10. Griffing, B. (1956). A generalized treatment of the use of diallel crosses in quantitative inheritance: *Heredity, 30*, 31-51.
11. Hayman, B. (1954). The theory and analysis of diallel crosses. *Genetics*, *39*: 789-809.
12. Hnatuszko-Konka, K., Kowalczyk, T., Gerszberg, A., & Wiktorek-Smagur, A. (2014). *Phaseolus vulgaris*- recalcitrant potential. *Biotechnol. Adv.*, *32*, 1205-1215.
13. Jacinto-Hernandez, C., Azpiroz-Rivero, S., Acosta-Gallegos, J.A., Hernandez-Sanchez, H. & Bernal-Lugo, I. (2003). Genetic analysis and random amplified polymorphic DNA markers associated with cooking time in common bean. *Crop Sci.*, *43*, 329–332.
14. Jood, S., Chauhan, B.M., & Kapoor, A.C. (1998). Contents and digestibility of carbohydrates of chickpea and black gram as affected by domestic processing and cooking. *Food Chemistry*, *30*, 113-127.
15. Kajiwara, V., Ribeiro, L.B., Hirose, A.A., Scholz M.B.S., & Moda-Cirino, V. (2017). Genetic variation for grain technological traits in Andean common bean genotypes. *Annual Report of the Bean Improvement Cooperative*, *60*, 163-164.
16. Maes, W.H., & Verbist, B. (2012). Increasing the sustainability of household cooking in developing countries: policy implications. *Renew. Sust. Energy Rev.*, *16*, 4204–4221.
17. Maryange, M., Msolla, N., Sawargaonkar, S.L., Hudge, B.V., & Thanki, H.P. (2010). Screening of 30 advanced common bean (*P. vulgaris*) lines for short cooking time using two different methods. *Electronic Journal of Plant Breeding*, *1*(4), 505-511.
18. Mashi, D.S. (2006). Genetic studies on seed coat texture and cooking time in some varieties of cowpea (*Vigna unguiculata* (L.) Walp.). Ph.D. thesis, University of Jos., Nigeria, 147p.
19. Mather, K., & Jinks, J.L. (1982). Biometrical genetics. Chapman and Hall, 2nd ed., London, U.K. 282p.
20. Mubaiwa, J., Fogliano, V., Chidewe, C., & Linnemann, A.R. (2017). Hard-to-cook phenomenon in bambara groundnut (*Vigna subterranea* L. Verdc.) processing: options to improve its role in providing food security. *Food Reviews International*, *33*(2), 167-194.
21. Mughi Mukai, I. (2017). Inheritance and characterization of cooking time, seed iron and zinc content in selected african common bean germplasm. Master thesis, Makerere University, South Africa, 74p.
22. Nakelema, R. (2015). Relationships between physicochemical properties and hard-to-cook phenomenon on dry beans. Master of Science, Michigan State University, 85p.
23. Nielsen, S.S., Wendy, E.B. & Singh, B.B. (1993). Genetic variability for nutritional composition and cooking time of improved cowpea lines. *Crop Science*; *33*, 469-472.
24. Noubissié, T.J.B., Bell, J.M., & Yaidi, H.T. (2012). Studies on variability and gene effects of seed

protein contents in Cameroonian bean (*Phaseolus vulgaris* L.) cultivars. *Journal of Agriculture and Social Sciences*, *8*, 17-23.
25. Noubissié, T.J.B., Bell, J.M., Megueni, C. (2000). Morphogenetic characterization of the main accessions of *Phaseolus vulgaris* L. cultivated in the highlands of Cameroon. *Biosciences Proceedings*, *7*, 437-445.
26. Osborn, T.C. (1988). Genetic control of bean seed protein. *C.R.C. Critical Review in Plant Science*, *7*, 93-116.
27. Özkan, H., Özer, S., Tümer, E., Baloch, F.S., Karaköy, T. & Toklu, F. (2012). Variation for nutritional and cooking properties among Turkish field pea landraces. *Journal of Food, Agriculture and Environment*, *10*(2), 324-329.
28. Paredes-Lopez, O., Carabez-Trejo, A., Palma-Tirado, L., & Reyes-Moreno, C. (1991). Influence of hardening procedure and cooking solution on cooking quality of common beans. *Plant Foods for Human Nutrition*, *41*, 155–164.
29. Paredes-Lopez, O., Reyes-Moreno, C., Montes-Riveira, R., & Carabez-Trejo, A. (1989). Hard-to-cook phenomenon in common beans: influence of growing location and hardening procedures. *Int. J. Food Sci. Technol.*, *24*, 535–542.
30. Pereira, H.S., Alvares, R.C., Melo, L.C., Da Costa, A.F., & Carvalho, H.W.L. (2017). Culinary and nutritional quality of common bean lines carioca grain type and interaction with environments. *Rev. Ceres, Vicosa*, *64*(2), 156-166.
31. Reyes-Moreno, C., & Paredes-Lopez, O. (1993). Hard-to-cook phenomenon in common beans-A review. *Reviews in Food Science and Nutrition*, *33*(3), 227-286.
32. Sandhu, K.S., You, F.M., Conner, R.L., Balasubramanian, P.M., & Hou, A. (2018). Genetic analysis and QTL mapping of seed hardeness trait in black common bean (*Phaseolus vulgaris*) recombinant inbred line (RIL) population. *Molecular Breeding*, *38*(34), 1-13.
33. Sethi, S., Samuel, D.V.K., & Khan, I. (2011). Development and quality evaluation of quick-cooking dhal-A convenience product. *J. Food Sci. Technol*., *51*, 595-600.
34. Stamboliev, M., Georgiev, D., Tsvetanova, K., & Tonev, Y.T. (1995). Effects of some agrotechnical and agroclimatic factors on the technological quality of *Phaseolus vulgaris* grown on calcareous chernozem. *Rastenievedni Nauki*, *32*, 65–67.
35. Syombua Syanda, J. (2019). The effects of physical properties of common bean (*Phaseolus vulgaris* L.) varieties on soaking and cooking time. Master of Science, South Eastern Kenya University, 44p.
36. Ukai, Y. (2002). DIAL, programs for the analysis of full or half diallel table. University of Tokyo, Japan, 18p. http: //plach.ab.a.u-tokyo ac.jp.
37. Walters, D.E., & Morton, J.R. (1978). On the analysis of variance of a half diallel table. *Biometrics*, *34*, 91-94.
38. Wang, N., & Daun, J.K. (2005). Determination of cooking times of pulses using an automated Matsson cooker apparatus. *J. Sci. Food Agric*., *85*, 1631-1635.
39. Wani, I.A., Sogi, D.S., & Gill, B.S. (2013). Physical and cooking characteristics of black gram (*Phaseolus mungo* L.) cultivars grown in India. *Int. J. Food Sci. Technol*., *48*, 2557–2563.
40. Williams, P.C., & Singh, U. (1987). Nutritional quality and evaluation of quality in breeding programs. In: The chickpea. Saxena M.C. and Singh K.B. (eds), Wallingford, U.K., p: 329-356.
41. Wood, J.A. (2016). Evaluation of cooking time in pulses: a review. *Cereal Chem*., *44*(1), 32-48.
42. Yousif, A.M., Kato, J., & Deeth, H.C. (2007). Effect of storage on the biochemical structure and processing quality of adzuki bean (*Vigna angularis*). *Food Reviews International*, *23*(1), 1-33.