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Elucidating the Effect of Genotype x Environment Interaction and Storage Period on Cooking Time of Selected Common Bean (Phaseolus vulgaris L.) Genotypes

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Abstract

The cooking time of Common beans (*Phaseolus vulgaris* L.) is among the important consumer's preferred traits. Slow-cooking beans lose some important micronutrients (Fe and Zn) because prolonged cooking degrades the beans at a cellular level. Fast-cooking beans save fuel energy and time which could have been spent on slow-cooking beans. Storage conditions, seed composition, cooking method, and growing environment also have an effect on the cooking time of common beans. Thirty bean genotypes with checks (Rojo and SUA-90) were laid in a Randomized Complete Block design in three environments (Ndole, Kasanga, and Mlali) in the Morogoro region. After harvesting cooking time determination was held using an automated Mattson Cooker soon after harvesting and repeated after three months (90 days). Analysis of variance revealed a significant variation ($P < 0.001$) among genotypes and across the environments for the first and second cooking tests. In a combined analysis, cooking time unveiled a continuous distribution ranging from 72.3-121.2 minutes for the first cooking test and 104.8-215.1 minutes for the second cooking test. Selian 10 and KT-002 recorded the shortest cooking time in the first and second cooking tests while TARI-06 and NUA-746 recorded the longest cooking time. The GGE biplot revealed SUA-90, Selian 10, NUA-672, and KT-002 were the most stable and fast-cooking genotypes in the first cooking test while NUA-746, TARI-06, and ADP-190 maintained stability but took a long time to cook. In the second cooking test, Selian 10, Uyole-04, and Selian 97 revealed high stability with a short cooking time while TARI-06 and NUA-746 revealed high stability with a long cooking time. These findings suggest that some bean genotypes can maintain the stability of fast cooking traits even after being stored for a certain time, hence these candidates can be used for breeding purposes or released as varieties.

Keywords: *Genotype-Environment interaction; storage-time; Phaseolus vulgaris; cooking-time*

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Introduction

Common bean (*Phaseolus vulgaris* L.) is a widely consumed legume and an inexpensive source of protein and micronutrients such as Fe and Zn (Beebe, 2012). The crop is cultivated in Latin America and Sub-Saharan countries of Africa. In Tanzania, the crop is primarily produced in mid to high-altitude areas that experience cooler temperatures and reliable rainfall (Ngowi et *al., 2007*). Common bean is among the well-known

crops because it is affordable in terms of price, palatable and has a long shelf life which ensures food security in the community (Amongi *et al.,* 2021). Also, common beans have been reported to minimize the risk of some diseases including cancer (breast and colon cancer) and heart diseases to potential consumers hence uplifting their health security (Campos-Vega *et al.,* 2013)

Consumption of common beans is enduring to be constrained by the tendency to take a long time to cook. Common beans that cook faster are highly preferred because they conserve fuel energy and time spent on the cooking process (Ribeiro *et al.,* 2014). Also, other researchers reported that extended cooking time degrades the beans at the cellular level, hence losing some important nutrients, especially Iron (Fe) and Zinc (Zn) (Chinedum *et al.,* 2018). Fast-cooking beans retain more nutrients and protein after being cooked in contrast to slow-cooking beans (Wiesinger *et al.,* 2018). Therefore, the use of fast-cooking beans has nutritional advantages, time-saving, and the fair cost incurred for fuel energy.

The cooking process enhances the digestibility of protein and inactivates lectins and trypsin inhibitors (Thompson, 2019). Cooked beans are prepared by boiling them in hot water, other people soak beans in water overnight for 8-12 hours before cooking while others just cook without soaking (Borchgrevink, 2013). Soaking beans in water for 8-12 hours facilitates softening of seedcoat and cotyledon membrane middle lamella hence making beans cook faster when subjected to hot water (Chigwedere *et al.,* 2018).
In Tanzania, the consumption of common beans is faced with the challenge of cost and cooking time (Medard, 2017). The cost comes from the extra use of fuel energy for cooking and the labour-intensive and time-consuming work of collecting firewood which is mostly held by women and children (Massawe *et al.,* 2015).

Storage conditions, seed composition, cooking method, and growing environment also have an effect on the cooking time of common beans (Wani *et al.,* 2017). Longevity of storage and increase in storage temperature (above 30^{o}C) and relative humidity (above 50%) have a tendency to induce hard-to-cook phenomena in common beans (Rousseau *et al.,* 2020). Also, the storage duration affects cooking time because freshly harvested beans cook two to four times faster than beans stored for six months (Coelho *et al.,* 2007). Common bean seed coat thickness and cotyledon cell wall composition and thickness have a significant contribution to genetic cooking time variation (Bassett *et al.,* 2021). Common beans with thicker seed coats and cotyledons take a long time to fully imbibe cooking water hence prolonging the cooking time.

The objective of this study was to determine the variation in cooking time among the common bean genotypes and the effect of the production environments and storage period on this trait.

Materials and methods

The study area
Three trials were set in different sub-ecological locations within Morogoro region (Ndole, Kasanga, and Mlali). Ndole is located within Mvomero district at Latitude 6° 9' 21.1"S, Longitude 37° 23' 23.9"E, and Elevation 759m above sea level. Mlali also is located within Mvomero district at Latitude 6^{o} 57’38.25” S, Longitude 37^{o} 32’47.19” E, and elevation of 590m above sea level. Kasanga is located in Morogoro municipality at Latitude 6^{o} 50’20.61” S, Longitude 37^{o}38’20.43” E, and elevation 505m above sea level. The soil type and weather conditions for all experimental locations are presented in Tables 2 and 3. Morogoro region receives annual bimodal rainfall from March-May which is considered as a long rain season and November-December (short rain season) in some places, while in other places rain season is from November-May which ranges from 500 to 2200 mm. The region has an average annual temperature of 18^{o} C in the highlands and 30 ^{o}C in the lowlands.

Soil sampling and analysis
Before planting, a total of 10 sub-samples were collected randomly at 0-20 cm depth in the whole experimental area per location and mixed to obtain a composite sample of 1kg for laboratory analysis. The composite soil samples were air-dried for 5 days and then ground to obtain fine textures that were sieved by using 2.0mm mesh. The sieved soil samples were submitted to the laboratory and used for the determination of the physical and chemical properties of the soil. The

soil samples were analyzed for soil texture and particle size distribution, soil pH, exchangeable bases (Mg, Ca, K and Na), cation exchange capacity (CEC), micronutrients (Fe and Zn), available phosphorus (P), total organic carbon (OC), and total nitrogen (N) based on Haluschak. (2006) laboratory soil analysis procedures.

Plant material used

A total of 30 common bean genotypes comprising 8 released varieties, 21 breeding lines and 1 local check were selected to be used in this study (Table 1). These common beans were selected based on their evaluated agronomic and nutritional advantages. Among them, 14 bean genotypes were obtained from the International Center for Tropical Agriculture (CIAT), Uganda, 11 genotypes from Tanzania Agricultural Research Institute (TARI)-Selian Centre, Arusha and 4 genotypes from Sokoine University of Agriculture (SUA), Morogoro. The last 1 local check variety was the farmer's cultivated variety and was obtained from farmers in each location (Ndole, Kasanga, and Mlali) where the trials were established.

Field experimental design and planting

The field experiment was laid out in a Randomized Complete Block Design with three replications in each location (Ndole, Kasanga and Mlali). Each replication contained a designed setup of 30 experimental plots measuring 1m x 4m with 2 rows of plants per plot. One seed per hill was sown at a spacing of 20cm x 50cm in each experimental plot. Planting in Ndole was conducted on 5th January 2022 followed by Kasanga and Mlali on 20th April 2022 and 17th May 2022, respectively. Fourteen days after emergence, the Nitrogen nutrient in the form of Urea was applied at 35kgN/ha. Three weeding regimes at an interval of three weeks and pest control by spraying Dudu Acelamectin (5% EC) were conducted to ensure healthy growth and performance of the common bean plants. All field activities from planting to harvesting in each location were performed by a group of twenty (20) farmers who were trained and supervised by a field research assistant. The reason why farmers participated in this work is because these trials were the on-farm trials held in their fields.

Cooking time determination

Seed samples for cooking time determination were obtained based on experimental plots, that is every treatment was replicated three times. After harvesting and seed cleaning, the seeds were sun-dried to 12-13% moisture content in order to induce uniform hardness and then stored in paper bags in the same storage room. The average storage room temperature and relative humidity were recorded in every month throughout the storage time. Before the cooking test, 100 bean seeds from each location were randomly picked from each paper bag and weighed on a digital weighing balance in order to obtain the 100 seed weight (seed size). Cooking time was conducted at an interval of 3 months (90 days) after harvesting. The first cooking test was held soon after harvesting the beans and the second test was held 3 months later. During the cooking test, 25 seeds per plot were randomly selected. Then the seeds from a single sample were subjected to each of the 25 cylindrical holes of the Automated Mattson Cooker. Cooking time was recorded when 80% of the beans are soft enough to be pierced through by the pin, this is corresponding to when the 20th of the 25 pins of the cooker pierced the seed (Wang and Daun, 2005). Distilled water was used for cooking to avoid some impurities found in tap water that could affect the cooking time recorded.

Data Analysis

Analysis of variance (ANOVA) for a cooking time was performed using the GenStat (16th Edition) Statistical package at $p \leq 0.05$ and means were separated by Tukey's test. GxE interaction was determined using ANOVA whereby significant interaction verified the significant effect of environment on the cooking time of the bean genotypes. The GGE biplot (Genotype and Genotype × Environment) was performed to determine bean genotype mean performance vs. stability for cooking time across the three experimental locations. R statistical software (Version 4.2.2) using the Metan Package was used to generate GGE biplots. The GGE biplot was proposed by (Yan *et al.,* 2000) to select stable high-performing genotypes and adaptable to multi-environment conditions. The GGE biplot model was formulated according to Gauch, (2006).

$$Yhij = \mu + Eh + Gi + GEhi + Bj(h) + ehij,$$

where μ is the population means for cooking time, Eh is the environmental effect, Gi is the genotypic effect, $GEhi$ is the genotype × environment effect, $Bj(h)$ is the block effect, and $ehij$ is the random error. Biplots of GGE were composed from the general mean and IPCA score and the biplots were based on Centering = 2, SVP = 1, and Scaling = 0.

Results

Soil analysis

The physical and chemical characteristics of the soil obtained from all experimental sites (Ndole, Kasanga, and Mlali) are presented in Table 2. Based on the soil physical properties, the results revealed that the textural class for the soil sample obtained from Kasanga and Mlali was sandy clay loam. On the other hand, the textural class for the soil sample obtained from Ndole was sandy loam. Based on the soil chemical properties, the results exhibited that the concentration of Fe in the soil was high in Kasanga (54.49 mg/kg) and Ndole (79.14 mg/kg) while in Mlali (21.13 mg/kg) the concentration was medium. On the other hand, Zn concentration was high in Mlali (2.14 mg/kg) and Ndole (1.86 mg/kg) while in Kasanga (0.78 mg/kg) the concentration of Zn was low. As reported by Noulas et al. (2018) normally a Zn soil test above 1.5 mg/kg using the DTPA extraction method is sufficient for most cultivated crops. The lowest soil pH value was read in Ndole (6.85) and the highest in Mlali (6.92) but all soil pH values were regarded as optimum for plant growth. In Mlali, soil Nitrogen (N), Phosphorus (P), Cation Exchange Capacity (CEC), and Calcium (Ca) levels were consistently found to be in an optimal range, creating an ideal foundation for crops. However, in contrast, Ndole and Kasanga exhibited a noticeable inadequacy in these essential soil nutrients, which presents a compelling opportunity for targeted soil improvement initiatives in these regions. The Magnesium (Mg) level in the soil was ideal while Potassium (K) and Sodium (Na) recorded the highest concentration in all three locations (Ndole, Kasanga, and Mlali). Organic carbon (OC) was high in Mlali and medium in Ndole and Kasanga which means that the soil in Mlali had a higher amount of organic matter than the soil in Ndole and Kasanga.

Experimental site's weather condition

From the recorded monthly weather conditions (Table 3), high rainfall was recorded in Ndole (277.4mm) and the lowest rainfall was recorded in Mlali (0.0mm). Mlali experienced an unusually dry spell, with rainfall levels reaching their lowest point from the inception of the experiment all the way through to the harvesting period. This prolonged period of insufficient rainfall necessitated the implementation of irrigation practices to ensure the successful growth and development of crops. In Ndole the rainfall was available from setting the experiment until harvesting with the maximum rainfall recorded in January and April. In Kasanga the maximum rainfall was recorded in the first and second months after planting. The variation in temperature among the three locations was not big, but the highest temperature was recorded in Ndole (23.4^{o}C) in January and the lowest temperature (20.1^{o}C) was recorded in Kasanga and Mlali in the month of July. The maximum relative humidity (85%) was recorded in April and May in two locations Kasanga and Mlali, respectively. In general, the weather records indicate that rainfall was consistently reliable from January to April. However, from June to August, there was a notable shortage of rainfall, which necessitated the implementation of irrigation measures to supplement the water needed for crop growth. The relative humidity and temperature had low variation in all three experimental locations that had less impact on the performance of the tested bean genotypes.

Table 1
Selected common bean genotypes used in the study, their seed size, and the source they were collected

Genotype	Source	Seed Size	Genotype	Source	Seed Size
NUA-642	CIAT	Large	NUA-714	CIAT	Large
Maini Ndefu	TARI-Selian	Medium	KT-002	SUA	Large
Rojo	SUA	Large	SUA-90	SUA	Medium
Lyamungo 90	TARI-Selian	Large	Jesca	TARI-Selian	Large
NUA-692	CIAT	Large	NUA-695	CIAT	Large
Selian 94	TARI-Selian	Large	ADP-190	SUA	Large
NUA-636	CIAT	Large	Selian 97	TARI-Selian	Large
NUA-735	CIAT	Large	Mashamba-PYT-4	TARI-Selian	Medium
Calima	TARI-Selian	Large	Selian 10	TARI-Selian	Small
NUA-708	CIAT	Large	NUA-682	CIAT	Large
NUA-660	CIAT	Large	NUA-672	CIAT	Large
NUA-256-4	TARI-Selian	Large	Uyole-04	TARI-Selian	Medium
NUA-746	CIAT	Large	NUA-527	CIAT	Large
NUA-590	CIAT	Large	Local Check	Farmers	Large
NUA-629	CIAT	Large	TARI-06	TARI-Selian	Large

Table 2
Physical and chemical properties of the soil collected from the experimental locations

Parameter	Mlali	Remark	Ndole	Remark	Kasanga	Remark
pH in Water	6.92	Medium	6.85	Medium	6.89	Medium
Organic Carbon (%)	2.24	High	1.56	Medium	1.54	Medium
Total N (%)	0.14	Low	0.11	Low	0.12	Low
Bray-1-P (mg/kg)	20.25	Medium	12.87	Low	0.55	Low
CEC (cmol(+)/kg)	18.56	Medium	10.68	Low	12.42	Low
Exchangeable Ca (cmol(+)/kg)	5.3	Medium	3.48	Low	3.74	Low
Exchangeable Mg (cmol(+)/kg)	2.13	Medium	1.06	Medium	1.64	Medium
Exchangeable K (cmol(+)/kg)	3.87	High	1.96	High	1.56	High
Exchangeable Na (cmol(+)/kg)	6.71	High	4.16	High	5.43	High

DTPA Fe (mg/kg)	21.13	Medium	79.14	High	54.49	High
DTPA Zn (mg/kg)	2.14	High	1.86	High	0.78	Low
Particle size analysis						
%Clay	31.04		17.04		33.04	
%Silt	13.28		7.28		3.28	
%Sand	55.68		75.68		63.68	
Textural class	Sandy Clay Loam		Sandy Loam		Sandy Clay Loam	

Table 3
The experimental location's average monthly rainfall, temperature, and relative humidity during the field experiments

	Ndole			**Kasanga**			**Mlali**		
	Temp (°C)	Rain (mm)	RH (%)	Temp (°C)	Rain (mm)	RH (%)	Temp (°C)	Rain (mm)	RH (%)
January	23.4	277.4	77.0						
February	23.3	151.3	83.0						
March	23.2	144.1	77.0						
April	22.5	242.6	82.0	23.2	207.7	85.0			
May				22.5	132.4	71.0	22.5	91.1	85.0
June				20.2	19.4	66.0	20.2	11.9	71.0
July				20.1	12.1	69.0	20.1	14.6	66.0
August							20.9	0.0	69.0

Table 4
Room temperature and relative humidity recorded during storage of the tested bean genotypes

	May	June	July	August	September	October	November	December
Temperature (°C)	20.9	22.3	22.8	25.7	29.5	31	32.5	32.6
Relative Humidity (%)	81.0	72.0	71.0	65.1	63.0	60.0	66.0	68.0

Table 5
100 seed weight (seed size) and cooking time variation among the tested bean genotypes for the first and second cooking tests

	100 Seed weight(g)				First Cooking Test(min)				Second Cooking Test(min)			
Genotype	**Ndole**	**Kasanga**	**Mlali**	**Combined**	**Ndole**	**Kasanga**	**Mlali**	**Combined**	**Ndole**	**Kasanga**	**Mlali**	**Combined**
ADP-190	38.9	37.6	45.9	40.8	80.3	94.0	76.0	83.4	103.3	216.0	210.3	176.6
Calima	46.2	34.0	53.5	44.6	93.0	79.0	84.0	85.3	121.0	244.0	146.0	170.3
Jesca	37.9	35.8	48.4	40.7	82.3	83.0	95.7	87.0	105.3	156.7	137.3	133.1
KT-002	37.4	35.7	48.0	40.3	78.0	78.0	87.3	81.1	108.0	179.3	123.3	136.9
Local Check	43.8	34.4	46.0	41.4	114.7	97.0	87.0	99.6	127.3	209.7	157.7	164.9
Lyamungo 90	47.9	32.0	57.9	45.9	99.0	85.7	73.7	86.1	116.7	118.0	242.0	158.9
Maini Ndefu	33.2	30.9	37.6	33.9	100.0	87.7	91.3	93.0	113.3	144.0	215.0	157.4
Mashamba-PYT-4	33.6	30.2	43.3	35.7	82.3	99.3	90.0	90.6	98.7	156.7	268.3	174.6
NUA-256-4	46.6	38.2	41.7	42.2	97.0	90.3	89.7	92.3	117.7	234.7	130.0	160.8
NUA-527	37.7	38.4	41.2	39.1	103.0	112.0	90.3	101.8	113.7	241.7	221.0	192.1
NUA-590	44.3	33.5	50.9	42.9	90.7	84.3	85.7	86.9	107.7	196.7	176.0	160.1
NUA-629	42.7	33.0	57.0	44.2	100.3	72.0	94.7	89.0	121.7	173.3	207.7	167.6
NUA-636	35.2	42.1	52.1	43.1	98.0	80.7	93.3	90.7	116.7	161.7	119.7	132.7
NUA-642	41.4	39.8	43.0	41.4	100.7	105.3	109.7	105.2	117.0	206.7	256.0	193.2
NUA-660	51.1	33.2	54.5	46.3	103.0	83.3	74.3	86.9	116.7	208.7	266.3	197.2
NUA-672	43.1	37.2	41.2	40.5	72.3	76.0	89.3	79.2	95.3	229.7	206.3	177.1
NUA-682	42.4	40.4	55.6	46.1	109.0	91.3	104.0	101.4	118.3	140.7	269.0	176.0
NUA-692	44.2	37.9	44.1	42.0	100.7	91.3	92.7	94.9	115.0	215.3	208.0	179.4
NUA-695	48.5	41.9	47.6	46.0	92.0	109.7	87.3	96.3	115.0	186.3	180.0	160.4
NUA-708	41.1	37.1	45.1	41.1	94.7	87.3	99.0	93.7	128.3	187.0	141.0	152.1
NUA-714	47.1	36.0	55.9	46.3	86.3	72.7	81.7	80.2	100.7	245.3	198.0	181.3
NUA-735	47.3	31.3	56.3	45.0	98.0	82.7	87.0	89.2	113.7	236.0	267.0	205.6
NUA-746	40.8	26.2	42.3	36.4	126.7	117.7	119.3	121.2	143.7	238.7	263.0	215.1
Rojo	39.0	27.8	38.4	35.1	115.7	99.0	91.7	102.1	127.0	189.0	180.7	165.6
Selian 10	19.9	20.1	19.5	19.9	69.0	77.7	73.0	73.2	94.7	116.0	103.7	104.8
Selian 94	37.7	32.5	40.9	37.0	101.0	93.7	93.3	96.0	120.3	219.3	201.0	180.2
Selian 97	39.6	27.5	45.1	37.4	88.3	71.0	87.3	82.2	114.0	152.7	152.0	139.6

SUA-90	28.7	20.7	26.8	25.4	73.3	67.0	76.7	72.3	103.3	154.0	248.0	168.4
TARI-06	40.1	32.0	21.7	31.3	109.0	97.0	109.3	105.1	126.7	249.7	236.0	204.1
Uyole-04	33.2	31.1	42.0	35.4	81.0	80.0	87.0	82.7	99.7	144.7	145.0	129.8
Mean	40.4	33.6	44.8	39.6	94.6	88.2	90.0	91.0	114.0	191.7	195.8	167.2
LSD	5.7	5.6	5.6	3.2	15.5	18.2	21.1	10.5	18	45.3	13.1	16.6
CV%	8.6	10.1	7.7	8.7	10	12.6	14.3	12.4	9.7	14.5	4.1	10.7
SE	3.5	3.4	3.5	3.4	9.5	11.1	12.9	11.3	11	27.7	8	17.8
P-Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001

Table 6

Simple correlation for 100 seed weight (seed size), cooking time, temperature, and relative humidity

	100 seed Weight(g)	1st Cooking(min)	2nd Cooking(min)	Temperature (oC)	Relative Humidity (%)
100 seed weight(g)	1				
1st Cooking(min)	0.1685	1			
2nd Cooking(min)	0.2893	0.5668**	1		
Temperature(oC)	-0.4794	0.5075	0.381*	1	
Relative Humidity (%)	0.0603	0.2301	0.638*	-0.3153	1

NS: No Significance *, **, ***, Significance difference 0.05, 0.01, 0.001, respectively.

Table 7

Mean square for combined analysis of variance for 1st and 2nd cooking tests.

Parameter	**Genotype(G)**	**Location(G)**	**Genotype x Location (GxE)**
1st Cooking test	978.2***	994.2 NS	198.2*
2nd Cooking test	5601***	191315.1**	3760.3***

NS: No Significance *, **, ***, Significance difference 0.05, 0.01, 0.001, respectively.

Storage temperature and relative humidity

The recorded storage room temperature and relative humidity (Table 4), showed that there was an increase in the maximum average storage room temperature from the month of August to December (25.7 to 32.6, respectively). This was inversely proportional to the recorded maximum average storage room relative humidity. As the storage room temperature increased the relative humidity decreased but the decrease was not below 60%. The range of recorded storage room temperature and relative humidity for the whole storage time was 20.9 to 32.6^{o}C and 60 to 81%, respectively.

Cooking time

Analysis of variance exhibited a highly significant variation (P<0.001) for cooking time among the bean genotypes harvested in Ndole for both the first and second cooking tests (Table 5). The genotypes, Selian 10 (69min), NUA-672 (72.3min), SUA-90 (73.3min), and KT-002 (78min), recorded short cooking times in the first cooking test while the Local check (114.7min), Rojo (115.7min) and NUA-746 (126.7min) took a long time to cook. In the second cooking test Selian 10 (94.7min), NUA-672 (95.3min), Mashamba-PYT-4 (98.7min), and Uyole-04 (99.7mn) recorded short cooking times while Local check (127.3min), NUA-708 (128.3min) and NUA-746 (143.7min) recorded long cooking time. Among the bean genotypes harvested in Kasanga, results exhibited a highly significant difference (P<0.001) for cooking time in the first and second cooking tests (Table 5). The genotypes, SUA-90(67min), Selian 97 (71min), NUA-629 (72min) and NUA-714 (72.7min) recorded short cooking times while NUA-695 (109.7min), NUA-527 (112.0min) and NUA-746 (117.7min) revealed a long cooking time (Table 5). The second cooking test recorded the genotypes Selian 10 (116min), Lyamungo 90 (118min), NUA-682 (140.7min), and Maini Ndefu (144min) as the fast-cooking genotypes while the genotypes Calima (244min), NUA-714 (245.3mn), and TARI-06 (249.7mn) were very slow in cooking. Cooking time results recorded for bean genotypes harvested in Mlali revealed a significant difference at (P<0.01) and (P<0.00) for the first and second cooking tests, respectively (Table 5). The genotypes, Selian 10 (73min), Lyamungo 90 (73.7min), NUA-660(74.3min), and ADP-190 (76min) recorded short cooking time in the first cooking test while TARI-06 (109.3min), NUA-642 (109.7min) and NUA-746 (119.3min) revealed short cooking time (Table 5). For the second cooking test the genotypes, Selian 10 (103.7min), NUA-636 (119.7min), KT-002 (123.3min), and NUA-256-4 (130min) recorded short cooking times while the genotypes NUA-735 (267min), Mashamba-PYT-4 (268.3min) and NUA-682 (269min) recorded a long cooking time. A combined analysis of variance also revealed significant differences (P<0.001) for the both first and second cooking tests (Table 5). The cooking time of the first cooking test ranged from 72.3 to 121.2 min, with a mean of 91 min across all three locations. The cooking time of the second cooking test ranged from 104.8 to 215.1 min, with a mean of 167.2min across locations. In the first cooking test SUA-90 (72.3min), Selian 10 (73.2min), NUA-672 (79.2min), and NUA-714 (80.2min) recorded a short time to cook while Rojo (102.1min), TARI-06 (1051min), NUA-642 (105.2min) and NUA-746 (121.2min) were slow-cooking genotypes. In the second cooking test, the cooking time in general was extended compared to the first one where Selian 10 (104.8min), Uyole-04 (129.8min), NUA-636 (132.7min) and Jesca (133.1min) were the fast-cooking bean genotypes while TARI-06 (204.1min), NUA-735 (205.6min) and NUA-746 (215.1min) were the slow-cooking bean genotypes.

Simple correlation among the variables

Correlation analysis (Table 6), revealed a positive correlation between seed size (100 seed weight) and both the first and second cooking tests but were not significant. Therefore, the cooking time was increasing with the increase in seed size. On the other hand, significant strong positive correlations were revealed between the first and the second cooking tests (0.5668**) implying that the increase in cooking time of the first cooking test affected positively the second cooking test. The storage temperature and relative humidity also had a positive correlation (0.381* and 0.638*, respectively) with the second cooking test implying that an increase in storage temperature and relative humidity had an effect on the cooking time.

Stability and genotype x environment interaction

The analysis of variance revealed a significant Genotype x Environment Interaction at (P<0.05) and (P<0.001) for the first and second cooking tests, respectively (Table 7). This implies the tested bean genotypes were sensitive to the production environments. The information obtained from Genotype x Environment Interactions can be a useful tool for developing effective breeding approaches. For that reason, the cooking time data were therefore projected onto the GGE biplot to aid in the comprehension of the GGE interactions. For the first cooking test, the biplot explained around 87.3% of the overall GGE variation (Figure 1). The discovered variation was explained by PC1 and PC2 to different degrees (72.62% and 14.68%, respectively). The genotype, SUA-90 (G18), NUA-672 (G26), KT-002 (G17), Selian 10 (G24), Jesca (G19), and Uyole-04 (G27) revealed high stability with a fast-cooking trait while NUA-746 (G13), TARI-30 (G30), NUA-642 (G1) and Rojo (G3) also exhibited high stability but took a long time to cook. For the second cooking test, the biplot explained approximately 97.56% of the total GGE variation (Figure 2). The observed variation was explained by PC1 and PC2 at 63.33% and 34.23% respectively. The genotypes Selian 10 (G24), Uyole-04 (G27), Selian 97 (G22) and Jesca (G19) revealed high stability with a short cooking time while NUA-746 (G13), TARI-06 (G30), NUA-735 (G8) and NUA-527 (G28) exhibited high stability with a long cooking time. The genotypes Selian 10(G24), Uyole-04 (G27), NUA-746 (G13), TARI-06 (G30), and Rojo (G3) revealed high stability for a cooking time trait across the production environments even after being stored for 90 days. They revealed high stability for both the first and second cooking tests conducted.

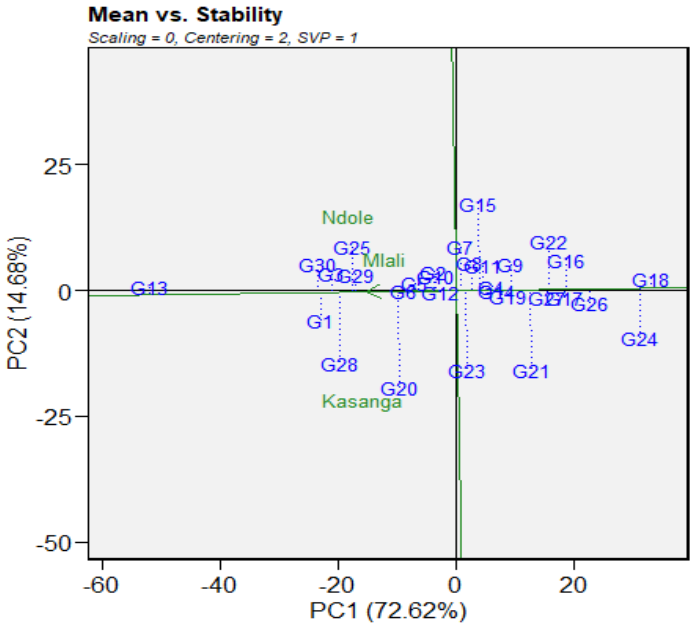

Figure 1:

Mean vs. stability pattern of GGE biplot illustrating interaction effect of 30 bean genotypes for a cooking time in the first cooking test

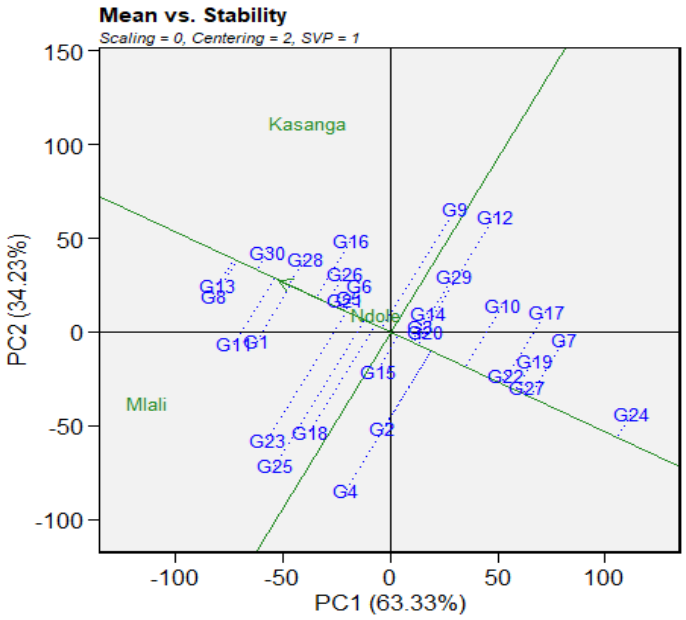

Figure 2:

Mean vs. stability pattern of GGE biplot illustrating interaction effect of 30 bean genotypes for a cooking time in the second cooking test

Discussion

The tested common bean genotypes exhibited variations in cooking time in all three locations. Cichy *et al.,* (2019) also observed the variation in cooking time among bean genotypes across fifteen production environments. The production environment had an effect on cooking time because of the variation in temperature, relative humidity, and rainfall. It has been found the water-stressed bean genotypes during growth will produce bean seeds with a hard shell that will inhibit easy water absorption and cotyledon softening during cooking (Cichy *et al.,* 2019). Therefore, the increased cooking time of bean genotypes harvested in Kasanga and Mlali in the second coking test could be due to insufficient rainfall during the growth period. The size of the seed also affects the cooking time of common beans. Small-seeded bean genotypes take a short time to cook in relation to large-seeded bean genotypes due to the fact that the small surface area of the seed imbibes cooking water in a short time in contrast to the large seed surface. The results revealed a positive correlation between seed size and cooking time for the first and second cooking tests, 0.168 and 0.289, respectively. This shows that there was an increase in cooking time due to an increase in seed size. Storage period and condition also affect the cooking time of common beans, results revealed that beans stored for three months after harvesting take a long time to cook. An increase in storage relative humidity and temperature induce hard-to-cook condition in common beans as was observed in the cooking time of bean genotypes harvested in Kasanga and Mlali. These bean genotypes took a long time to cook because they were stored when the storage room had an increased relative humidity and temperature. From a simple correlation analysis, the results revealed a positive correlation between storage temperature and relative humidity to cooking time. According to Rousseau *et al.*, (2020), storage of beans in tropical environments with high relative humidity (above 50%) and high temperature (above 30 °C) primarily results in the hard-to-cook condition. Solubilization of pectin in the parenchymal cell's middle lamella of the cell wall contributes to the softening of the bean texture (Chigwedere *et al.,* 2018). The Genotype x Environment interaction was significant ($P < 0.05$) and ($P < 0.001$) for the first and second cooking tests, respectively. This shows that the superiority of the bean genotypes in cooking time

has undoubtedly been conditioned by the production environments and there are genetic differences among the tested genotypes. Regarding the cooking time, most of the tested bean genotypes were sensitive to the environments but the existence of environments on one side of the GGE biplot pattern revealed crossover Genotype x Environment interaction was not high (Cichy *et al.,* 2019). The GGE biplot pattern revealed some of the genotypes were insensitive to the environments and exhibited high stability across environments for the first and second cooking tests. The stability revealed some of the tested bean genotypes could be influenced by the difference in the genetic makeup among the genotypes on sensitivity to production environments.

Conclusion

The research conducted has successfully identified significant variations in cooking time among various bean genotypes. This finding highlights the importance of developing fast-cooking common bean cultivars that exhibit stability and predictability across diverse production environments. By achieving this goal, we can ensure that consumers and canners can rely on consistent cooking times while retaining essential micronutrients such as iron (Fe) and zinc (Zn) during the cooking process.
Moreover, the study investigated the effect of G x E interaction on cooking time, emphasizing the need to consider the interaction between genotype and environmental factors. This investigation offers valuable insights into how external conditions influence the cooking time of different bean genotypes, enabling us to make informed decisions in breeding programs and food production processes.

To preserve the desirable cooking characteristics of common beans, it is recommended to adhere to specific post-harvest conditions, including maintaining low temperatures (below 30°C) and relative humidity (below 50%). This practice helps minimize the negative impact of hard-to-cook conditions, ensuring that the beans retain their optimal cooking properties even after being stored for extended periods, like three months.
Finally, among the bean genotypes assessed, those that exhibited fast-cooking properties and remained stable across different environments, even after storage, are considered promising candidates for release or inclusion as elite material in breeding programs. These selected genotypes hold great potential in contributing to the development of improved common bean cultivars, meeting the preferences of consumers and facilitating more efficient production and processing in the bean industry.

Recommendation

The cooking test was performed using distilled water in order to solve the hard (mineral-rich) water problem which could have slowed down the cooking process. However, in other cases will be a need to test the cooking time of common beans by using tape water which is normally used by most common bean consumers although mineral content of tape water varies from place to place.

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References

Amongi, W., Kato, F., Male, A., Mbiu, J., & Mukankusi, C. (2021). Development of common bean genotypes with high iron and zinc seed concentrations and superior canning thickness and agronomic quality traits. *African Journal of Food, Agriculture, Nutrition and Development*, *21*(8), 18450-18473.

Bassett, A., Hooper, S., & Cichy, K. (2021). Genetic variability of cooking time in dry beans (Phaseolus vulgaris L.) related to seed coat thickness and the cotyledon cell wall. *Food Research International*, *141*, 109886.

Borchgrevink, C. P. (2013). Culinary perspective of dry beans and pulses. In *Dry beans and pulses production, processing and nutrition*. USA: John Wiley & Sons, Inc. pp. 311-334.

Campos-Vega, R., Oomah, B. D., Loarca-Piña, G., & Vergara-Castañeda, H. A. (2013). Common beans and their non-digestible fraction: cancer inhibitory activity an overview. *Foods*, *2*(3), 374-392.

Chigwedere, C. M., Olaoye, T. F., Kyomugasho, C., Kermani, Z. J., Pallares, A. P., Van Loey, A. M., ... & Hendrickx, M. E. (2018). Mechanistic insight into softening of Canadian wonder common beans (Phaseolus vulgaris) during cooking. *Food Research International*, *106*, 522-531.

Chinedum, E., Sanni, S., Theressa, N., & Ebere, A. (2018). Effect of domestic cooking on the starch digestibility, predicted glycemic indices, polyphenol contents and alpha-amylase inhibitory properties of beans (*Phaseolus vulgaris*) and breadfruit (*Treculia africana*). *International journal of biological macromolecules*, *106*, 200-206.

Cichy, K. A., Wiesinger, J. A., Berry, M., Nchimbi-Msolla, S., Fourie, D., Porch, T. G., ... & Miklas, P. N. (2019). The role of genotype and production environment in determining the cooking time of dry beans (Phaseolus vulgaris L.). *Legume Science*, *1*(1), e13.

Haluschak, P. (2006). Laboratory methods of soil analysis. *Canada-Manitoba soil survey*, 3-133.

Massawe, F. A., Bengesi, K. M., Kweka, A. E. (2015) Patterns of household cooking energy and associated factors: experience from Kilimanjaro region, Tanzania. Intersect Stanf J *Science, Technology and Society*, 8:1-25.

Medard, E. (2017). *Factors underlying common Beans' (Phaseolus vulgaris L.) consumption decisions in Dar es Salaam, Tanzania* (Doctoral dissertation, Sokoine University of Agriculture).

Ngowi, A. V. F., Mbise, T. J., Ijani, A. S., London, L., & Ajayi, O. C. (2007). Smallholder vegetable farmers in Northern Tanzania: Pesticides use practices, perceptions, cost and health effects. *Crop protection*, *26*(11), 1617-1624.

Ribeiro, N. D., Rodrigues, J. D. A., Prigol, M., Nogueira, C. W., Storck, L., & Gruhn, E. M. (2014). Evaluation of special grains bean lines for grain yield, cooking time and mineral concentrations. *Crop Breeding and Applied Biotechnology*, *14*, 15-22.

Rousseau, S., Celus, M., Duijsens, D., Gwala, S., Hendrickx, M., & Grauwet, T. (2020). The impact of postharvest storage and cooking time on mineral bioaccessibility in common beans. *Food & function*, *11*(9), 7584-7595.

Thompson, H. J. (2019). Improving human dietary choices through the understanding of the tolerance and toxicity of pulse crop constituents. *Current opinion in food science*, *30*, 93-97.

Wang, N., & Daun, J. K. (2005). Determination of cooking times of pulses using an automated Mattson cooker apparatus. *Journal of the Science of Food and Agriculture*, *85*(10), 1631-1635.

Wani, I. A., Sogi, D. S., Wani, A. A., & Gill, B. S. (2017). Physical and cooking characteristics of some Indian kidney bean (*Phaseolus vulgaris* L.) cultivars. *Journal of the Saudi*

Society of Agricultural Sciences, *16*(1), 7-15.

Wiesinger, J. A., Cichy, K. A., Tako, E., & Glahn, R. P. (2018). The fast cooking and enhanced iron bioavailability properties of the Manteca yellow bean (*Phaseolus vulgaris* L.). *Nutrients*, *10*(11), 1609.