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Original Article

Variation in agronomic performance, cooking time and quality of high performing second-generation biofortified common bean in Democratic Republic of Congo

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ABSTRACT

Common bean (Phaseolus vulgaris L.) is a vital source of protein and micronutrients for millions of people in sub-Saharan Africa, yet adoption of improved varieties depends on both agronomic performance and consumer-preferred traits. The present study evaluated 285 second-generation biofortified common bean genotypes alongside five local checks at Butembo and Lukanga, Democratic Republic of Congo (DRC), during the 2022 long rain season. Farmer participatory selection was conducted at flowering and maturity stages, emphasizing vigor and pod number. Hydration coefficient, cooking time, integrity after cooking, and sensory evaluation of cooked beans were also assessed. Results showed that 124 biofortified genotypes were selected by farmers, with pod numbers ranging from 14 to 27 compared to 9–13 for local checks. Hydration coefficients were higher in biofortified genotypes (1.4–3.4) than in local varieties (1.7–2.0). Conversely, cooking times were shorter in biofortified genotypes (73–170 min) compared to local lines (120–144 min). A significant negative correlation (p<0.001) was observed between hydration coefficient and cooking time. Sensory evaluation revealed acceptable taste, flavour, and starchiness for most biofortified genotypes, though some showed undesirable traits. Overall, biofortified genotypes combined large pod numbers with shorter cooking times, meeting both farmer and consumer preferences, and hence being promising for adoption in Eastern DRC.

KEYWORDS: *Biofortification, Common bean, Cooking time, Farmer participatory selection*

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INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is an important legume crop, source of daily proteins for almost half a billion people (Farrow & Muthoni-Andriatsitohaina, 2020). It represents the species of choice for the study of grain legume nutrition as half of the grain legumes consumed worldwide are common beans (Broughton *et al*., 2003). Common bean is consumed by 83% of the population of the Democratic Republic of Congo (Mbikayi *et al*., 2018).

Analysis of factors influencing the acceptance of novel varieties should be done where farmers and consumers are involved in testing processes. Mulugeta (2011) listed high yield potential, duration to maturity, resistance to pests and diseases, grain color, grain size and storability as the main factors influencing adoption of novel varieties of common bean at farmers' level.

Consumer preferences are also determinant factors influencing adoption of novel varieties. These preferences include visual characteristics such as seed color and shape and culinary properties such as cooking time and texture of cooked beans (Bassett *et al*., 2017). Asiimwe *et al*. (2024) stated that the cooking time, taste, grain color and bean swelling on cooking are important attributes for consumers. Short cooking time is widely emerging as a consumer preferred character for variety acceptability and adoption (Yadji Haman *et al*., 2020). Due to scarcity of firewood and reduction in resources in Eastern Africa, fast cooking bean varieties would be a means contributing to the four pillars of food security (Petry *et al*., 2010). In addition, prolonged cooking time leads to important losses of proteins, starch and iron (Bassett *et al*., 2017).

Even when farmers are well involved in variety development, high yielding and disease resistant varieties newly developed are not necessary adopted at farmers' level when they lack consumer preferred traits such as short cooking time and good taste (Bassett *et al*., 2017). In addition, consumers do not prefer varieties that break at cooking (Mulugeta, 2011).

The second-generation biofortified common bean genotypes are a result of iron and zinc biofortification programme that was initiated in 2001 at the University of Nairobi (Kimani *et al.,* 2008). These varieties are reported to cook fast and yield more than 4 t ha^{-1} (Kimani & Warsame, 2019 ; Mondo *et al*., 2019). The Université Catholique du Graben of Butembo (DRC) requested for and received 285 lines, which were tested in destination site and assessed for cooking time together with other quality characteristics.

The objectives of the present study were to assess agronomic performance of second-generation biofortified common bean genotypes, and determine the cooking time and quality of cooked beans of high performing second-generation biofortified common bean genotypes.

MATERIAL AND METHODS

Experimental sites

Field experiments were carried out in Butembo and Lukanga during the 2022 long rain season between October 2022 and January 2023. In Butembo, experiments were conducted at the field station of the Université Catholique du Graben (UCG-Butembo) located at 0.1238815° latitude N, 29.268894° longitude E at 1,762 m above the sea level (masl). At Lukanga, studies were carried out in the field station of the Université Adventiste de Lukanga (UNILUK) at 0.05° latitude S, 29.03° longitude E at 1,952 masl in Lukanga city. Determination of cooking time and hydration coefficient were done in the laboratory of UCG-Butembo located at the University campus in Butembo in March 2023.

Experimental materials

Two hundred and eighty-five (285) second-generation biofortified common bean genotypes were used for field trial together with five local varieties. Biofortified genotypes were obtained from the University of Nairobi and their agronomic description was reported by Kimani & Warsame (2019) and Mondo *et al*. (2019).

According to these authors, the average yield performance ranged from 0.8 to more than 4.0 t ha^{-1} across different test sites of Kenya. These sites include Kabete, Nakuru, Thika, Mwea and Tigoni. Using an Automated Mattson Bean cooker, Kimani & Warsame (2019) reported that these genotypes take less than an hour to cook.

Experimental design and crop management

Test genotypes were evaluated in a rectangular augmented design where only local varieties were replicated. Five blocks containing 57 biofortified genotypes each and the five local varieties were used. Checks were involved to allow farmers make comparison between the later and biofortified genotypes.

An experimental unit was represented by a single row of 2.70 m containing 10 hills 30 cm apart each from another. The inter-row distance was 60 cm. A hill received two seeds. Thinning out to one plant per hill was carried out two weeks after emergence. Diammonium phosphate (18% N and 46% P_2O_5) was applied at planting at 150 kg ha^{-1} as recommended by Hundie *et al*. (2000) cited by Kataliko *et al*. (2018). Plots were maintained weed-free by manual weeding. Manual weeding was done at 25-days interval. The experiment was conducted with minimum input to mimic farmers' practices such as no insecticide or fungicide application. Harvesting took place when pods dried for each genotype.

Seed preparation for cooking and quality assessment

After harvesting, seeds were sun dried for three days and stored for one month. Thereafter, seeds for each genotype were sorted to remove broken, wrinkled and rotten seeds. Using an electronic computerized balance (WT-N Serries, WANT

Balance Instrument Co., Ltd, Jiangsu, China), a sample weighing of 250g each genotype was soaked in water. As recommended by Munthali *et al*. (2022), equal volume of water is needed and should be high enough to cover the amounts absorbed during hydration of beans. In this study, equal volume of 1,000 ml of water was used in each soaking plastic container.

Data collection

Vigorous genotypes selected by farmers were used to determine hydration coefficient, cooking time (minutes) of dry beans, integrity of beans at cooking (%), particularly on selected genotypes. In addition, data collection was extended to visual evaluation and sensory parameters of cooked beans of selected genotypes.

Two rounds were organized in each location where 25 farmers selected genotypes that they judged vigorous. These panelists were purposively selected among the farmers that have grown common bean for more than five years. The first round was undertaken at flowering and the last at harvesting. During flowering, farmers selected genotypes whose plants were judged healthy and vigorous. Meanwhile, the color of flowers was mentioned during this activity. At maturity, selected genotypes at flowering that did not have high pod numbers were discarded. Farmers were interested in large numbers of pods. They selected genotypes whose numbers of pods were large enough. At the end of the selection phase, the number of initiated pods was recorded on selected genotypes. A sample of five plants per genotype was used to estimate the average number of pods per plant.

Cooking started one month after harvesting and took 11 days considering the capacity of the cooker. Only four genotypes were cooked at a time, while for a whole day, three rounds of cooking were realized. In total, 12 genotypes were cooked daily following a modified method proposed by Castillo *et al*. (2012) since no Mattson cooker was available.

The common cooking protocol has been proposed by the "*Una Norma Española*" (UNE) 87028-1 (UNE, 1997). This protocol is general for legumes but differs in key ways from the methods consumers used. In addition, it leads to a high proportion of broken beans (Sanz, 1997). For this study, a revised protocol originally proposed by Castillo *et al*. (2012) was adopted, as it is better suited to the available resources.

According to the protocol, 250 g of dry beans were soaked in 1,000 ml of natural and cleaned water for 14 h and drained. Hydration coefficient (HC) was then determined by Van Der Merwe *et al*. (2006) formula as the ratio between the weight of soaked and drained beans (g) and the weight of dry beans (250g). These beans were then placed in a 1 l thick-bottomed stainless-steel pot with water to cover the beans by 1 cm. This way increases the proportion of whole beans in cooked samples. When water overlaps the level of beans in a pot brought to a boil during cooking, and particularly when a smaller quantity of beans is cooked, important thermal differences result in streams in water and cause beans to move, collide one with others and break.

During cooking, the level of water was controlled and water was periodically added due to losses of water resulting from evaporation. To reduce the importance of water evaporation and maintain constant temperature in the pot, beans were cooked with a lid on. The protocol recommended that 2.5 g NaCl should be added shorty before the beans are cooked unless nutritional properties are to be performed. Beans were deemed cooked when they were soft enough to be eaten. To assess this, they were gently pressed between the thumb and forefinger, and considered adequately cooked if the applied pressure caused them to yield without resistance. Cooking was realized at 135°C. The cooking time was recorded in minutes as the period from when beans are brought to a cooker up to when they were soft enough to be eaten (Castillo *et al*., 2012).

From there, 100 g of cooled beans were drained and the whole beans were separated from the broken ones. Integrity of beans (%) was recorded using the formulae as follows:

$$Integrity\ of\ beans\ (\%) = \frac{Qwb}{Qwb+Qbb} \times 100 \qquad (1)$$

(Castillo et al., 2012). Where: Qwb= quantity of whole beans, and Qbb= quantity of the broken beans

A panel of 15 tasters was used in this study to appreciate visual characteristics and sensory parameters. Visual evaluation included the size, shape and the uniformity of beans, while sensory parameters included the taste, flavour and the starchiness of beans. For visual evaluation, a seven-point hedonic scale was used for size (1 indicates very small and 7 very large), shape (1 indicates very elongated and 7 very round) and uniformity (1 indicates very variable and 7 vey uniform) (Hosfield & Uebersax, 1980). However, a five-point hedonic scale was used to appreciate the starchiness (1 indicating that beans are very clear to 5 indicating that beans are extremely cloudy), the taste and flavour (1 indicates that parameter is judged unpleasant, while 5 indicates that the character is excellent) (Teshome & Emire, 2012).

Data analysis

Data were analyzed using Statistix 8.0 statistical software. Means were computed for the number of pods per plant in biofortified and local varieties, and differences were assessed by comparing mean values across sites. Descriptive statistics (mean, minimum, maximum, variance, and coefficient of variation) were generated, and a two-tailed t-test was performed to compare the mean performance of biofortified genotypes and local varieties with respect to hydration coefficient, cooking time, and bean integrity after cooking.

In addition, Pearson's correlation coefficients were calculated to examine relationships among hydration coefficient, cooking time, and bean integrity. Results were presented in tables and figures to facilitate interpretation of agronomic performance, cooking quality, and sensory attributes.

To complement the descriptive statistics, sensory data were subjected to Principal Component Analysis (PCA) using the SensoMineR package implemented in R statistical software, version 4.4.0.

RESULTS

Farmers' selection of vigorous biofortified common beans

Performing second-generation biofortified genotypes were selected on the basis of healthy and vigorous leaves at flowering. At maturity, biofortified genotypes were selected on the basis of the number of pods per plant of a given genotype. Performing candidates selected were genotypes with large pod numbers.

A total of 124 biofortified genotypes were selected. The color of flowers for most genotypes was white. Number of pods per plant varied from 14 for genotypes BCB11-509, BF08-13-170 and BF08-1-30 to 27 for genotype BF08-13-44B (Table 1). The number of pods for local varieties varied from 9 for IKINIMBA to 13 for MAFUTALA.

Table 1 : Agronomic and cooking quality traits of selected 124 high performing second-generation biofortified genotypes and five local common bean varieties in DRC

N°	Genotype	Color of the flower	No. of pods/plant	Hydration coefficient	Cooking time (min)	Integrity of beans (%)
	Biofortified lines					
1	BF08-26-69	White	15	1.886	100	97.9
2	BF08-01-45A	Purple	15	1.976	116	83
3	BF08-13-102	White	15	2.043	100	92.1
4	KMA13-28-5	White	15	1.543	110	98.6
5	BF08-14-51A	White	18	3.373	106	96.5
6	BF08-01-21	White	16	1.986	73	90
7	KMA13-22-27	Purple	18	1.671	120	97.8
8	BF08-3-23B	White	20	1.971	112	94.4
9	MV-14	White	17	1.943	93	97.8
10	BCB11-509	White	14	2.6	125	82.9
11	BF08-07-74A	White	22	1.99	100	96.1
12	G4-585	Purple	17	1.614	141	100
13	BF08-14-20	White	15	2.1	118	98.6
14	BF08-13-38	White	18	2.013	137	97.7
15	KMA13-10-05	White	17	2.125	120	98.8
16	BF08-16-21	White	19	2.0125	110	97.7
17	MBC23	White	15	1.875	131	89
18	BF08-7-112D	White	16	2.014	168	99.4
19	BF08-26-68B	Purple	20	1.986	140	100
20	BF08-16-36A	White	19	2.015	133	94.7
21	NAIN DE KYONDO	White	16	1.943	113	21.3
22	BF08-7-114	White	15	1.986	133	95.4
23	BF08-16-76	White	21	1.88	120	98.1
24	BF08-13-44A	White	24	2.028	101	97
25	G2333(B)	White	15	1.471	129	98.5
26	BF08-1-77	White	19	2.029	110	98.6
27	BF08-14-24	Purple	15	1.843	118	100
28	BF08-03-13	White	19	1.942	123	96

29	BF08-16-67B	Pink	15	1.986	129	98
30	BF08-1-18C	White	15	1.857	128	86.1
31	BF08-14-116	Purple	15	1.743	150	98.7
32	BF08-07-74C	White	21	1.99	100	96
33	BF08-03-22	White	15	1.943	122	96
34	BF08-13-47	White	16	1.793	105	95.35
35	BF08-13-44B	White	27	2.03	99	99
36	RK14	White	15	2.1	95	82.4
37	BF08-16-67A	White	15	1.98	131	97.8
38	GLP585	White	16	1.614	142	100
39	BF08-1-60	White	15	2	105	96.6
40	BF08-1-47A	White	15	1.871	116	98.6
41	BF08-1-29	White	16	2.029	111	98.6
42	SR6	White	15	1.912	135	95
43	BF08-01-50	White	16	1.946	116	83
44	BF08-36-53	White	15	1.946	75	98.7
45	BF08-14-153A	White	23	3.32	101	89.7
46	BCB11-492	Pink	16	2.45	127	82.9
47	BF08-13-43A	White	15	1.753	105	95.35
48	KMA-21-19	White	15	1.427	151	82
49	BF08-14-96A	White	16	3.3	105	94.7
50	BF08-13-170	White	14	1.793	105	95.35
51	BF08-14-102	White	15	3.423	102	92.7
52	BF08-14-51B	White	17	3.253	108	96.7
53	BF08-01-18A	White	21	2.002	114	84
54	BF08-14-96B	White	16	3.338	105	94.7
55	BF08-14-51C	White	18	3.353	106	96.7
56	BF08-01-45B	White	15	1.986	115	83
57	KMA13-28-21	Purple	15	1.414	170	82.2
58	BF08-03-12B	White	20	1.981	117	98.8
59	BF08-1-80	White	15	1.871	115	98.6
60	RK11	Purple	15	2.1	95	82.4
61	BF08-03-13B	White	22	1.944	121	96.1
62	BF08-1-49B	White	16	2	104	96.6
63	KMA13-22-19	White	15	1.786	156	95.4
64	BF08-03-05	White	15	1.929	103	97.4
65	KMA13-05-21	White	15	1.793	105	95.35
66	BF08-14-153B	White	24	3.353	98	86.7
67	BF08-7-19B	White	19	2.14	148	95.3
68	BF08-13-18D	White	15	1.793	105	95.35
69	BF08-16-82B	White	22	1.6	116	98.5

70	BF08-01-18B	White	23	1.976	116	83
71	KMA13-23-22	White	15	1.427	153	81
72	BF08-3-23A	White	20	1.971	112	94.4
73	KMA13-10-18	White	21	1.406	149	81.4
74	BF08-7-19A	White	21	2.13	149	95.5
75	BF08-1-51	White	17	2.03	109	98.6
76	RK12B	White	15	2.2	94	82.2
77	BF08-07-112D	White	18	1.96	104	95.5
78	MC20	Purple	15	2.03	117	96.8
79	BF08-16-14	White	16	1.6	116	98.5
80	BF08-07-116	White	16	1.96	102	95.5
81	KMA13-23-21	White	20	1.406	150	81.4
82	BF08-16-52	White	17	1.6	120	98.5
83	G4-24A	White	15	1.6	116	90.5
84	BF08-01-90	White	15	1.961	118	83
85	BF08-03-20	White	15	1.6	120	98.6
86	BF08-1-60B	White	15	1.95	109	96.6
87	BF08-1-27	White	15	2.01	111	98.6
88	KENYA UMOJA	Pink	15	1.943	118	77.7
89	BF08-01-47B	White	23	1.986	75	90
90	BCB11-433	White	15	2.00	118	93.3
91	BF08-01-92	White	15	2.056	75	94
92	BCB11-372	White	15	2.3	130	84.3
93	BF08-07-74B	White	21	1.96	102	95.5
94	BF08-16-18E	White	15	1.61	116	98.5
95	BF08-03-12A	White	19	1.961	119	98.4
96	SR9	White	17	1.897	139	95
97	BF08-01-62B	White	16	1.976	116	84
98	BF08-01-01	White	15	2.115	94	90
99	SER12	White	15	1.987	136	95
100	KMA13-13-70	White	16	1.406	151	81.4
101	MEX54	Purple	15	1.877	129	95
102	BCB11-303	Purple	15	2.5	127	92.9
103	BF08-01-62A	White	16	1.966	115	85
104	BF08-16-92	White	15	1.71	116	98.5
105	BCB11-138	Pink	15	2.4	131	85.3
106	BF08-7-80	White	15	1.926	133	95.4
107	RK6	White	15	2.2	100	83.1
108	BF08-26-162	White	15	1.98	123	92.5
109	RK12A	White	14	2.1	95	82.4
110	BF08-16-31	White	19	1.78	117	98.6

111	KMA13-03-35	White	14	1.406	151	81.4
112	MV1	White	14	1.903	92	97
113	BF08-16-68	White	15	1.88	118	98.1
114	BF08-01-49A	White	15	1.976	116	86
115	BF08-07-22	White	21	1.986	133	95.4
116	MC29A	Purple	15	1.90	124	95
117	BCB11-342	White	15	2.356	129	84.3
118	BF08-7-75	White	15	2.115	94	90
119	KMA13-32-28	White	15	1.506	145	82.4
120	BF08-01-54	White	15	1.976	116	84
121	BF08-1-30	White	14	1.99	109	96.6
122	KMA13-19-33	White	15	1.506	143	84.4
123	BF08-16-36B	White	20	2.013	136	95
124	BF08-13-43B	White	16	1.693	112	95.35
	Mean	-	**16.7**	**2.00**	**117.85**	**92.2**
N°	**Genotype**	**Color of the flower**	**No. of pods/plant**	**Hydration coefficient**	**Cooking time (min)**	**Integrity of beans (%)**
	Local lines					
1	IKINIMBA	Purple	9	1.729	139	99.3
2	KALANGITI	Purple	10	1.72	144	99.1
3	MAFUTALA	Purple	13	1.9	130	99.8
4	OBUSOSERA	White	11	2	120	93
5	DEMAI	Purple	12	1.89	139	98.5
	Mean	-	**11**	**1.8**	**134.4**	**97.9**

Mean hydration coefficient, cooking time and integrity of beans at cooking

Hydration coefficient varied from 1.4 to 3.4 among all genotypes and biofortified types. Among local varieties, it varied from 1.7 to 2.0. Among biofortied genotypes, it varied from 1.4 to 3.4 (Table 1). Biofortified genotypes had higher hydration coefficient compared to local varieties (Table 2).

Cooking time varied from 73 to 170 minutes among biofortified genotypes and from 120 to 144 minutes among checks. Among biofortified genotypes, BF08-01-21 cooked faster, while KMA13-28-21 cooked the last (Table 1). In general, biofortified genotypes cooked faster than checks (Table 2).

Percentage of beans remaining whole after cooking was high for checks than for biofortified common beans (Table 2). It varied from 21.3 to 100% and from 93.0 to 99.8% respectively for biofortified and local genotypes.

Table 2: Description of hydration coefficient, cooking time and integrity of beans at cooking of biofortified genotypes and local varieties

Variable	Hydration coefficient	Cooking time (minutes)	Integrity of beans (%)
Lower 95% CI	1.9	112.05	89.3
	1.7	122.60	94.5
Mean	2.0	117.85	92.2
	1.8	134.40	97.9
Upper 95% CI	2.1	123.66	95.1
	2.0	146.20	101.4
Variance	0.13	513.69	127.9
	0.01	90.30	7.8
Coefficient of variation	18.2	19.23	12.3
	6.5	7.07	2.9
Minimum	1.4	73.00	21.3
	1.7	120.00	93.0
Maximum	3.4	170.00	100.0
	2.0	144.00	99.8
T-value	42.9	40.61	63.7
	34.3	31.63	78.2
P-value	0.00	0.00	0.00
	0.00	0.00	0.00

Association between hydration coefficient, cooking time and integrity of beans at cooking

A significant negative correlation (r=-0.36; p<0.001) was observed between cooking time and hydration coefficient. Correlations between integrity of beans and each of the two other traits (hydration coefficient and cooking time) were not significant (Table 3).

Table 3: Correlation between hydration coefficient, cooking time and integrity of beans at cooking

	Hydration coefficient	Cooking time	Integrity of beans
Hydration coefficient	1.00	-	-
Cooking time	-0.36***	1.00	-
Integrity of beans	0.006 ns	-0.05 ns	1.00

** p<0.001; ns – no significant

Variation in visual characteristics of cooked biofortified common beans

Visual characteristics of cooked biofortified genotypes varied (Table 4). The size of cooked beans for most biofortified common bean genotypes varied from slightly small to indifferent. Some genotypes produced beans that were a bit smaller, while other genotypes produced beans whose size was neither notably small nor large. These sizes accounted for more than 70% of all biofortified genotypes. Checks were slightly small except KALANGITI whose size was judged moderately small.

Moderately elongated shape was the most represented among biofortified common beans followed by slightly elongated shape. These shapes accounted for more than 68% of biofortified genotypes. The shape for checks varied from slightly elongated too slightly round.

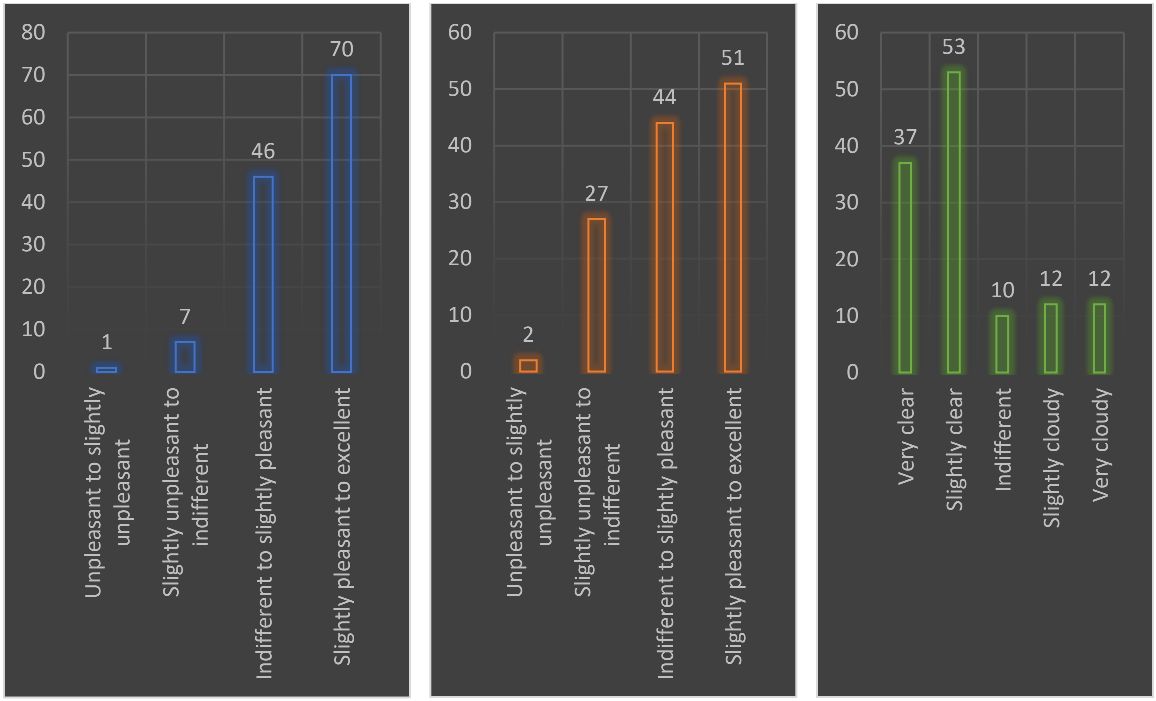
Most biofortified genotypes were moderately and very uniform. These genotypes accounted for more than 58% of biofortified genotypes. Very few (about 6%) biofortified genotypes were slightly variable. Among checks, IKINIMBA and MAFUTALA were very uniform, while others had indifferent to slightly variable cooked seeds.

Multivariate sensory characteristics of cooked biofortified common beans

The taste was unpleasant for BF08-26-68B and slightly pleasant to excellent for 70 biofortified genotypes. Flavour was unpleasant and slightly unpleasant for BF08-26-68B and RK13 and varied from indifferent to excellent for 95 biofortified common beans. Most cooked beans (about 90 biofortified genotypes) were slightly and very clear. They were slightly to very cloudy for 24 biofortified genotypes (Figure 1). For local varieties, cooked beans had indifferent starchiness and slightly pleasant taste and flavour.

Table 4: Visual characteristics of cooked biofortified and local common beans

	Size of common beans					
Category	Moderately small	Slightly small	Indifferent	Slightly large	Moderately large	Very large
Biofortified	5	34	54	18	10	3
Local	1	4	-	-	-	-
	Shape of common beans					
Category	Very elongated	Moderately elongated	Slightly elongated	Indifferent	Slightly round	Moderately round
Biofortified	13	46	39	13	3	10
Local	-	-	1	3	1	-
	Uniformity of common beans					
Category	Slightly variable	Indifferent	Slightly uniform	Moderately uniform	Very uniform	-
Biofortified	8	23	21	41	31	-
Local	2	1	-	-	2	-



A: Taste of cooked biofortified beans   B: Flavour of cooked biofortified beans   C: Starchiness of cooked biofortified beans

Figure 1: Sensory characteristics of cooked biofortified common beans

Multivariate analysis revealed that the first two principal components (PC) accounted for the majority of the variance, with PC1 explaining 79.3% and PC2 explaining 17.2%, thereby capturing the major sensory differences among genotypes. PC 1 (79.3%) captured most of the sensory variation, separating genotypes based on taste and starchiness. Biofortified genotypes clustered on the right side of the plot showed strong alignment with taste and flavour vectors (Figure 2).

Biofortified genotypes such as GEN1, GEN3, GEN6 were closely associated with flavour. They exhibited aromatic or palatable qualities favored in sensory evaluation. Biofortified lines GEN7, GEN9, GEN10 aligned with starchiness, indicating cloudier textures.

Local genotypes were positioned on the left side of the plot, with limited association to any sensory vector, suggesting weaker sensory appeal.

This visualization supports that biofortified beans offer superior sensory characteristics, particularly in taste and flavour, which are key drivers of consumer preference.

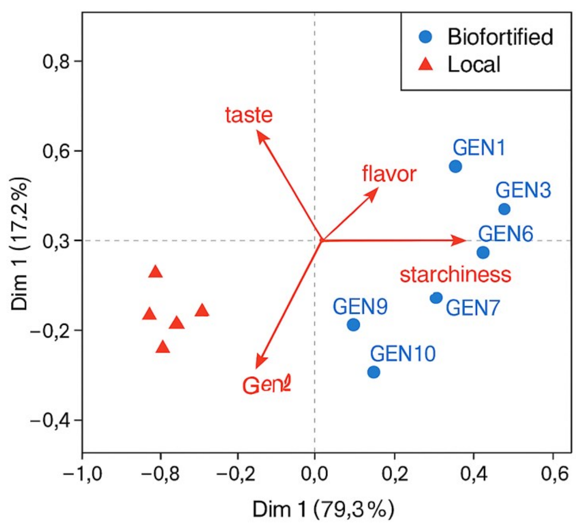


Figure 2: Principal component analysis biplot showing the relationship between bean genotypes and taste, flavour, and starchiness.

(Biofortified genotypes are represented by blue circles, and local genotypes by red triangles. Sensory attributes are shown as vectors).

DISCUSSION

Farmer assessment of agronomic performance of second-generation common bean genotypes

High yield potential is the foremost character that influences variety selection at farmer level (Mulugeta, 2011). Farmers in North Kivu favor climbing bean genotypes with vigorous foliage, likely due to the additional value of leaves as a vegetable resource.

Farmers preferred genotypes with large pod numbers. This trait is a key determinant of grain yield. Its positive significant correlation with grain yield has been previously reported in several studies (Kataliko *et al*., 2024; Mondo *et al*., 2019; Batumike, 2018).

For all the biofortified genotypes, the number of pods per plant was larger than that for all the checks. This meets the breeding objective of these genotypes. In fact, these genotypes were bred to increase the yield and the mineral levels in seeds (Kimani & Warsame, 2019). In addition, these authors reported the short cooking time (about 45 minutes) associated with these genotypes.

Cooking time of the second-generation biofortified common bean genotypes

Cooking time is currently a priority for common bean improvement due to its implications for nutritional value, energy utilization and gender equity. Among biofortified genotypes, cooking time varied from 73 to 170 minutes with a mean of 117.85 minutes and from 120 to 144 minutes among checks with a mean of 134.40 minutes. Mukai (2017) found cooking time varying from 35 to 122 minutes with an average of 66 minutes. Yadji Haman *et al*. (2020) observed ranges from 49.28 to 89.28 minutes for freshly harvested beans and from 128.38 to 270.52 minutes for beans that were stored first for 10 days suggesting that storage period after harvest influences cooking time. Coelho *et al*. (2007) reported that freshly harvested beans cook 2-4 times faster than beans stored for six months.

Differences in cooking times observed from other studies arise from varietal differences, water absorption, cooking method used and storage period. While Yadji Haman *et al*. (2020) ; Mukai (2017) used 12 hours for soaking in distillated water and used an Automated Mattson Bean cooker developed by Canadian Grain Commission (Winnipeg, Canada), in this study, due to an unavailability of a Mattson cooker, a method proposed by Castillo et al. (2012) which recommended 14 hours for soaking was used.

Hydration coefficient varied from 1.4 to 3.4 among all genotypes and biofortified types. Among the checks, it varied from 1.7 to 2.0. Common beans whose water absorption is high tend to cook fast. In terms of water absorption expressed into percentages, it ranged from 41.4 to 235.3% among biofortified genotypes with an average of 102.7% and from 72 to 100% among the local varieties with an average of 84.8%. Mukai (2017) found water absorption varying from 63 to 137% in 152 common bean lines with an average of 94%. Variations might be due to varietal differences. Local varieties might have compact seed coat texture. This might be the reason why hydration coefficient was low and cooking time high for this category. This is in line with Shellie-Dessert & Hosfield (1990) who reported that water absorption capacity of beans influences their cooking time and is controlled by the texture of seed coat. Similar findings have been reported by Mukai (2017). Other factors affecting water absorption include differences in orifice dimensions in bean seed microphyle, presence and number of seed coat pores and the microstructural differences (Agbo *et al*., 1987).

Water absorption seems to be another important factor influencing the cooking time. Shorter cooking time might be associated with common beans which absorb enough water. Findings revealed a negative significant correlation ($r=-0.36$; $p<0.001$) between cooking time and hydration coefficients indicating that short cooking time occurred in bean with high water absorption. This might be attributed to the degradation properties of water, particularly its hydrolysis ability (IFC, 2016). When hydration coefficient is high, the cooking time is short. This is evident considering that biofortified genotypes, the most hydrated beans, cooked faster than the local varieties with low hydration coefficients. Similar findings were reported by Munthali *et al*. (2022). Shellie-Dessert & Hosfield (1990) also reported that a high state of cellular hydration allows cells to soften and separate. Even during her study, Mukai (2017) revealed a narrow range of cooking time during the rainy season (from 35 to 100 minutes) and a delayed cooking time when the amount of rains decrease (from 43 to 122 minutes). This might be due to the fact that beans retained more water during the rainy season as the treatment processes were identical over the two seasons.

The temperature is another key factor of difference. For the study carried by Mukai (2017), the Mattson cooker operated at 350°C, while in this study, the cooker was at 135°C. This is a temperature that can be achieved by any farmer or consumer, and particularly under poor energy resources in Eastern and Central Africa.

Differences in cooking time might also have been attributed to the storage period before cooking. When storage period is too long, common beans take longer to cook. Similar findings have been reported by Yadji Haman *et al*. (2020). Freshly harvested beans cooked 3-4 times faster than beans that have been stored for 10 days. In fact, in seeds, as reported by Pereira *et a*l. (2014) ; Mubaiwa *et al*. (2017), phytate storing calcium during storage, is broken down and free calcium is released to crosslink pectin in the cell wall leading to strengthening the last and increasing cooking time.

Quality characteristics of cooked beans of selected second-generation common bean genotypes

It was revealed that percentage of beans remaining whole after cooking was high for checks than for biofortified common beans. It varied from 21.3 to 100% among biofortified genotypes and from 93.0 to 99.8% among local varieties. This might be due to the texture of seed coat that should be more compact for local varieties than for biofortified genotypes. This is evident considering that hydration coefficient was low for local varieties indicating the compact structure and reduced orifice dimensions and few pores to allow important water penetration in cells as reported by Shellie-Dessert & Hosfield (1990) ; Agbo *et al*. (1987). Barros & Helena (2016) observed percentages of whole beans after cooking ranging from 30.0 to 94.91%. Munthali *et al*. (2022) found percentages of split beans varying from 4 to 60%.

Another factor affecting integrity of beans might be the heating temperature and the amount of water used. When smaller quantities of beans are cooked in overlapping water, due to streams produced in the jar, beans move, collide and break (Van Der Merwe et al., 2006). High heating temperature may result in increased number of broken beans.

The size for most biofortified common bean genotypes varied from slightly small to indifferent. Biofortified common beans had moderately and slightly elongated shape and were moderately and very uniform. These attributes are linked to raw beans. For instance, when raw seeds are too small, after cooking, the size slightly increases due to the amount of absorbed water. In their study, Barros & Helena (2016), working on seven common bean genotypes with very small size, realized, after cooking, small size for six genotypes and very small size for the remaining genotype.

Color and lightness or clear aspects of beans influence their attractiveness. This attribute is the primary signal for consumer choice (Asiimwe *et al*., 2024). According to Barros & Helena (2016), consumers prefer lighter colored beans because they relate lighter and clear aspect to starchiness and darker color to old and hard beans that require more cooking time. Most of biofortified genotypes had yellow and lighter seed coats; hence, most of cooked beans were preferred and appeared clear and slightly clear.

Sensory characteristics might have been affected by genotypes. Similar observations have been reported by Barros & Helena (2016) ; Bassett *et al*. (2017). In addition to genotypic influences, the seed type might be another factor affecting sensory characteristics. Bassett *et al*. (2017) reported that mottled/red speckled beans vary the most, while brown genotypes tend to vary the least. This might be due to the high level of polyphenolics, an aromatic compound, in red and purple seed coats as reported by Wu *et al*. (2004).

CONCLUSION AND RECOMMENDATIONS

This study demonstrated that second generation biofortified common bean genotypes in Eastern DRC combine superior agronomic performance with consumer preferred traits. Farmer participatory selection identified lines with higher pod numbers, while quality assessments confirmed shorter cooking times and acceptable sensory attributes. The strong negative correlation between hydration coefficient and cooking time further highlighted their efficiency in household food preparation.

Based on these findings, it is recommended that high performing biofortified genotypes be prioritized for dissemination and adoption in Eastern DRC to improve nutrition and reduce cooking fuel demand. Strengthening farmer led selection and integrating consumer preferences into breeding programs will accelerate acceptance and impact.

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Author's Contributions

RKK conceived and designed the study, coordinated the field experiments, and drafted the manuscript. PMK provided the biofortified bean genotypes and, together with KO, developed the experimental design and methodology for assessing quality and sensory parameters. LKS facilitated farmer engagement. Alain Katembo Sabuni and Patient Mumbere Mapendo assisted in data collection and coordinated farmer participatory selection. JSYE and IA supported statistical analyses and interpretation of results. Alongside PMK and KO, the latter co-authors provided critical revisions, and overall supervision. All authors read and approved the final manuscript.

Ethical Statement

This study was conducted in accordance with ethical standards for agricultural and food research. Farmer participation in variety selection and sensory evaluation was entirely voluntary, and informed consent was obtained prior to involvement. No personal identifiers were recorded, and data were analyzed and reported in aggregate to ensure confidentiality. The research involved only plant materials and did not include human or animal experimentation requiring institutional ethical clearance. All procedures adhered to the principles of fairness, transparency, and respect for participants.

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