



Research article

Genotype-by-environment interaction on canning and cooking quality of advanced large-seeded common bean genotypes

Samir Hashim Gelete^{a,*}, Firew Mekbib^b, Berhanu Amsalu Fenta^a, Mulgeta Teamir^a^a Ethiopian Institute of Agricultural Research, Melkassa Agricultural Research Center, Adama, Ethiopia^b Haramaya University, Haramaya, Ethiopia

ARTICLE INFO

Keywords:

Multi-environment trial
Broad adaptation
Canning quality
Common bean

ABSTRACT

Developing beans for high canning and cooking quality has been a major concern of plant breeders as the demand of consumers for beans in terms of quality is increasing. This study determined the effect of genotype-by-environment (GEI) on canning and cooking quality of common beans. Twenty three newly developed large-seeded bean genotypes and two standard checks collected from five growing sites of Ethiopia were tested using randomized completed block design with three replicates. Additive main effect and multiplicative Interaction (AMMI) and genotype plus genotype-by-environment interaction (GGE) biplot models were used in the data analysis. Genotypes were genetically different ($P \leq 0.01$) for all of the quality traits varied from 42.3 to 57.4 minutes for cooking time and 260.4–278.6g for washed drained weight. Percent washed drained weight of all the tested genotypes was >60%, as required by processors. However, hydration coefficient (HC) was below the desired optimum level of 1.8, which could be improved through prolonged soaking period. From moderate to no clumping, and from moderately clear to clear brine were observed for canned beans. Generally, the newly developed genotypes had better canning and cooking quality except for HC. However, GEI exerted considerable effect on the quality traits especially cooking time. The interaction effect (34.25%) shared nearly three times greater effect than genotype (13.31%) and environment (11.44%); hence highly determined the cooking time. Both AMMI2 and GGE polygon view biplots captured 69.05 and 74.10% of the GEI variation, respectively, using the first and the second principal component axes (PCAs). In conclusion, plant breeders should think of GEI when testing beans for canning and cooking quality at substantial environments.

1. Introduction

According to a FAO report (2019) common beans are among the major pulses in terms of global production and consumption levels. They are important sources of proteins, vitamins and minerals in human consumption (Amanuel and Girma, 2018; Caproni et al., 2018; Nicoletto et al., 2019). They are consumed in various forms such as cooked, baked in soups or used in combination with other foods (Siddiq and Uebersax, 2012). There green young pods also represent major fresh vegetable in many parts of world (Souri et al., 2017; Aslani and Souri, 2018). However, common beans are mostly processed and value added before consumption, and canning is the most common method especially in developed countries such as Europe and North America (Schoeninger et al., 2017). Based on the report of USDA-ARS (2010) near to 90% of navy beans and 45% of pinto beans are sold as canned beans in United States. Nowadays, canned bean products are typically known by their

convenience to consumer (Uebersax, 2006), being a ready-made food and preserving the shelf life of the produce.

In Ethiopia, common beans are the most widely grown legume especially in the dry areas being key sources of food and cash for the poor rural farmers (Zelege et al., 2016; Fitsum et al., 2020). Furthermore, the crop is used for generating income through export to the country (Berhanu et al., 2018). However, the share of Ethiopia to export canning industries has been still lower, which is mainly because of the high focus of the country on specific bean cultivars. The most predominantly supplied to export market for the canning industries is the navy bean or white pea beans (Kidane et al., 2013) while the market and consumers preference is steadily increasing. To fill this gap, there is a need to diversify and involve other cultivar types.

Cultivars should meet the consumer expectations and certain quality standards which otherwise be rejected. Processors require beans that are easily cooked and give high processor yield while consumers prefer beans

* Corresponding author.

E-mail address: samirhashim2009@gmail.com (S.H. Gelete).

that cook fast because of the limited resource for fuel, electricity and time (Mkanda et al., 2007). Nowadays, the highest attention given by consumers and bean processors for quality has changed the research trends towards the produce quality. Due to this fact, the Ethiopian national common bean breeding program which is based at Melkassa Agricultural Research Center (MARC) has put canning quality as one of its main breeding objective beside evaluation of beans for yield and other traits.

Canning and cooking quality combines several properties which are quantitatively inherited (Lange and Labuschagne, 2000). Such characters are affected by the genetics, environment and the genotype-by-environment interaction (GEI) (Hosfield et al., 1984; Fabbri and Crosby, 2016; Ejara et al., 2017). The genotypes inconsistent performance across diverse environment is expressed by GEI (Araus et al., 2008; Asnake et al., 2013). The presence of such interaction complicates the efficiency of selection and there need to assess the nature and magnitude of GEI. As the standard combined analysis of variance (ANOVA) only quantifies the significance of interaction effect (Asnake et al., 2013), additive main effect and multiplicative interaction (AMMI) and genotype plus genotype-by-environment interaction (GGE) biplot models can efficiently examine GEI patterns graphically by using of principal component axes (PCAs) (Yuksel et al., 2002; Ding et al., 2007; Aarthi et al., 2020). In this work, the canning and cooking quality of the newly developed large-seeded bean genotypes and the GEI effect on beans quality traits were studied.

2. Materials and methods

2.1. Study sites

Data for the major cooking quality traits such as cooking time and mass of soaked beans were taken from the five bean growing sites of Ethiopia (Table 1): Melkassa, Arsinegelle, Mieso, Haramaya and Goffa during 2018/19. However, for the canning quality evaluation, samples collected from Mieso location were not incorporated because of shriveled and unhealthy seeds due to the occurrence of severe moisture stress mainly at the vegetative and pod filling stage of the trial (Data not shown). Thus, evaluation of canned beans was carried out for the samples collected from four locations.

2.2. Plant materials

Twenty three advanced bean genotypes from white and large seed market class and two released varieties as standard check were used for the study and evaluated for cooking quality. The twenty three selected genotypes were generated from crosses of Canpsula and Ranjonombay and selection was made based on their yield potential for the study. For canning however, top-ten common bean genotypes which are high yielding and widely adapted as well as the two standard checks were selected and used for canning quality evaluation. The seeds of all genotypes were collected from the national lowland pulse breeding program of MARC (Table 2).

Table 1. Description of the study sites.

Location	Soil type	Altitude (m.a.s.l)	Latitude	Longitude	Annual average		
					Min T (°C)	Max T (°C)	Rainfall (mm)
Melkassa	Andosols	1550	8° 30'N	39° 21'E	14.0	33.0	763
Mieso	Vertisols	1332	9° 28'N	38° 08'E	14.9	28.2	787
Arsinegelle	Nitosols	1890	7° 35'N	38° 65'E	13.8	23.3	807
Haramaya	Fluvisols	1980	9° 26'N	42° 03'E	3.5	25.0	790
Goffa	Andosols	1750	7° 15'N	37° 04'E	14.4	25.9	964

Where, m.a.s.l = meters above sea level, E = east, N = north, Min = minimum, Max = maximum, T = temperature, °C = degree centigrade, mm = millimeter; Source: Melkassa Agricultural Research Centers and National Meteorology Agency.

2.3. Study design and traits measured

This study was done at MARC food and nutrition science laboratory and ELFORA food processing agro-industry PLC during 2018/19. Randomized complete block design (RCBD) was used with three replicates. The canning process was carried out as per the procedure of modified laboratory canning protocol (Balasubramanian et al., 2000) (Figure 1). Common bean samples collected from each growing sites were cleaned manually for any damaged seeds and foreign entities before the canning process was started. Samples equivalent to 90 g were soaked for 30 min at room temperature and blanched for 30 min at 88 °C to deactivate enzymes which could produce off flavor and remove gases. Tin cans with dimension of 73 × 110mm were filled with soaked and blanched samples and boiling brine (15.6g sucrose and 12.4g salt/1kg of tap water). The tin cans were then sealed using automatic can seamer (Angelus Sanitary Can Machine Co., USA) (Figure 2) and cooked in horizontal automatic retort for 1 h at 120 °C and 10.4×10^4 Pa (Figure 5). Soon after cooking, canned bean samples were cooled under cold running tap water inside the retort for about 30min. Finally, cans were stored upside down for two weeks for beans and brine medium to reach equilibrium before evaluation.

Accordingly, data on initial weight of the sample, weight of soaked bean, hydration coefficient of soaked bean (HCS), hydration coefficient of soaked and blanched bean (HCB), as well as washed drained weight and percent washed drained weight of canned beans were determined based on Van Der Merwe et al. (2006) procedures. Cooking time was conducted objectively using automated Mattson bean cooker apparatus developed by Canadian Grain Commission (Winnipeg, Canada) (Figure 3) following procedures of Wang and Daun (2005). In addition, through visual rating score, degrees of clumping and brine clarity data for canned beans were also collected where;

Degree of clumping (1–3 scale): 1 = beans clumped solidly at the bottom of the can; 2 = beans clumped, but easily decanted; and 3 = no clumping. Brine clarity (1–7 scale): the canned beans exhibit loss of color and solids to the canning medium. This was determined subjectively using 1–7 scale, where the value 1 = very cloudy, 2 = moderately cloudy, 3 = slightly cloudy, 4 = neither clear nor cloudy, 5 = slightly clear, 6 = moderately clear and 7 = very clear brine.

2.4. Data analysis

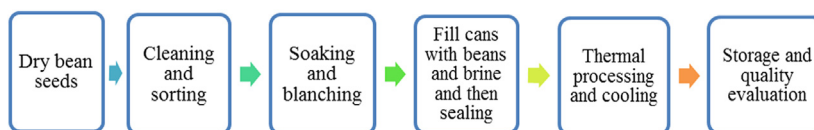
Collected quality data were subjected to combined analysis of variance to assess variation among genotypes and quantify the significance of genotype-by-environment interaction using PROC GLM of SAS 9.2 version software (SAS Institute, 2008). Additionally, to determine the magnitude of GEI and assess genotypes adaptation, additive main effect and multiplicative interaction (AMMI) was applied using GenStat ver.18 statistical package (Payne, 2015) following Gauch (2013) model:

$$Y_{ij} = \mu + g_i + e_j + \sum_{k=1}^n \lambda_k \alpha_{ik} \gamma_{jk} + e_{ij}$$

Table 2. List of common bean genotypes used for the study.

No	Genotype	Genotype code	Status	Source
1	CCSS 6915-11-4	G1	Advanced line	MARC
2	CCSS 6915-11-12	G2	Advanced line	MARC
3	CCSS 6915-11-15	G3	Advanced line	MARC
4	CCSS 6915-11-16	G4	Advanced line	MARC
5	CCSS 6915-11-17	G5	Advanced line	MARC
6	CCSS 6915-11-18	G6	Advanced line	MARC
7	CCSS 6915-11-19	G7	Advanced line	MARC
8	CCSS 6915-11-27	G8	Advanced line	MARC
9	CCSS 6915-11-32	G9	Advanced line	MARC
10	CCSS 6915-11-33	G10	Advanced line	MARC
11	CCSS 6915-11-37	G11	Advanced line	MARC
12	CCSS 6915-11-38	G12	Advanced line	MARC
13	CCSS 6915-11-42	G13	Advanced line	MARC
14	CCSS 6915-11-43	G14	Advanced line	MARC
15	CCSS 6915-11-47	G15	Advanced line	MARC
16	RNSS 6915-89-12	G16	Advanced line	MARC
17	RNSS 6915-89-2	G17	Advanced line	MARC
18	RNSS 6915-89-26	G18	Advanced line	MARC
19	RNSS 6915-89-23	G19	Advanced line	MARC
20	RNSS 6915-89-34	G20	Advanced line	MARC
21	RNSS 6915-89-24	G21	Advanced line	MARC
22	RNSS 6915-89-16	G22	Advanced line	MARC
23	RNSS 6915-89-3	G23	Advanced line	MARC
24	SAB-736 (check)	G24	Released	MARC
25	Batu (check)	G25	Released	MARC

MARC = Melkassa Agricultural Research Center.

**Figure 1.** Schematic diagram of the canning process of common bean samples.

Where, Y_{ij} is the yield of the i^{th} genotype in the j^{th} environment, g_i is the mean of the i^{th} genotype minus the grand mean, e_j is the mean of the j^{th} environment minus the grand mean, n is the number of components retained in the model, λ_k is the square root of the eigenvalue of the PCA axis k , α_{ik} and γ_{jk} are the principal component scores for PCA axis k of the i^{th} genotype and the j^{th} environment, respectively, and e_{ij} is the residual.

3. Results

3.1. Analysis of variance

The current study showed significant ($P \leq 0.01$) difference among main effects of genotypes and environment and the interaction effect of genotype-by-environment interaction (GEI) for the quality parameters (Tables 3 and 4). Evaluated newly developed bean genotypes were genetically variable for initial weight of the sample, mass of soaked beans, hydration coefficient, cooking time, washed drained weight, percent washed drained weight, as well as for clumping and brine clarity of canned beans. Observed considerable effect of GEI implies the influence of growing site in determining the beans quality properties as well as the genotypes performance fluctuation across the changing test sites.

Wider genetic variability was observed among genotypes, from 33.4 to 45.79g for initial weight of the sample and 66.92 – 92.91g for soaked bean weight (Table 5). Genotypes scored above the optimum industrial

requirement of 1.8, from 1.97 to 2.09 for hydration coefficient of soaked bean (HCS) (the ratio of initial weight of bean samples divided by the weight of overnight soaked beans for 16hr). However, hydration coefficient of beans soaked for 30min and blanched for 30 min at 88 °C (HCB) was below the optimum required level of 1.8 (Table 6). This indicates that large beans require longer soaking period to meet the industrial requirement for hydration coefficient. In mean cooking time, the tested genotypes took from 42.3 to 57.4 min which fell into a moderate cooking period (Table 5). G21, G13 and G9 had short cooking time as compared to other genotypes took 42.3, 42.6 and 44.3min, respectively, to get tender and palatable for consumption.

Washed drained weight (WDWT) of canned beans (Figure 4) cooked in automatic retort (Figure 5) was the maximum, fall between 260.4 to 278.6g and the highest score was obtained by genotype G11, 278.6g. All genotypes had percent washed drained weight (PWDWT) of above 60% and had met the regulation of Canadian agricultural products standard act (Table 6 and Figure 6). Bean genotypes were also subjectively evaluated using visual rating score for the two quality traits namely, degree of clumping and brine clarity and the mean performance is shown in Table 6 and Figure 6. Accordingly, most of the genotypes showed no clumping at the bottom of cans. Clumping of beans is associated to the release of starch in the canning medium and is an indication of poor canning quality. In terms of brine clarity of canned beans, slight variation was observed among genotypes, from a moderately clear obtained by genotype G11, to very clear brine by G10 and G23.



Figure 2. Automatic can seamer.

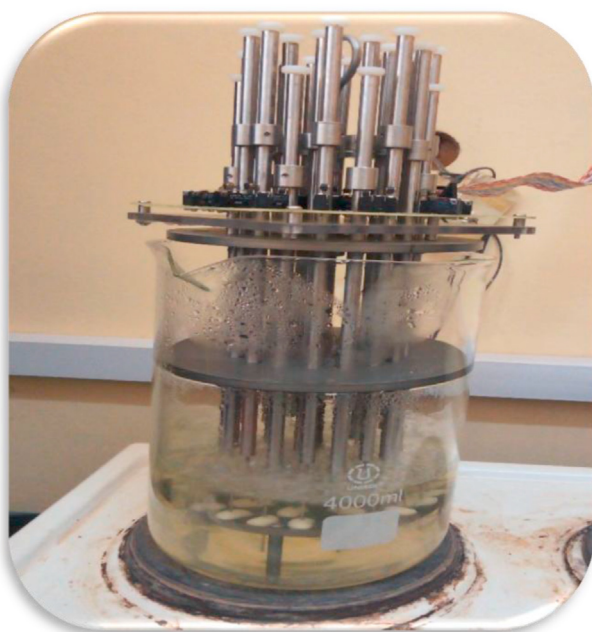


Figure 3. Automated Mattson bean cooker.

3.2. Genotype-by-environment interaction

3.2.1. AMMI analysis

AMMI model analysis of variance for cooking time revealed significant ($P \leq 0.01$) effects of genotype, environment and GEI (Table 7). The GEI (34.25%) effect contributed largely to the total variation and moderately by genotype (13.31%) and environment (11.44%) to express the cooking time (Table 7 and Figure 7). The model partitioned GEI into the first and the second interaction principal component axes. Both IPCA1 and IPCA2 were significant ($P \leq 0.01$) explained 42.29% and 26.23%, respectively, and together captured 69.05% of the GEI variation. Strong considerable effect of the interaction effect challenges the efficiency of selection which requires further diagnosis to identify superior low cooking time and widely adapted genotypes.

AMMI1 biplot (Figure 8) clearly showed the relationship between genotypes and environments as well as the adaptability of genotypes for the mean cooking time. The positive or negative IPCA score shows the interaction between the test locations and the genotypes. Genotypes found closer to zero IPCA score had little interaction while those located far, exhibited high interaction characters with specific environment. In addition, genotypes can be categorized as short and long cooking time based on their location on the biplot graph. Accordingly, G13, G21 and G9, placed closer to horizontal line or zero interaction effects and located on the left side of the midpoint of the axis had short cooking time and environmentally less responsive genotypes. Even though G17 was the nearest to zero IPCA score and the least interacted, it is categorized under long cooking time genotype as it is located on the right quadrant of the biplot. On the other hand, G4 and G5 were located far from the zero horizontal line and found on the right corner of the biplot. Thus, they were the longest to cook and environmentally the most sensitive genotypes. From the biplot graph, the three test sites namely, Haramaya, Miesso and Arsinegelle were placed on the left side of the biplot and are desirable locations as they gave fast cooking time genotypes. In contrast, as Melkassa and Goffa located on the biplot right side, they provided long cooking time genotypes and are undesirable (Figure 8).

The interaction between and among genotypes and environments are displayed in Figure 9 of AMMI2 biplot. The biplot explained 69.05% of the total variation, of which 42.92% was explained by the first Principal Component (PC1) and 26.13% was explained by the second Principal Component (PC2). Genotypes, G7, G4, G5, G13, G21, G18, G19 and G22 which placed far from the biplot origin are highly interactive to particular environment either positively or negatively. G7 was specifically adapted to Goffa site; G4, G5 and G18 adapted to Miesso; G13 and G21, adapted to Arsinegelle; G19, adapted to Haramaya and G22 adapted to Melkassa for cooking time. In contrary, G17, G3 and G8 which located relatively closer to the biplot origin expressed low interaction characteristics with the test sites.

3.2.2. GGE-biplot analysis

The GGE polygon view biplot could visualize the relationship between genotypes and environments efficiently (Yan and Kang, 2003). The polygon is formed by connecting the genotypes that are furthest from the biplot origin such that all other genotypes are contained in the

Table 3. Mean squares of combined analysis of variance for cooking quality traits of the newly developed large-seeded bean genotypes.

Source of variation	df	IWS	SBWT	HCS	CT
Genotype (G)	24	111.18**	440.74**	0.009**	147**
Environment (E)	4	825.92**	3906.8**	0.054**	757.7**
Block (E)	10	37.45**	214.12**	0.004	13.3
GxE	96	38.87**	176.16**	0.006**	94.58**
Error	240	10.31	44.03	0.002	14.4

** = Significant at $P < 0.01$ probability level; df = Degree of freedom; IWS = Initial weight of the sample; SBWT = Soaked bean weight; HCS = Hydration coefficient of soaked bean; CT = Cooking time; Note: Block (E) implies block nested within Environment.

Table 4. Mean squares of combined analysis of variance for canning quality traits of 12 selected large-seeded bean genotypes.

Source of variation	df	HCB	WDWT	PWDWT	CLMP	BRCL
Genotype (G)	11	0.11**	422.35**	30.71**	1.43**	3.40**
Environment (E)	3	0.035**	322.09*	52.04**	0.11	3.87*
Block (E)	8	0.003	115.63	6.65	0.17	0.84
GxE	33	0.052**	122.81**	9.05**	0.70**	4.25**
Error	88	0.003	64.04	4.53	0.22	1.02

*, ** = Significant at $P < 0.05$ and $P < 0.01$ probability levels, respectively; df = Degree of freedom; HCB = Hydration coefficient of soaked and blanched bean; WDWT = Washed drained weight; PWDWT = Percentage washed drained weight; CLMP = Clumping; BRCL = Brine clarity; Note: Block (E) implies block nested within Environment.

Table 5. Mean performance of the tested large-seeded bean genotypes for cooking quality traits.

Genotype code	IWS	SBWT	HCS	CT
G1	41.34 ^{cde}	84.35 ^{cdef}	2.035 ^{bcd}	51.05 ^{bcd}
G2	44.78 ^{ab}	90.92 ^{abc}	2.034 ^{bcd}	46.55 ^{ij}
G3	37.05 ^g	75.02 ^g	2.029 ^{bcd}	51.76 ^{bcd}
G4	44.41 ^{abc}	91.36 ^{ab}	2.052 ^{abc}	55.33 ^{ab}
G5	38.3 ^{efg}	78.18 ^{fg}	2.043 ^{abcd}	57.41 ^a
G6	42.49 ^{abcd}	83.71 ^{def}	1.973 ^c	49.43 ^{defghi}
G7	38.01 ^{fg}	77.42 ^{fg}	2.04 ^{bcd}	50.58 ^{cdefghi}
G8	37.87 ^{fg}	77.65 ^{fg}	2.051 ^{abcd}	54.95 ^{abc}
G9	33.4 ^h	66.92 ^h	2.011 ^{cde}	44.25 ^{jk}
G10	40.79 ^{def}	80.33 ^{efg}	1.97 ^c	53.21 ^{abcd}
G11	45.72 ^a	90.16 ^{abcd}	1.972 ^c	52.48 ^{bcd}
G12	44.53 ^{abc}	89.97 ^{abcd}	2.021 ^{bcd}	48.08 ^{fghi}
G13	42.54 ^{abcd}	86.48 ^{abcde}	2.025 ^{bcd}	42.65 ^k
G14	41.91 ^{bcd}	85.87 ^{bcd}	2.049 ^{abcd}	50.35 ^{defghi}
G15	43.63 ^{abcd}	89.99 ^{abcd}	2.057 ^{abc}	46.55 ^{ij}
G16	38.73 ^{efg}	80.03 ^{efg}	2.062 ^{abc}	46.88 ^{ghij}
G17	38.24 ^{efg}	75.97 ^g	1.993 ^{de}	50.81 ^{cdefgh}
G18	37.89 ^{fg}	77.85 ^{fg}	2.05 ^{abcd}	50.35 ^{defghi}
G19	35.65 ^{gh}	74.63 ^g	2.098 ^a	46.66 ^{hij}
G20	37.81 ^{fg}	78.35 ^{fg}	2.071 ^{ab}	48.86 ^{defghi}
G21	45.79 ^a	92.91 ^a	2.021 ^{bcd}	42.26 ^k
G22	43.36 ^{abcd}	89.23 ^{abcd}	2.045 ^{abcd}	48.64 ^{efghi}
G23	40.93 ^{def}	83.54 ^{def}	2.041 ^{abcd}	52.84 ^{bcd}
G24	38.43 ^{efg}	78.57 ^{fg}	2.047 ^{abcd}	49.09 ^{defghi}
G25	42.16 ^{bcd}	86.38 ^{abcde}	2.046 ^{abcd}	47.863 ^{fghij}
Mean	40.63	82.63	2.03	48.98
CV	7.90	8.03	2.63	2.08

CV = Coefficient of variation; IWS = initial weight of the sample; SBWT = Soaked bean weight; HCS = Hydration coefficient of soaked bean; CT = Cooking time; Note: Means with the same letter are not statistically ($p > 0.05$) different.

polygon. It displays which genotype won in where environment (which-won-where pattern) and can briefly summarize the GEI pattern of multi environment data. As shown in Figure 10, the GGE polygon view biplot explained 74.10% of the total variation of which 50.44% was explained by the first PCA and 23.66% was explained by the second PCA; and the biplot had captured the variation among genotypes for cooking time efficiently. Generally, from the biplot, 6 rays were formed and they are lines that are perpendicular to the sides of the polygon (Yan 2002). These 6 rays divided the biplot into 6 sectors, but test environments fell into four sectors. Based on Figure 10, G4, G5, G7, G13 and G1 are the vertex genotypes and are environmentally the most responsive (Meng et al., 2016). Melkassa and Miesso locations clustered into one sector and G5 was the winning genotype: Goffa formed the next sector and G4 is the most favorable genotype: Arsinegelle formed the third sector and G7 was its favorable genotype: and the last sector was formed by Haramaya with G1 its winning genotype. Generally, four distinct environments were

detected, indicating the presence of different growing environments for cooking time.

4. Discussions

The current study revealed significant genetic variations among the newly developed common bean genotypes for the selected quality traits. Wide genetic variability in bean cultivars with respect to quality traits such as water uptake, washed drained weight, hydration coefficient and cooking time was reported (Hosfield and Uebersax, 1980; Zacharias et al., 2012; Cichy et al., 2015). However, the quality of beans including canning properties depends on many factors such as plant genotype, varieties, environmental conditions and cultivation practices (Souri et al., 2017, 2018; Souri and Aslani, 2018).

Hydration coefficient soaked for 30min and blanched for 30min at 88°C hadn't met the industrial requirement of 1.8 (Table 6). From this, large beans meet the requirement of industries only if they are subjected

Table 6. Mean performance of 12 selected newly developed large-seeded bean genotypes for canning quality traits.

Genotype code	HC	WDWT	PWDWT	CLMP	BRCL
G2	1.61 ^{ab}	276.8 ^{ab}	67.1 ^{ab}	2.7 ^{abc}	5.3 ^{ab}
G6	1.52 ^c	269.0 ^{cde}	64.8 ^{cde}	2.3 ^c	5.9 ^a
G9	1.38 ^e	270.5 ^{bcd}	64.8 ^{cde}	1.8 ^d	5.8 ^a
G10	1.44 ^d	261.0 ^f	63.3 ^{ef}	2.9 ^{ab}	6.0 ^a
G11	1.38 ^e	278.6 ^a	67.8 ^a	2.5 ^{bc}	4.3 ^c
G12	1.42 ^{de}	262.3 ^{ef}	63.4 ^{ef}	3.0 ^a	5.6 ^{ab}
G15	1.62 ^a	272.0 ^{abcd}	65.4 ^{bcd}	2.8 ^{ab}	5.5 ^{ab}
G20	1.51 ^c	272.8 ^{abc}	65.7 ^{bc}	2.8 ^{ab}	5.9 ^a
G22	1.41 ^{de}	265.3 ^{def}	63.6 ^{def}	2.5 ^{bc}	5.3 ^{ab}
G23	1.57 ^b	265.3 ^{def}	64.3 ^{cde}	2.8 ^{ab}	6.0 ^a
G24	1.44 ^d	268.3 ^{cde}	64.8 ^{cde}	2.3 ^c	4.7 ^{bc}
G25	1.32 ^f	260.4 ^f	62.1 ^f	2.6 ^{abc}	5.6 ^{ab}
Mean	1.47	268.5	64.7	2.6	5.5
CV	3.87	2.98	3.29	18.37	18.39

CV = Coefficient of variation; HC = Hydration coefficient of soaked and blanched bean; WDWT = Washed drained weight; PWDWT = Percentage washed drained weight; CLMP = Clumping; BRCL = Brine clarity; Note: Means with the same letter are not statistically ($p > 0.05$) different.

**Figure 4.** Common bean samples sealed in can.**Figure 5.** Horizontal automatic retort.

to prolonged soaking period. Hydration coefficient of 1.8 is taken as optimum for beans indicating an 80% increase in weight after soaking and is an indication of a well soaked bean (Hosfield and Uebersax, 1980). Despite the low hydration coefficient (HC), they had maximum WDWT: 260.4 – 278.6g. This suggests that low HC led beans to imbibe more water amid the can storage period. WDWT of beans associated to processors yield and the higher WDWT of beans, the fewer beans is required to fill a given can volume (Varner and Uebersax, 1995). It is a measure of the degree of hydration during cooking and thermal processing (Mendoza et al., 2014). A lower value of this parameter indicates extensive loss of beans during processing; and results in increased degree of clumping at the bottom of the can after processing and during storage which finally leads to cultivar rejection (Khanal et al., 2014). Almost all the genotypes tested in the current study had no clumping which could be attributed to their maximum washed drained weight. Similarly, all the genotypes gave percent washed drained weight of above 60% as desired by processors and had met the Canadian agricultural products standard act regulation (Balasubramanian et al., 2000).

The tested genotypes cook nearly 1hr to get softer and palatable to consumers (Table 5). They can be categorized under a moderate cooking class and such a moderate character could be related to the longer storage period and large seed size. The genotypes were stored relatively for 6 months before quality test was undertaken which could favor hard-to-cook. Especially, the prolonged storage time accompanied by high temperature and relative humidity will expose beans to hard-to-cook phenomenon (Arruda et al., 2012) which directly reduces the water absorption and increases the cooking time. Generally, wider variation in bean cultivars for cooking time was reported, from 42.4 to 97.8min (Mkanda et al., 2007); or took below 45min, a short cooking time; up to more than 3hr, a long cooking time cultivar (Muyonga et al., 2008). However, short cooking time is widely preferable consumers' trait for variety acceptance and adoption (Torga et al., 2011; Beebe et al., 2013). This is because of the short time invested for cooking and the low cost of fuel and electricity (Cichy et al., 2012; Wood, 2017). Besides, prolonged cooking time could minimize the nutritional value of protein (Wang

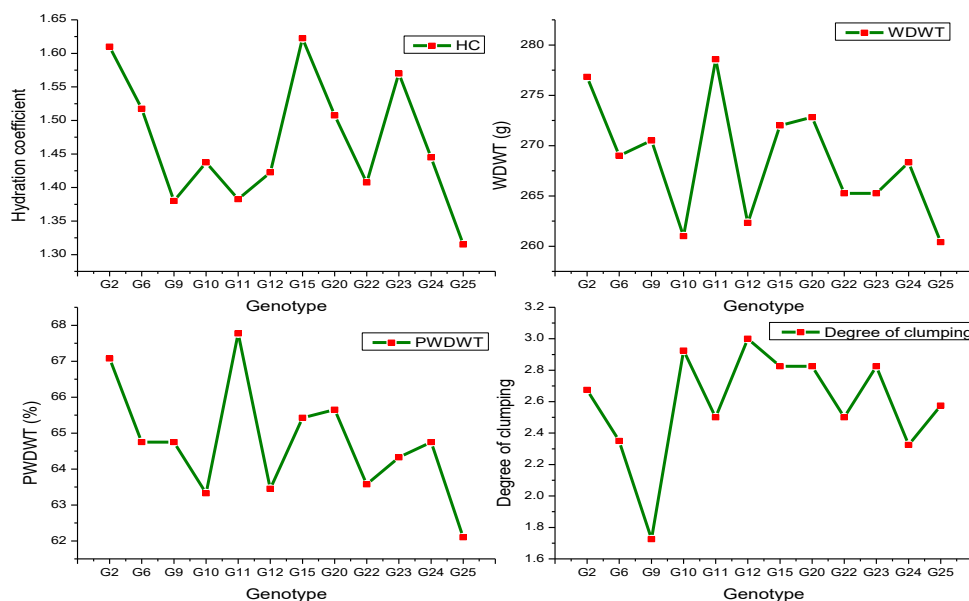


Figure 6. Performances of large-seeded bean genotypes for canning quality traits. Genotypes codes (G1-G25) are shown in Table 2.

Table 7. AMMI analysis of variance for cooking time of large-seeded bean genotypes tested at five test sites.

Sources of variation	Degree of freedom	Sum of Squares	Mean of squares	%Total variation explained SS	G x E explained (%)
Genotypes (G)	24	3528	147**	13.31	
Environments (E)	4	3031	757.7**	11.44	
Block (E)	10	66	13.3	0.25	
GxE	96	9078	94.6**	34.25	
IPCA 1	27	3896	144.3**		42.29
IPCA 2	25	2372	94.9**		26.23
Residuals	44	2810	63.9		
Error	240	1723	14.4		

** = Significant at P ≤ 0.01 probability level.

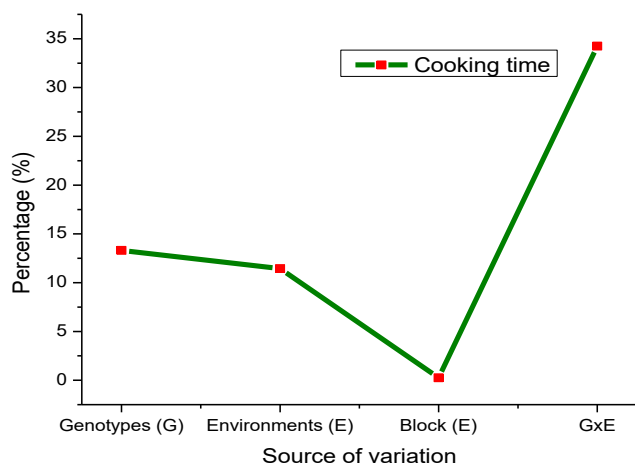


Figure 7. Percentage contribution of different sources of variation for cooking time (min).

et al., 2003) and results in a loss of essential nutrients in the human consumption (Ribeiro et al., 2013).

Significant GEI effect in this study indicates the inconsistent performance of genotypes to diverse environments and the variability of the test sites for quality traits. The test sites are variable in terms of soil types,

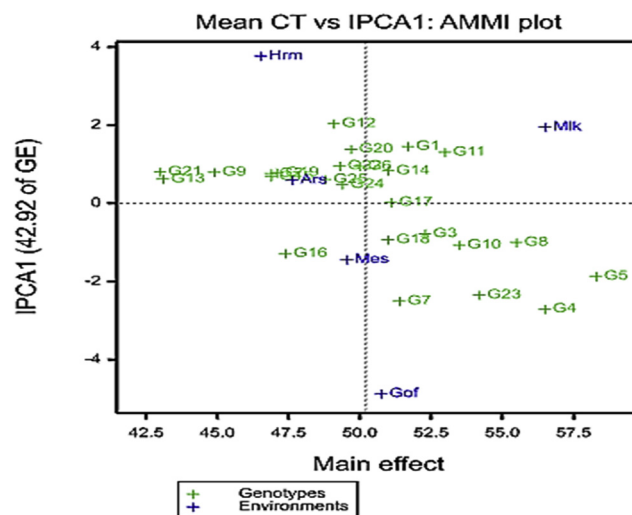


Figure 8. AMMI model (Means vs. IPCA1) for cooking time (min) showing the means of genotypes and locations against the first interaction principal component axis (IPCA1) scores. Environment: Mlk = Melkassa; Arn = Arsinegelle; Mes = Miesso; Hrm = Haramaya; Gof = Goffa. Genotypes codes (G1-G25) are shown in Table 2.

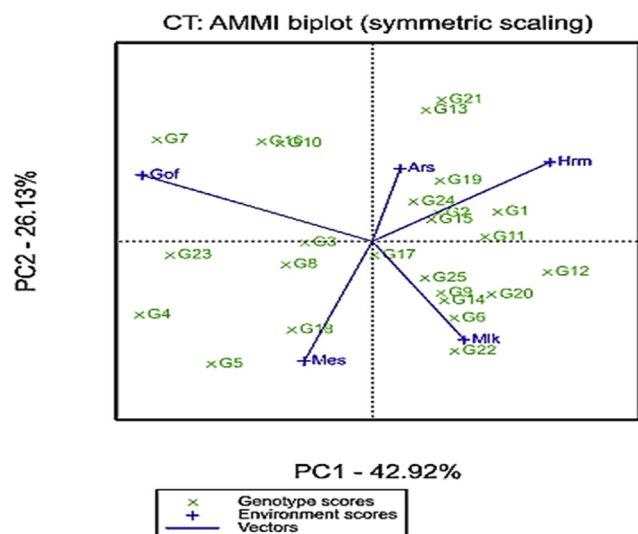


Figure 9. AMMI2 biplot model for cooking time (min) showing the means of genotypes and locations against the first and the second principal component axes (PCA1 and PCA2) scores. Environment: Mlk = Melkassa; Arn = Arsinigelle; Mes = Miesso; Hrm = Haramaya; Gof = Goffa. Genotypes codes (G1-G25) are shown in Table 2.

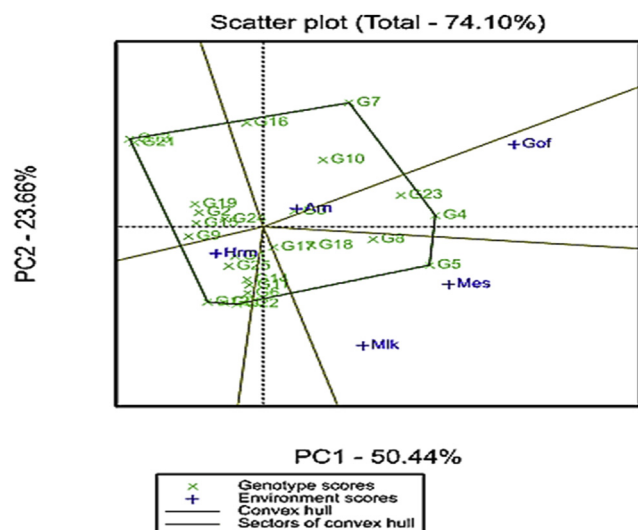


Figure 10. GGE-Polygon view biplot for cooking time (min) showing mega-environments and winning genotypes. Environment: Mlk = Melkassa; Arn = Arsinigelle; Mes = Miesso; Hrm = Haramaya; Gof = Goffa. Genotypes codes (G1-G25) are shown in Table 2.

altitude and rainfall patterns (Table 1) and highly influenced the quality traits. GEI effect was nearly three times greater than genotype and environment and determined most of variation related to cooking time (Table 5). From AMMI biplot graphs, Figures 8 and 9, it is possible to visually observe the performance and adaptability of genotypes for cooking time. G17 was the closest to zero IPCA score, indicating its wider adaptability to all the test sites (Zobel et al., 1988). However, as the interaction effect was larger, 34.25%, it is necessary to exploit the specific adaptability of genotypes for cooking time (Figure 7). Thus, In Figure 9, G1, G7, G4, G5, G18, G21, G19, G22 and G13 located distant from the biplot origin with their long vectors are environmentally the most responsive genotypes (Volts et al., 2002). Further, GGE polygon view biplot (Figure 10) has clearly showed the existence of four different mega environments and their winning genotypes for cooking time. Accordingly, G1, G4, G5 and G7 were the most favorable and winner

genotypes at each particular environment. However, these winners are those genotypes that gave the longest cooking time and are undesirable by processors and consumers.

5. Conclusions

This work investigated that the newly developed bean genotypes were genetically variable for the canning and cooking quality properties; and thus enable for designing of new breeding strategies for improved quality traits. All the tested genotypes had better canning and cook quality except for hydration coefficient of canned beans, soaked for 30min and blanched for 30min at 88°C, which varied from 1.32 to 1.62. However, the trait can be improved by increasing of the soaking period. Strong considerable impact of genotype-by-environment interaction on bean canning properties was observed, indicating that genotypes reacted differently to the variable test sites. To sum up, GEI should be given due consideration when evaluating beans for canning and cooking quality at multiple environments.

Declarations

Author contribution statement

Samir Hashim Gelete: Analyzed and interpreted the data; Wrote the paper.

Firew Mekbib: Wrote the paper.

Berhanu Amsalu Fenta: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Mulgeta Teamir: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This work was supported by the national common bean breeding program of Melkassa Agricultural Research Center (MARC) of Ethiopia funded jointly from Government and Tropical Legume-III Project.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

- Aarhi, S., Suresh, J., Leela, N.K., Prasath D, D., 2020. Multi environment testing reveals genotype-environment interaction for curcuminoids in turmeric (*Curcuma longa* L.). *Ind. Crop. Prod.* 145.
- Amanuel, A., Girma, A., 2018. Production status, adoption of improved common bean (*Phaseolus vulgaris* L.) varieties and associated agronomic practices in Ethiopia. *J. Plant Sci. Res.* 5 (1), 178.
- Araus, J.L., Slafer, G., Royo, C., Serret, M.D., 2008. Breeding for yield potential and stress adaptation in cereals. *Crit. Rev. Plant Sci.* 27, 377–412.
- Arruda, B., Altamir, F.G., Jefferson, L.M., Jaqueline, B., 2012. Environment is crucial to the cooking time of beans. *Ciência Tecnol. Aliment.* 110, 573–578.
- Aslani, M., Sour, M.K., 2018. Growth and quality of green bean (*Phaseolus vulgaris* L.) under foliar application of organic chelate fertilizers. *Open Agric.* 3, 146–154.
- Asnake, W., Mwambi, H., Temesgen, Z., Girma, T., 2013. Additive main effects and multiplicative interaction model (AMMI) and genotype main effect and genotype by environment interaction (GGE) biplot analysis of multi-environmental wheat variety trials. *Afr. J. Agric. Res.* 8, 1033–1040.

- Balasubramanian, P., Slinkard, A., Tyler, R., Vandenberg, A., 2000. A modified laboratory canning protocol for quality evaluation of dry bean (*Phaseolus vulgaris* L.). *J. Sci. Food Agric.* 80, 732–738.
- Beebe, S., Rao, I., Blair, M., Acosta, J., 2013. Phenotyping common beans for adaptation to drought. *Front. Physiol.* 4, 1–20.
- Berhanu, A., Kassaye, N., Tigist, S., Kidane, T., Dagmawit, T., Rubyogo, J.C., Clare, M.M., 2018. Progress of common bean breeding and genetics research in Ethiopia. *Ethiop. J. Crop. Sci.* 6 (3), Special issue.
- Caproni, L., Raggi, L., Tissi, C., Howlett, S., Torricelli, R., Negri, V., 2018. Multi-environment evaluation and genetic characterization of common bean breeding lines for organic farming systems. *Sustainability* 10, 777.
- Cichy, K., Wiesinger, J., Porch, T., Miklas, P., 2012. Diversity for cooking time in Andean dry beans. *Bean Improv. Cooper.* 54, 50–51.
- 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, 1555–1567.
- Ding, M., Tier, B., Yan, W., 2007. Application of GGE biplot analysis to evaluate genotype (G), environment (E) and G×E interaction on *P. radiata*: case study. In: *Australasian Forest Genetics Conference*, 11–14, Tasmania, Australia.
- Ejara, E., Wasu, M., Berhanu, A., 2017. Correlations and path coefficient analyses of yield and yield related traits in common bean accessions (*Phaseolus vulgaris* L.) at Abaya and Yabello, Southern Ethiopia. *Int. J. Plant Breed. Crop. Sci.* 4 (2), 215–224.
- Fabbri, A.D., Crosby, G.A., 2016. A review of the impact of preparation and cooking on the nutritional quality of vegetables and legumes. *Int. J. Gastron Food Sci.* 3, 2–11.
- Food and Agricultural Organization (FAO), 2019. *Of the United Nation: Pulses of Phaseolus and Vigna Genera*, Rome.
- Fistum, M., Gemechu, G., Belay, R., 2020. Evaluation of newly released common bean varieties through on-farm demonstrations in ATJK and Shalla districts of Oromia regional state, Ethiopia. *Int. J. Res. Stud. Agric. Sci.* 6 (1), 43–48.
- Gauch, H.G., 2013. A simple protocol for AMMI analysis of yield trials. *Crop Sci.* 53, 1860–1869.
- Hosfield, G.L., Uebersax, M.A., 1980. Variability in physico-chemical properties and nutritional components of tropical and domestic dry bean germplasm. *J. Am. Soc. Hortic. Sci.* 105, 246–252.
- Hosfield, G.L., Uebersax, M.A., Isleib, T.G., 1984. Seasonal and genotypic effects on yield and physico-chemical characteristics related to food quality in dry beans (*Phaseolus vulgaris*). *J. Am. Soc. Hortic. Sci.* 109, 182–189.
- Khanal, R., Burt, A.J., Woodrow, L., Balasubramanian, P., Navabi, A., 2014. Genotypic association of parameters commonly used to predict canning quality of dry bean. *Crop Sci.* 54, 2564–2573.
- Kidane, T., Rubiyogo, J.C., Kassaye, N., 2013. Sustainable access to quality seed by small holders: the case of decentralized seed production of common bean in Ethiopia. In: Ojiewo, C.O., Kugbie, S., Bishaw, Z., Rubiyogo, J.C. (Eds.), *Community Seed Production, Workshop Proceedings 9-11 December 2013*, Addis Ababa, Ethiopia.
- Lange, A.D., Labuschagne, M., 2000. Multivariate assessment of canning quality, chemical characteristics and yield of small white canning beans (*Phaseolus vulgaris* L.) in South Africa. *J. Sci. Food Agric.* 81, 30–35.
- Mendoza, F.A., Cichy, K., Lu, R., Kelly, J.D., 2014. Evaluation of canning quality traits in black beans (*Phaseolus vulgaris* L.) by visible/near-infrared spectroscopy. *Food Bioprocess Technol.* 7, 921–1218.
- Meng, M., Fallavollita, P., Seelbach, I., Von Der Heide, A., Euler, E., Waschke, J., Navab, N., 2016. Personalized augmented reality for anatomy education. *Clin. Anat.* 29, 446–453.
- Mkanda, A.V., Minnaar, A., De kock, H.L., 2007. Relating consumer preferences to sensory and physicochemical properties of dry beans (*Phaseolus vulgaris*). *J. Sci. Food Agric.* 87, 2868–2879.
- Muyonga, J.H., Balamaze, J., Kyamuhangire, W.M., Kikafunda, J.K., Nakimbugwe, D., Ugen, M., 2008. Influence of variety, growth location and storage conditions on development of Hard-To-Cook defect in common bean (*Phaseolus vulgaris* L.). *Afr. J. Food Nutr. Sci.* 8, 332–340.
- Nicoletto, C., Zanin, G., Sambo, P., Luisa Dalla Costa, L.D., 2019. Quality assessment of typical common bean genotypes cultivated in temperate climate conditions and different growth locations. *Sci. Hortic.* 256.
- Payne, R., 2015. *A Guide to ANOVA and Design in GenStat*, eighteenth ed. VSN International, 2 Umberside, Wood lane Hemel Hempstead, Hertfordshire, HP2 4TP, UK.
- Ribeiro, N.D., Ritiela Baptista, M., Lindolfo, S., Marina, P., Cristina Wayne, N., 2013. Combined selection for grain yield, cooking quality and minerals in the common bean. *Revista Brasileira de Agronomia* 44, 869–877.
- SAS Institute, 2008. Release 9.2. *The SAS System for Windows*. SAS Inst., Cary, NC.
- Schoeninger, V., Coelho, S.R., Bassinello, P.Z., 2017. Industrial processing of canned beans. *Ciência Rural* 47 (5).
- Siddiq, M., Uebersax, M.A., 2012. Dry beans and pulses production and consumption— an overview. In: Siddiq, M., Uebersax, M.A. (Eds.), *Dry Beans and Pulses: Production, Processing and Nutrition*. John Wiley and Sons, Inc. USA, pp. 3–22.
- Souri, M.K., Aslani, M., 2018. Beneficial effects of foliar application of organic chelate fertilizers on French bean production under field conditions in a calcareous soil. *Adv. Horticul. Sci.* 32 (2), 265–272.
- Souri, M.K., Naiji, M., Aslani, M., 2018. Effect of Fe-Glycine amino chelate on pod quality and iron concentrations of bean (*Phaseolus vulgaris* L.) under lime soil conditions. *Commun. Soil Sci. Plant Anal.* 49 (2), 215–224.
- Souri, M.K., Sooraki, F.Y., Moghadamyar, M., 2017. Growth and quality of cucumber, tomato, and green bean under foliar and soil applications of an amino chelate fertilizer. *Horticul. Environ. Biotechnol.* 58 (6), 530–536.
- Torga, P., Pereira, H.S., Melo, L.C., Brassanello, P.Z., Costa, A.F., Magaldi, M.C., Melo, P.G., 2011. Cooking time of common beans carioca type evaluated in different environments. *Bean Improv. Cooper.* 54, 40–41.
- Uebersax, M.A., 2006. *Dry edible beans: indigenous staple and healthy cuisine (Report)*. Forum Publ. Pol. <http://forumonpublicpolicy.com/archive06/uebersax.pdf>.
- USDA-ESR, 2010. *Dry Edible Beans, Historic Data*. United States Department of Agriculture.
- Van Der Merwe, D., Osthoff, G., Pretorius, A.J., 2006. Comparison of the canning quality of small white beans (*Phaseolus vulgaris* L.) canned in tomato sauce by small scale and industrial methods. *J. Food Sci. Agric.* 86, 1046–1056.
- Varner, G.V., Uebersax, M.A., 1995. Research report. *Mich. Dry. Bean Dig.* 19, 22–23.
- Voltas, J., Van, E.F., Igartua, E., Garcia Del Moral, L.F., Molina-Cano, J.L., Romagosa, I., 2002. Genotype-by-environment interaction and adaptation in barley breeding: basic concepts and methods of analysis. In: Slafer, G.A., Molina, R., Savin, J.L., Araus, I.R. (Eds.), *Barley Science: Recent Advances from Molecular Biology to Agronomy of Yield and Quality*. The Harworth Press Inc., New York, pp. 205–241.
- Wang, N., Daun, J.K., Malcomson, J.L., 2003. Relationship between physicochemical and cooking properties, and effects of cooking on ant nutrients, of yellow field peas (*Pisum sativum*). *J. Sci. Food Agric.* 83, 1228–1237.
- Wang, N., Daun, J.K., 2005. Determination of cooking times of pulses using an automated Mattson cooker apparatus. *J. Sci. Food Agric.* 85, 1631–1635.
- Wood, J.A., 2017. Evaluation of cooking time in pulses: a review. *Cereal Chem.* 94 (1), 32–48.
- Yan, W., 2002. Singular-value partitioning in biplot analysis of multi environment trial data. *Agron. J.* 94, 990–996.
- Yan, W., Kang, M.S., 2003. *GGE Biplot Analysis: A Graphical Tool for Breeders, Geneticists, and Agronomists*. CRC Press, Boca Raton, FL.
- Yuksel, K., Palta, C., Taner, S., 2002. Additive main effects and multiplicative interactions analysis of yield performances in bread wheat genotypes across environments. *Turk. J. Agric.* 26, 275–279.
- Zacharias, J., Leilani, A., Jacob, D., Miklas, P.N., Hossain, K.G., 2012. Genetic variability of mineral composition in common bean seed. *Annu. Rep. Bean Improv. Cooper.* 55, 59–60.
- Zelege, A., Berhanu, A., Kidane, T., Kassaye, N., Asnake, F., 2016. Seed yield stability and genotype × environment interaction of common bean (*Phaseolus vulgaris* L.) lines in Ethiopia. *Int. J. Plant Breed. Crop. Sci.* 3 (2), 135–144.
- Zobel, R.W., Wright, M.J., Gauch, H.G., 1988. Statistical analysis of a yield trial. *Agron. J.* 80, 388–393.