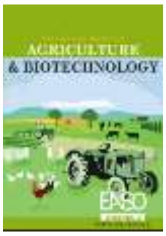


East African Journal of Agriculture and Biotechnology
eajab.eanso.org
Volume 7, Issue 2, 2024
p-ISSN: 2707-4293 | e-ISSN: 2707-4307
Title DOI: https://doi.org/10.37284/2707-4307

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

The Physical and Physiological Quality of Informal Seeds of Rwanda: Case of Common Bean (*Phaseolus Vulgaris L.*)

Felix Muhizi[1], Prof. Julius Onyango Ochuodho, PhD[2] & Dr. Lucas Ngode, PhD[2]*

[1] University of Rwanda, P. O. Box 210, Musanze, Rwanda
[2] University of Eldoret, P. O. Box 1125-30100, Eldoret, Kenya.
* Author for Correspondence Email: muhizi55felix@yahoo.com

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

Date Published:

14 October 2024

Keywords:

Common Bean, Seed, Seed Physical Quality, Seed Physiological Quality, Germination Test, Vigor Tests, Thousand Seed Weight, Informal Seeds, Southern Province of Rwanda.

ABSTRACT

This study was carried out at the laboratories of the Department of Seed, Crop, and Horticultural Sciences; School of Agriculture and Biotechnology; University of Eldoret, Kenya, on common bean seed samples collected in major growing areas' markets of the Southern Province of Rwanda, where informal seeds are predominant and with a varied physical and physiological seed quality. Therefore, we conducted this study to assess the physical and physiological quality of seeds in Rwanda's informal system through laboratory tests. The GenStat computer package was used to run data. The markets of Kamonyi, Muhanga, and Nyanza are sources of market common bean informal seed in the southern province of Rwanda. The physiological qualities were more in the sample M1E from Muhanga market, locally known as Shyushya, because this local variety proved to be the best to have better seeds that develop into normal plants (96.5%) and vigorous plants through first count and speed of germination with 95.5% and 26.11, respectively. This was also observed on the sample M2C from Nyanza that shares the same local name. Nyanza market had more physiological qualities than the others; its seeds grew more into normal plants (72.2%) and vigorous plants via first count and speed of germination with 63.3% and 21.68, respectively, than the others. Muhanga market had more good physical characteristics of seeds, with the highest mean of thousand seed weight (340.9 grams) and seed length (1.31 cm). The sample M2B, locally known as Mutiki, is a variety with the highest mean of thousand seed weights (446.1 grams), and this is common with other samples (M2B and M3A) locally known as Mutiki from other markets. This study revealed that the inform variety known as Shyushya is to be considered for agronomical purposes, while the formal variety locally known as Mutiki could be considered for market purposes. Nyanza market to be considered as the source of seeds for the agronomical aspects, while Muhanga market could be the source of seed for the grains of market.

APA CITATION

Muhizi, F., Ochuodho, J. O. & Ngode, L. (2024). The Physical and Physiological Quality of Informal Seeds of Rwanda: Case of Common Bean (*Phaseolus Vulgaris L.*). *East African Journal of Agriculture and Biotechnology*, *7*(2), 80-94. https://doi.org/10.37284/eajab.7.2.2300

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

CHICAGO CITATION

Muhizi, Felix, Julius Onyango Ochuodho and Lucas Ngode. 2024. "The Physical and Physiological Quality of Informal Seeds of Rwanda: Case of Common Bean (*Phaseolus Vulgaris L.*)". *East African Journal of Agriculture and Biotechnology* 7 (2), 80-94. https://doi.org/10.37284/eajab.7.2.2300

HARVARD CITATION

Muhizi, F., Ochuodho, J. O. & Ngode, L. (2024) "The Physical and Physiological Quality of Informal Seeds of Rwanda: Case of Common Bean (*Phaseolus Vulgaris L.*).", *East African Journal of Agriculture and Biotechnology*, 7(2), pp. 80-94. doi: 10.37284/eajab.7.2.2300.

IEEE CITATION

F. Muhizi, J. O. Ochuodho & L. Ngode "The Physical and Physiological Quality of Informal Seeds of Rwanda: Case of Common Bean (*Phaseolus Vulgaris L.*)", *EAJAB*, vol. 7, no. 2, pp. 80-94, Oct. 2024.

MLA CITATION

Muhizi, Felix, Julius Onyango Ochuodho & Lucas Ngode. "The Physical and Physiological Quality of Informal Seeds of Rwanda: Case of Common Bean (*Phaseolus Vulgaris L.*)". *East African Journal of Agriculture and Biotechnology*, Vol. 7, no. 2, Oct. 2024, pp. 80-94, doi:10.37284/eajab.7.2.2300

INTRODUCTION

In Rwanda, common bean is the most widely produced crop, with 80% of all households involved in crop cultivation. NISR (2023) reports that the Southern province accounts for 85% of the households who grow beans, followed by the Northern province (82%), and the Western province (72%). Higher agricultural yields can be achieved using seeds of superior quality that exhibit high germination rates, vigor, and genetic purity. Better seed quality has been shown to boost production by 15% to 20% or more, depending on the crop and environmental conditions. (FAO, 2018).

High-quality seeds frequently have characteristics that increase their resistance to biotic and abiotic challenges, such as pests, diseases, droughts, and high temperatures. Crops need to be resilient in order to continue producing even in the face of shifting environmental conditions (FAO, 2020). Good seeds enable farmers to operate more predictably and with greater crop stands, which makes management tasks like planting, fertilization, and pest control easier (Bullock, 2020).

Food security is directly impacted by the availability of high-quality seeds, which guarantee steady and adequate food production both locally and worldwide (Huffman *et al*., 2017). Long-term benefits of investing in premium seeds include higher yields and fewer input costs for crop protection and maintenance (FAO, 2020).

Maize, soybeans, and wheat are the only three primary crops grown by farmers in Rwanda that are covered by the seed subsidy program. As a result, farmers who grow crops not covered by the seed subsidy program are unable to obtain improved certified seeds (IRDP, 2020). According to NISR (2021) data, 44.6% of Rwandan farming families used certified seeds. Of the many agricultural varieties, maize (61.1 percent), beans (1.4 percent), vegetables (23.5 percent), paddy rice (44.7 percent), wheat (29.6 percent), and Irish potatoes (3.4 percent) were the most common crops planted with certified seeds.

According to Sperling and McGuire (2010), most households also don't grow enough seed to meet their needs, so they look for other ways to increase seed volume, replace low-quality seed, get seed that they can't grow or store well enough (such as many exotic vegetables or legumes), or acquire new varieties with desired traits. The informal system, sometimes called the traditional, local, or farmers' seed system, refers to the networks and techniques that farmers employ to control crop diversity on their properties and acquire seed through their own production, farmer-to-farmer exchanges, and local markets. One important medium via which these behaviors are mediated are social norms and regulations that have evolved over time and are intricately linked to local cultures and customs (Louwaars & de Boef, 2012). Informal seed systems comprise methods used by farmers for producing, dispersing, and selecting seeds in addition to seed exchange (Ricciardi, 2015).

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

The seed quality that is traded within this system varies in terms of both physical purity and physiological characteristics. Furthermore, post-harvest handling procedures in informal systems are not often clear (Hlatshwayo, 2021). The informal seed system is often characterized by the lack of a legal certification required for the quality (germination rate, identity, etc.) of the seed distributed or exchanged (Sisay *et al*., 2017). This presents a challenge.

Since only 1.4% of farmers have access to certified seed and bean seeds are not covered by the subsidy scheme, it is unknown what quality of seed most farmers use. Thus, the objective of this study was to determine the physiological and physical characteristics of common bean seeds obtained from various marketplaces in Rwanda's southern province and to identify the market that offered higher-quality common bean seeds.

MATERIALS AND METHODS

Description of the study area

This study was carried out at the laboratories of the Department of Seed, Crop, and Horticultural Sciences; School of Agriculture and Biotechnology; University of Eldoret, Kenya. Common bean seed samples were collected in major growing areas' markets of the Southern Province of Rwanda, namely Kamonyi, Muhanga, and Nyanza. The Kamonyi district, which has 317 villages, 59 cells, and 12 sectors, is situated in Rwanda's southern province. Kamonyi is 655.5 km2 in size and home to 450,849 people. Apart from HarvestPlus's iron bean seed sales, Kamonyi was one of the six districts in the nation to implement an experimental seed payback system. Muhanga is a district of the Southern Province consisting of 12 sectors, 63 cells, and 331 villages. Muhanga District is 647.7 km² in size and home to 378,760 people. Another district in Rwanda's Southern Province is called Nyanza; it has 420 villages, 51 cells, and 10 sectors. It covers 671.2 km2 and is home to 365,718 people. The 5th Population and Housing Census results show that private households in the Nyanza area grow more beans than any other crop. Households that work in agriculture may be found in the following rural sectors of the Nyanza district: Busasamana, Busoro, Cyabakamyi, Kibilizi, Kigoma, Mukingo, Muyira, Ntyazo, Nyagisozi, and Rwabicuma (NISR, 2023).

Determination of physiological quality

Standard seed germination

The germination test was conducted by following the procedures outlined by ISTA (2020) where pure seed component, separated during purity analysis on all seed samples collected from both markets of Kamonyi, Muhanga and Nyanza were used and germinated using sand medium in Complete Randomized Design. Four replicates of 100 seeds each were germinated in germination chamber (growth room) set at 25^0 C and 70 humidity for seven days. The final count was carried out on the seventh day after planting respectively (ISTA, 2020). On the final day of germination test, seedlings were evaluated into normal seedlings, abnormal seedlings, dead seeds and hard seed to calculate the percentage of each. The number of germinated seed in each replication was counted and based on the mean values of germinated seeds, the germination was calculated and expressed in percentage as follows:

$$Germination\ (\%) = \frac{Number\ of\ germinated\ seeds}{Number\ of\ seeds\ sown} \times 100$$

Seed vigour

First count of germination

The first count of germination test was conducted by following the procedures outlined by ISTA (2003), where pure seed components, separated during purity analysis on all seed samples, were used and germinated using sand medium in a complete randomized design. Four replicates of 100 seeds each were germinated in a germination chamber (growth room) set at 25^0 C and 70 humidity. The first count was conducted on the fourth day after planting (ISTA, 2003). The number of germinated seeds in each replication was counted, and the mean values of germinated seeds on the fourth day were computed.

Electro-conductivity test

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

The electroconductivity test was carried out on four replicates of twenty seeds, each obtained after mixing and dividing the pure seeds of the working sample. The twenty seeds in each replicate were soaked in 100 ml of distilled water for 24 hours, and readings from an automated electroconductivity meter were recorded and mean of replicates were calculated for each sample for both Formal and Informal seed systems.

Speed of germination test - type of vigour test

The speed of germination was used to assess the vigor index. Four hundred seeds were taken from each of the bean seed samples and divided into four replications, with each replica having 100 seeds. The seeds were germinated in the sand medium method of germination test and were kept in a growth room set at 25 °C and 70 % humidity for 7 days. The speed of germination was recorded daily, according to Maguire (1962). From the number of seeds germinated on each counting day up to the day of the final count (7^{th} day), the speed of germination was calculated by adopting the following formula and expressed in numbers.

$$Speed\ of\ germination = \frac{X_1}{Y_1} + \frac{(X_2 - X_1)}{Y_2} + \cdots + \frac{X_n - (X_{n-1})}{Y_n}$$

Where,

X_n- Number of seeds germinated at n^{th} count

Y_n- Number of days from sowing to n^{th} count

X_1– Number of seeds germinated at 1^{st} count

X_2– Number of seeds germinated at 2^{nd} count

Y_1– Number of days from sowing to 1^{st} count

Y_2– Number of days from sowing to 2^{nd} count

Determination of seedling characteristics

a) Shoot Length (cm)

Ten normal seedlings were selected at random from each replication of the standard germination test, and the shoot length was measured from the collar region to the tip of the primary leaf using a graduated ruler, and the mean values were calculated and expressed in centimeters.

b) Root Length (cm)

Ten normal seedlings were selected at random from each replication of the standard germination test, and the length of the root was measured from the collar region to the tip of the primary root using a graduated ruler, and the mean values were calculated and expressed in centimeters.

c) Vigor Dry weight (g 10 seedlings^{-1})

We placed ten randomly selected normal seedlings for seedling measurements in a small envelope, dried them under shade for 24 hours, and then dried them in a hot air oven that maintained a temperature of 85 ± 1^0 C for 72 hours. Then it was cooled in a dessicator for 30 minutes and weighed. The mean values were expressed as g 10 seedlings^{-1}. The formula used is as follows:

$$vigor\ dry\ weight = \frac{Seedling\ dry\ weight\ (grams)}{10\ normal\ seedlings} \times 100$$

d) Seedling Vigour Index

(Abdul – Baki and Anderson, 1973)

The vigor index was calculated by using the following formula suggested by Abul-Baki and Anderson (1973) and expressed in whole numbers.

$$Seedling\ Vigour\ Index = Standard\ germination\ (\%) \times Lenght\ of\ seedlings\ (Cm)$$

Determination of seed physical quality

Analysis of physical purity (Analytical purity)

Seed samples from both formal and informal seed systems were collected and reduced to a working sample, and only 750 gm seeds were used for laboratory tests. Each working sample was separated into three purity components, which included pure seeds, other crops seeds, and inert

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

matter (ISTA, 2020), and their weights were recorded for each replicate in each working sample. Each component was weighed on an analytical balance to the nearest two decimal places, and the percentage of each component was computed using the following formula:

$$Component\ (\%) = \frac{Weight\ of\ each\ component\ fraction}{Weight\ of\ total\ test\ sample} \times 100$$

Thousand seeds weight

The thousand seeds were counted in four replicates, and each replicate was randomly selected from pure seeds and was made of 250 seeds that were later rounded to a thousand by a multiplication of 4; weighed using a sensitive physical balance for each replication of all samples and expressed in grams.

A. Seed length

To measure the seed length, 40 seeds in four replicates were used. The replicates were randomly selected through mixing and dividing with the help of the soil divider from the pure seed component of each sample until 20 seeds, from which 10 seeds were again randomly selected, which made a replicate. The seed length was measured using a graduated ruler and expressed in centimeters.

B. Seed width

Forty seeds in four replicates were used to measure the seed width. The replicates were randomly selected through mixing and dividing with the help of the soil divider from the pure seed component of each sample until 20 seeds, from which 10 seeds were again randomly selected, which made a replicate. The seed width was measured using a graduated ruler and expressed in centimeters.

Statistical analysis

Analysis of variance (ANOVA) was employed to ascertain statistical differences among the measured parameters under various tests, with a confidence level of 5% using GENSTAT 14th edition. The mean separation was done using Fischer's Unprotected Least Significance difference mean separation at 5% confidence interval.

RESULTS AND DISCUSSION

Given that the minimum certification standard for Pure Seed of the bean-certified seeds class is 99%, the pure seed percentage of the samples of Mutiki (100%), and Shyushya (99.06%) from Muhanga market, Coltan (99.16%), and Mutiki (99.63%) from Nyanza market, and Inkundwa (99.07%) from Kamonyi market could qualify them as certified bean seeds and represents 31.25% of the total number of samples (Figure 1).

As a result, they do match the standards and account for 28.57% of all the seed samples. The samples Mutiki, and Shyushya from Muhanga market, Mutiki from Nyanza market, and Inkundwa from Kamonyi market were determined to contain Other Seed qualities with values of (0.0%) each, which is below the maximum permissible standard (Figure 1). A maximum of 0.05% is allowed to certify the attribute of Other Seed presence for the bean seeds certified class

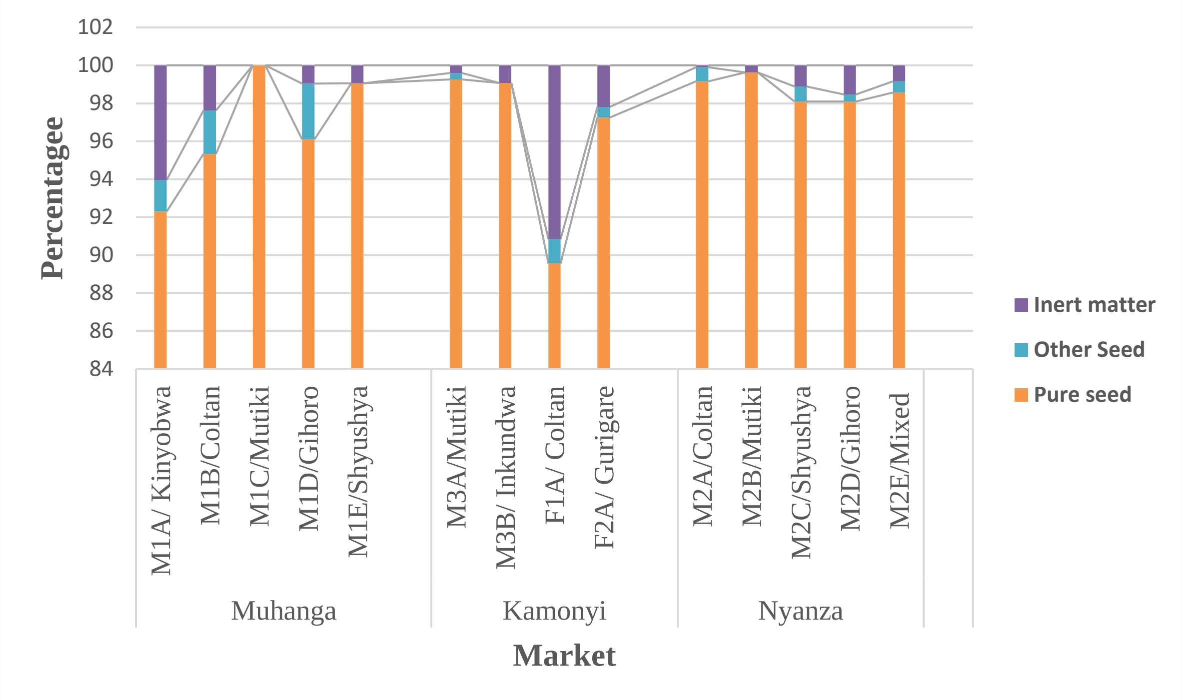
The proportion of inert matter in the samples Kinyobwa, Coltan, Gihoro from Muhanga market, Shyushya, Gihoro from Nyanza market, Mutiki, Coltan, and Gurigare from Kamonyi market was higher than the upper limit standard (0.95%) for the certified bean seeds (Figure 1). These samples make up 42.86% of all the collected seed samples.

Only Mutiki and Shyushya from Muhanga market, Mutiki from Nyanza market, and Inkundwa from Kamonyi market bean seed samples, or 28.57% of all the seed samples, meet the requirements for certified seed class status based on the three analytical purity test attributes. This suggests that there may be deficiencies in quality assurance procedures and a lack of rigorous quality control measures present in Formal systems.

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

It concurs with Ndinya *et al*. (2020), who emphasized that compared to informal seed systems, formal seed systems typically have stricter quality control procedures. This entails more stringent purity and other quality attribute testing.

Figure 1: Analytical purity of informal common bean seeds in the Southern province of Rwanda.



In comparison of all the markets, Muhanga had the highest grand mean of thousand seeds weight of 340.9 ± 54.39 g while the lowest grand mean was observed in Kamonyi with 288.9 ± 88.90 g. The weight of the thousand seeds varied between 189.3 ± 9.751 grams (Gurigare of Kamonyi market) and 446.1± 3.40 grams (Mutiki of Nyanza market) in the samples (Table 1). This could be because the genetic characteristics of the plant species have a significant influence on Thousand Seeds Weight. A species's Thousand Seeds Weight may vary naturally throughout its variations or cultivars. It concurs with Khan *et al*. (2022), who emphasized that Thousand Seeds Weight is greatly influenced by genetic diversity, with certain types generating noticeably heavier seeds than others.

Muhanga market of all the markets had longest seeds with a grand mean of 1.31 ± 0.18 cm while Kamonyi had the shortest seeds with grand mean of 1.10 ± 0.219 centimeters. These samples from informal seed system have a wider range of seed lengths (from 0.925 cm to 1.587 cm) (Table 1). This implies that there may be more variance in seed length since informal samples originate from a less regulated or inconsistent source. According to Brown and Hardner (2021), there may be noticeable variations in seed qualities because informal seed systems frequently preserve a greater diversity of crop varieties than formal seed systems. It is also in accordance with Gallego *et al*. (2020) who discovered that differences in seed length and other seed characteristics were caused by genetic variability among various rice cultivars.

Kinyobwa from Muhanga Market was the sample with the highest mean Seed Width (0.7875 ± 0.05 cm); Shyushya from Nyanza Market and Shyushya from Muhanga market were the samples with the lowest mean (0.6 ± 0.00 cm) (Table 1). The differences in seed width imply that there is variation in seed size within every sample category. Significant differences in seed size can result from genetic variability within plant populations, as demonstrated by Westoby *et al*. (2002). Jones and Smith (2015) found that variability in seed size can also be influenced by factors other than genetics and environment, such

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

as pollination dynamics and competition within plant communities.

Table 1: Physical characteristics of informal common bean seeds of different markets in the Southern province of Rwanda.

Markets	Samples	TSW (gram)	Seed length (cm)	Seed Width (cm)
Muhanga	M1A/ Kinyobwa	403.6 ± 7.01 d	1.225 ± 0.03 a	0.7875 ± 0.05 c
	M1B/Coltan	367.3 ± 20.53 c	1.188 ± 0.06 a	0.7 ± 0.00 b
	M1C/Mutiki	327.6 ± 17.33 b	1.587 ±0.12 c	0.7 ± 0.00 b
	M1D/Gihoro	354.3 ± 9.56 c	1.387 ± 0.12 b	0.6875 ± 0.03 b
	M1E/Shyushya	251.8 ± 25.34 a	1.15 ± 0.06 a	0.6 ± 0.00 a
	Grand mean	340.9 ± 54.39	1.31 ± 0.18	0.69 ± 0.064
	LSD p<0.05	26.15	0.128	0.036
	CV %	5.1	6.5	3.5
	e.s.e	8.67	0.042	0.012
	s.e.d	12.27	0.06	0.017
Kamonyi	M3A/Mutiki	387.5 ± 5.33 d	1.438 ± 0.11 b	0.7125 ± 0.03 b
	M3B/ Inkundwa	219.7± 14.08 b	1 ± 0.00 a	0.6125 ± 0.03 a
	F1A/ Coltan	359.2 ± 5.44 c	1.025 ± 0.06 a	0.7125 ± 0.10 b
	F2A/ Gurigare	189.3 ± 9.75 a	0.925 ± 0.09 a	0.6125 ± 0.03 a
	Grand mean	288.9 ± 88.90	1.10 ± 0.219	0.66 ± 0.07
	LSD p<0.05	14.44	0.123	0.086
	CV %	3.2	7.3	8.4
	e.s.e	4.68	0.04	0.028
	s.e.d	6.63	0.057	0.04
Nyanza	M2A/Coltan	368.5 ± 0.60 d	1.087 ± 0.06 a	0.637 ± 0.05 a
	M2B/Mutiki	446.1 ± 3.40 e	1.512 ± 0.03 d	0.775 ± 0.03 c
	M2C/Shyushya	239.4 ± 3.37 a	1.125 ± 0.05 ab	0.6 ± 0.00 a
	M2D/Gihoro	295 ± 5.72 c	1.163 ± 0.05 bc	0.7125 ± 0.05 b
	M2E/Mixed	269.1 ± 6.15 b	1.218 ± 0.05 c	0.64 ± 0.03 a
	Grand mean	323.62 ± 76.73	1.22 ± 0.162	0.67 ± 0.07
	LSD p<0.05	6.527	0.073	0.055
	CV %	1.3	4	5.4
	e.s.e	2.165	0.024	0.018
	s.e.d	3.062	0.034	0.026

Mean ± Standard deviation is shown. The values followed by same letters within each column are not significantly different at Fisher's protected least significant difference (5% level), LSD= Least Significance Difference, CV= Coefficient of Variation, e.s.e= Standard errors of means, s.e.d= Standard error of differences of means.

Muhanga market had the greatest mean of germination percentage of all the markets with 92.15±10.28 percent, while Kamonyi had the lowest mean with 70.4±28.83 percent. Mutiki from Kamonyi market had the greatest germination percentage of 100 ± 0.00 % and Inkundwa from Kamonyi market had the lowest with 28.5 ± 5.26 % (Table 2). These disparities may be due to the genetic variability, handling techniques, storage conditions, and seed production environments can all have an impact on variations in germination rates. It is consistent with Mdlalose *et al*. (2021), who stressed that seed viability can be greatly impacted by appropriate storage conditions. Higher germination percentages are typically retained by seeds that are stored in ideal conditions of cool, dry, and dark.

In comparison to the germination standard of the certified seed class of common bean of 90%, the samples INKUNDWA, COLTAN, and GURIGARE from Mugina market, KINYOBWA from Muhanga market, and COLTAN from

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

NYANZA, or 31.25% of Informal seed samples, could not meet the minimum germination standard and did not qualify for the certified seed class. The remaining samples (68.75%) of the Informal system qualified for the germination standard of the certified class of bean seeds (Table 2).

The highest mean percentage of normal seedlings, when comparing market, was observed to be from Nyanza market with 72.2±25.05 percent, while the lowest mean percentage was recorded in Kamonyi with 44.5±30.12 percent. Of the seed samples, Shyushya from Muhanga had the highest percentage of normal seedlings (96.5 ± 3.42 %), while Coltan from Kamonyi market had the lowest rate (15.75 ± 6.65 %) (Table 2). The origin and processing techniques of these seeds may have an impact on the greater normal seedlings rate observed in Shyushya from Muhanga market. On the other hand, substandard seed storage conditions or inadequate processing may have an impact on lesser-quality seeds, such as those in Coltan from Kamonyi market. It aligns with Wijewardana *et al*. (2019), who highlighted that the quality of seedlings and germination are greatly influenced by the seed source. For example, well-managed seed sources frequently exhibit greater vigor and consistency.

Kamonyi market was the source of the highest mean percentage of abnormal seedlings of the markets with 25.8±17.37 percent. The Coltan from Nyanza market seed sample had the highest mean percentage of abnormal seedlings across the Informal seed samples (53.25 ± 12.01 %), whereas the Shyushya from Muhanga market seed sample had the lowest mean percentage (1.5 ± 1.29 %) (Table 2). This may be due to genetic mutations, variations, quality of seed handling and processing can affect seedling development. It aligns Chhabra and Singh (2019), who highlighted that abnormal seedlings are more likely to occur when seeds are not properly stored and conditioned. It is consistent with Raina *et al*. (2021), who emphasized that mutations or genetic instability may increase the frequency of abnormal seedlings.

The greatest mean percentage of dead seed was observed in samples from Kamonyi market with 17.9±15.24 percent, while the lowest mean was recorded in Muhanga market with 7.50±10.25 percent. Sample Mutiki from Kamonyi market had the lowest percentage of dead seed (0 ± 0.00 %), whereas sample Inkundwa from Kamonyi market had the highest rate (31.25 ±3.78 %) (Table 2). Sample M3B has a serious problem with seed viability. Mutiki from Kamonyi market, an Informal sample, displays zero dead seeds. This specific sample indicates good seed quality and viability. High percentages of dead seeds may be a sign of improper handling, improper storage (high humidity, harsh temperatures, etc.), or aging of the seeds. Bad handling and storage habits accelerate the natural process of seed aging. As seeds lose their capacity to germinate with age, the percentage of dead seeds rises (Walters, C., 1998). It also aligns with ISTA (2020) which stipulated that there are guidelines to help keep seeds viable while they are being stored. These recommendations stress how crucial it is to regulate humidity and temperature to reduce seed degeneration and increase germination potential.

The samples Inkundwa and Coltan from Kamonyi market had the highest hard seeds with mean proportions of 40.25 ±.34 % and 6.25 ± 6.65 %, respectively (Table 2). Informal seeds could come from various locations or growth methods that alter the hardness of the seed, or they might be handled less carefully. It aligns with Dai *et al*. (2023), who highlighted that seed hardness is also influenced by environmental factors such as climate, soil type, and water availability. It is consistent with Zhong *et al*. (2018), who stressed that the overall quality and hardness of the seed coat can be greatly impacted by various seed processing techniques.

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

Table 2: Sand germination test and its evaluation of informal common bean seeds of different markets in the Southern Province of Rwanda.

Market	Samples	Germination (%)	Normal Seedling (%)	Abnormal Seedling (%)	Dead seed (%)	Hard seed (%)
Muhanga	M1A/ Kinyobwa	73.5±7.05 a	47±11.92 a	26.5±5.45 bc	26.25±7.04 b	0.25±0.50 a
	M1B/Coltan	97.75±3.30 b	54.75±25.40 a	43±22.70 c	1.5±1.92 a	0.75±1.50 a
	M1C/Mutiki	96.5±3.00 b	62.75±15.2 ab	33.75±12.37 bc	2.75±2.22 a	0.75±0.96 a
	M1D/Gihoro	95±2.71 b	81.25±15.35 bc	13.75±14.41 ab	5±2.71 a	0±0.00 a
	M1E/Shyushya	98±2.16 b	96.5 ± 3.42 c	1.5 ± 1.29 a	2±2.16 a	0±0.00 a
	Grand mean	92.15±10.28	68.5±23.30	23.7±19.21	7.50±10.25	0.35±0.81
	LSD p<0.05	6.088	23.97	20.3	5.646	1.246
	CV %	4.4	23.2	56.8	49.9	236.2
	e.s.e	2.02	7.95	6.73	1.873	0.413
	s.e.d	2.856	11.25	9.52	2.649	0.585
Kamonyi	M3A/Mutiki	100±0.00 d	68.25±10.81 b	31.5±10.47 b	0±0.00 a	0±0.00 a
	M3B/Inkundwa	28.5±5.26 a	17±5.83 a	11.5±7.85 a	31.25±3.78 b	40.25±8.34 b
	F1A/Coltan	63.25±6.80 b	15.75±6.65 a	47.5±11.39 c	30.5±13.33 b	6.25±6.65 a
	F2A/Gurigare	89.75±2.36 c	77±8.29 b	12.75±6.08 a	9.75±2.06 a	0.5±1.00 a
	Grand mean	70.4±28.83	44.5±30.12	25.8±17.37	17.9±15.24	11.8±17.84
	LSD p<0.05	6.87	12.51	14.16	10.79	8.25
	CV %	6.3	18.3	35.6	39.2	45.6
	e.s.e	2.23	4.06	4.6	3.5	2.68
	s.e.d	3.15	5.74	6.5	4.95	3.79
Nyanza	M2A/Coltan	81.5±3.11 a	28.25±11.93 a	53.25±12.01 b	18.5±3.11 c	0±0.00 a
	M2B/Mutiki	94.75±3.86 bc	83.5±4.44 b	11.25±3.78 a	5±3.92 ab	0.25±0.5 a
	M2C/Shyushya	98.25±2.36 c	92±4.39 b	6.25±3.30 a	1.75±2.36 a	0±0.00 a
	M2D/Gihoro	91.25±8.38 b	78±18.85 b	13.25±11.32 a	8.75±8.38 b	0±0.00 a
	M2E/Mixed	90±1.83 b	79.25±7.68 b	10.75±7.32 a	10±1.83 b	0±0.00a
	Grand mean	91.2±7.04	72.2±25.05	18.9±19.25	8.8±7.08	0.05±0.22
	LSD p<0.05	6.87	16.45	12.63	6.88	0.337
	CV %	5	15.1	44.2	51.9	447.2
	e.s.e	2.28	5.46	4.19	2.28	0.1118
	s.e.d	3.22	7.72	5.93	3.23	0.1581

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

Mean ± Standard deviation is shown. The values followed by same letters within each column are not significantly different at Fisher's protected least significant difference (5% level), LSD= Least Significance Difference, CV= Coefficient of Variation, e.s.e= Standard errors of means, s.e.d= Standard error of differences of means.

Nyanza was the market with the common bean seed samples with the highest mean percentage of the first count of germination with 63.3 ± 21.04 percent and Kamonyi the lowest with 45.31 ± 15.59 percent. Sample wise for the first count of germination, Shyushya from Muhanga Market had the greatest rate of 95.5 ± 3.32 %, respectively, and Inkundwa from Kamonyi market had the lowest percentage of 25.5 ± 7.42 % (Table 3). Greater percentages of first count of germination indicate higher quality and viability of the seed. Various factors, including storage conditions, seed age, genetic variability within varieties, and variations in seed treatment techniques, may impact variability. It is in accordance with the findings of Han *et al*. (2015) that genetic variation between different seed kinds can result in variations in germination rates and seed quality—genetic features affecting seed vigor, dormancy, and general viability impact this variability. It also aligns with Bewley & Black (2013) who stated that the germination rates of seeds can be impacted by their age because seeds naturally deteriorate with age. Compared to newly obtained seeds, older seeds may have poorer viability and slower germination.

Coltan from Kamonyi market had the highest mean electro-conductivity (0.5475 ± 0.09), whereas Mutiki from Kamonyi market had the lowest mean (0.26 ± 0.07). Shyushya from Muhanga market exhibited the highest percentage of speed of germination (26.11 ± 0.94) among the seed samples, whereas Inkundwa from Kamonyi market had the lowest rate (7.37 ± 1.59) (Table 3). The differences in the speed of germination percentages between seed samples suggest varying characteristics in seed vigor and initial growth rates. To achieve consistent and timely crop establishment, it is crucial to assess and select high-quality seeds, as evidenced by the wide range of germination percentages found in both official and informal samples.

Table 3: The vigor quality distribution of informal common bean seeds of different markets of the Southern Province of Rwanda.

Markets	Samples	1st Count (%)	EC	Germ Speed
Muhanga	M1A/ Kinyobwa	38.5 ± 11.96 a	0.4225 ± 0.04 b	16.32 ± 1.53 a
	M1B/Coltan	47.25 ± 7.37 a	0.3775 ± 0.04 b	21.76 ± 0.89 b
	M1C/Mutiki	39.25 ± 15.63 a	0.42 ± 0.01 b	21.26 ± 1.27 b
	M1D/Gihoro	75.25 ± 8.06 b	0.2875 ± 0.09 a	22.72 ± 1.41 b
	M1E/Shyushya	95.5 ± 3.32 c	0.27 ± 0.01 a	26.11 ± 0.94 c
	Grand mean	59.15 ± 24.85	0.36 ± 0.08	21.63 ± 3.42
	LSD p<0.05	15.33	0.073	1.859
	CV %	17.2	13.7	5.7
	e.s.e	5.09	0.024	0.617
	s.e.d	7.19	0.034	1.859
Kamonyi	M3A/Mutiki	55.5 ± 4.66 c	0.26 ± 0.07 a	23.03 ± 0.43 d
	M3B/ Inkundwa	25.5 ± 7.42 a	0.3025 ± 0.02 a	7.37 ± 1.59 a
	F1A/ Coltan	40.75 ± 2.50 b	0.5475 ± 0.09 b	14.3 ± 1.05 b
	F2A/ Gurigare	59.5 ± 13.23 c	0.2925 ± 0.03 a	20.41 ± 1.57 c
	Grand mean	45.31 ± 15.59	0.35 ± 0.13	16.28 ± 6.34
	LSD p<0.05	12.37	0.091	1.934
	CV %	17.7	16.8	7.7
	e.s.e	4.01	0.03	0.628
	s.e.d	5.68	0.042	0.887
Nyanza	M2A/Coltan	48.5 ± 8.85 b	0.38 ± 0.043 d	18.6 ± 0.84 a
	M2B/Mutiki	35.75 ± 6.55 a	0.3725 ± 0.03 cd	20.44 ± 1.04 ab

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

Markets	Samples	1st Count (%)	EC	Germ Speed
	M2C/Shyushya	84.5 ± 3.69 d	0.29 ± 0.05 ab	24.12 ± 0.69 c
	M2D/Gihoro	63.75 ± 13.50 c	0.275 ± 0.01 a	21.27 ± 2.59 b
	M2E/Mixed	84 ± 3.37 d	0.325 ± 0.017 bc	23.95 ± 0.81 c
	Grand mean	63.3 ± 21.04	0.33 ± 0.052	21.68 ± 2.49
	LSD p<0.05	12.22	0.049	2.092
	CV %	12.8	9.8	6.4
	e.s.e	4.05	0.016	0.694
	s.e.d	5.73	0.023	0.982

Mean ± Standard deviation is shown. The values followed by same letters within each column are not significantly different at Fisher's protected least significant difference (5% level), LSD= Least Significance Difference, CV= Coefficient of Variation, e.s.e= Standard errors of means, s.e.d= Standard error of differences of means.

In comparison, Kinyobwa from Muhanga market had the lowest mean (6.43 ± 1.14 cm) and Mutiki from Kamonyi market had the greatest mean (13.45 ± 1.20 cm) Root Length sample (Table 4). Informal seeds—which may originate from less regulated settings—exhibited greater variation in root length under various circumstances. The variation in mean root lengths between Kinyobwa from Muhanga market and Inkundwa from Kamonyi market indicates this diversity. It is in accordance with De Haan and Treuren (2015) who found that informal seeds obtained from less regulated environments frequently show more variation in root length under various circumstances. Different genetic backgrounds and different environmental conditions impacting seed development can be linked to this heterogeneity.

Shyushya from Nyanza market had the largest shoot length of 24.41 ± 1.53 centimeters, while Coltan from Muhanga market had the smallest, measuring 10.11 ± 2.45 centimeters, for the informal seed samples (Table 4). The large variation in shoot lengths between the groups suggests that each group's growth potential differs. This variety may be caused by genetic variation, environmental factors, and perhaps distinct seed sources or treatments. It concurs with Myles (2019), who found that growth capacity within plant groups is largely determined by genetic variation. Differences in features like shoot length can result from different genetic backgrounds. It also aligns with Crisp *et al*. (2019) who stated that variability in shoot lengths and other growth parameters can also result from the origin of the seeds (geographical location, parent plants), as well as from various treatments (fertilization regimes, growing circumstances).

Nyanza market had samples with the highest mean percentage of vigor dry weight of 21.17 ± 5.832 grams. Between the seed samples, Mutiki from Kamonyi market had the highest Vigor Dry Weight (26.94 ± 2.36 grams), whereas Inkundwa of the same market had the lowest (15.77 ± 3.99 grams) (Table 4). This implies that, compared to the other seeds, Mutiki from Kamonyi market seeds have a comparatively high vigor. Of all the seed samples, Inkundwa from Kamonyi market has the lowest vigor dry weight and it suggests weaker vigor than the other samples. The vigor of seedlings depends on the quality of the seed. The quality of seeds is determined by various factors, including seed size, physiological maturity, genetic purity, and storage conditions. Better seed quality usually produces stronger seedlings with faster early growth (Walters *et al*., 2005).

A large portion of seedling vigor is determined by genetic variables. Due to genetic differences, different plant kinds display differing degrees of vigor. Vigor-based breeding has been demonstrated to improve crop output overall and seedling establishment (Sattler et al., 2014).

Compared to the other seed samples, Shyushya from Nyanza market had the greatest Vigor Index (37.05 ± 3.42) and Inkundwa from Kamonyi market the lowest (8.62 ± 2.24) (Table 4).

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

The emergence and early growth of seedlings are significantly influenced by environmental conditions during planting, including soil moisture, temperature, and seed depth. According to Finch-Savage and Bassel (2016), ideal planting circumstances encourage quick and even germination, which increases the vitality of the seedlings.

The values of the Vigor Index offer important information about the condition and possible performance of the seeds. Seeds with higher Vigor Index values have a higher chance of germinating well, establishing swiftly, and withstanding environmental challenges. Lower Vigor Index readings, on the other hand, indicate seeds that can have trouble germinating or establishing.

Table 4: The seedling characteristics of informal common bean seeds from different markets of the Southern province of Rwanda.

Markets	Samples	Root length (cm)	Shoot length (cm)	Dry vigor weight (grams)	Vigor index
Muhanga	M1A/ Kinyobwa	6.43 ± 1.14 a	19.53 ± 1.22 bc	19.81 ± 2.37 ab	19.09 ± 2.04 a
	M1B/Coltan	9.14 ± 1.46 b	10.11 ± 2.45 a	23.42 ± 2.58 b	18.85 ± 3.99 a
	M1C/Mutiki	11.73 ± 1.01 c	18.37 ± 1.96 b	22.61 ± 1.14 b	29.05 ± 2.21 b
	M1D/Gihoro	7.58 ± 0.68 ab	20.76 ± 0.70 bc	17.07 ± 3.68 a	26.93 ± 1.46 b
	M1E/Shyushya	11.8 ± 1.38 c	21.64 ± 1.23 c	17.98 ± 2.33 a	32.77 ± 1.24 c
	Grand mean	9.34 ± 2.45	18.08 ± 4.49	20.18 ± 3.42	25.34 ± 6.06
	LSD p<0.05	1.76	2.463	3.845	3.606
	CV %	12.5	9	12.6	9.4
	e.s.e	0.584	0.817	1.276	1.196
	s.e.d	0.826	1.156	1.804	1.692
Kamonyi	M3A/Mutiki	13.45 ± 1.20 c	13.91 ± 1.49 a	26.94 ± 2.36 b	27.36 ± 2.24 c
	M3B/ Inkundwa	10.81 ± 0.39 b	19.16 ± 2.03 c	15.77 ± 3.99 a	8.62 ± 2.24 a
	F1A/ Coltan	7.65 ± 0.52 a	16.57 ± 0.48 b	18.83 ± 4.29 a	15.33 ± 1.85 b
	F2A/ Gurigare	9.32 ± 2.15 ab	20.55 ± 0.89 c	21.29 ± 5.22 ab	26.82 ± 1.72 c
	Grand mean	10.31 ± 2.48	17.55 ± 2.89	20.71 ± 5.59	19.53 ± 8.382
	LSD p<0.05	1.963	2.09	6.314	3.121
	CV %	12.4	7.7	19.8	10.4
	e.s.e	0.637	0.678	2.049	1.013
	s.e.d	0.901	0.959	2.898	1.433
Nyanza	M2A/Coltan	8.08 ± 1.59 a	18.88 ± 1.31 a	19.7 ± 4.28 ab	22 ± 2.28 a
	M2B/Mutiki	11.16 ± 1.16 bc	19.19 ± 0.29 a	18.7 ± 0.37 ab	28.75 ± 1.59 bc
	M2C/Shyushya	13.3 ± 1.86 c	24.41 ± 1.53 b	25.45 ± 8.04 b	37.05 ± 3.42 d
	M2D/Gihoro	10.34 ± 1.41 ab	23.68 ± 1.86 b	25.87 ± 5.78 b	30.95 ± 2.16 c
	M2E/Mixed	9.48 ± 1.75 ab	19.11 ± 1.96 a	16.14 ± 0.67 a	25.69 ± 2.61 ab
	Grand mean	10.47 ± 2.273	21.05 ± 2.855	21.17 ± 5.832	28.89 ± 5.652
	LSD p<0.05	2.374	2.279	7.284	3.745
	CV %	15	7.2	22.8	8.6
	e.s.e	0.788	0.756	2.417	1.242
	s.e.d	1.114	1.069	3.418	1.757

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

Mean ± Standard deviation is shown. The values followed by same letters within each column are not significantly different at Fisher's protected least significant difference (5% level), LSD= Least Significance Difference, CV= Coefficient of Variation, e.s.e= Standard errors of means, s.e.d= Standard error of differences of means.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

This study concludes that Nyanza markets offer greater physiological and agronomic benefits than other markets because the seeds have a high chance of developing into vigorous plants (first count, speed of germination with 63.3 ± 21.04% and 21.68 ± 2.49, respectively) and normal plants (72.2 ± 25.05%). The sample locally known as Shyushya from Muhanga Market, exhibits both physiological and agronomical benefits. This local variety was found to be the best in terms of having better seeds that would develop into both normal plants (96.5 ± 3.42%) and vigorous plants (first count and speed of germination with 95.5 ± 3.32 % and 26.11 ± 0.94, respectively). The sample Shyushya from Nyanza, which also has the same local name, also exhibits these benefits.

The Muhanga market has a higher concentration of seeds with strong physical qualities, as evidenced by the thousand seed weight (340.9 ± 54.39 grams) and seed length (1.31 ± 0.18 cm). The sample Mutiki from Nyanza market, has the highest weight (446.1 ± 3.40 grams). It is shared with two additional samples from other marketplaces that are also locally known as Mutiki but weigh more than others. In comparison to other markets, the Kamonyi market's seeds exhibit poor physical and physiological features, despite sample Coltan (M3A) showing the greatest germination%.

Recommendations

The seed dealers in the markets of the southern province of Rwanda need to practice the minimum seed sorting before selling the seeds.

The locally known variety as Shyushya, which is an informal seed, should be considered for agronomical purposes, while the variety locally known as Mutiki, a formal seed, should be considered for market purposes.

Nyaza market should be considered as the source of seeds in the agronomical aspect, while Muhanga market could be the seed source for the market of grains. The Kamonyi seeds and the practices of seed handling and storage should be revised and improved as their seeds are physically and physiologically poor.

REFERENCES

Abdul- Baki, A.A and J.D. Anderson. 1973. Vigour determination in Soyabean seed by multiple criteria. *Crop Sci., 13:* 630- 633.

Bewley, J. D., & Black, M. (Eds.). (2013). *Seeds: Physiology of development, germination and dormancy* (3rd ed.). Springer Science & Business Media.

Brown, A. H. D., & Hardner, C. M. (2021). Improving plant genetic resources. In J. Janick (Ed.), *Plant Breeding Reviews, 44* (pp. 43-76). Wiley.

Bullock, D. S. (2020). The importance of high-quality seed for farmers. *CropWatch*. University of Nebraska-Lincoln. https://cropwatch.unl.edu/2020/importance-high-quality-seed-farmers

Chhabra, R., & Singh, T. (2019). Seed aging, storage, and deterioration: An irresistible physiological phenomenon. *Agricultural Reviews, 40*(3), 234-238.

Crisp, P. A., et al. (2019). Reconsidering plant memory: Intersections between stress recovery, RNA turnover, and epigenetics. *Science Advances*, *5*(8), eaax2301. https://doi.org/10.1126/sciadv.aax2301

Dai, L., Chen, Y., & Wei, X. (2023). Hard seed characteristics and seed vigor of *Ormosia hosiei*. *Agriculture*, *13*(5), 1077. https://doi.org/10.3390/agriculture13051077

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

De Haan, S., & van Treuren, R. (2015). On-farm management of plant genetic resources - Concepts and practices. In M. Jackson, B. Ford-Lloyd, & M. L. Parry (Eds.), *Plant Genetic Resources and Climate Change* (pp. 1- 16). CABI. https://doi.org/10.1079/9781780645144.0000

FAO. (2018). *Seed policies and regulations: A literature review*. FAO Seed Policies.

FAO. (2020d). *Why are seeds important for food security?* http://www.fao.org/news/story/en/item/1242328/icode/

Finch-Savage, W. E., & Bassel, G. W. (2016). Seed vigour and crop establishment: Extending performance beyond adaptation. *Journal of Experimental Botany, 67*(3), 567-591. https://doi.org/10.1093/jxb/erv490

Gallego, P., et al. (2020). Genetic diversity and population structure analysis to construct a core collection from a large *Capsicum* germplasm. *Scientia Horticulturae, 265*, 109195. https://doi.org/10.1016/j.scienta.2020.109195

Han, J., Shi, J., Zhao, L., & Dong, X. (2015). Genetic and epigenetic control of plant seed performance. *Science China Life Sciences, 58*(3), 220- 225. https://doi.org/10.1007/s11427-015-4844-7

Hlatshwayo, S. I., Modi, A. T., Hlahla, S., Ngidi, M., & Mabhaudhi, T. (2021). Usefulness of seed systems for reviving smallholder agriculture: A South African perspective. *African Journal of Food, Agriculture, Nutrition and Development*, *21*(2), 17581-17603.

Huffman, W. E., Rousu, M. C., & Shogren, J. F. (2017). *The economics of food: How farming affects our health and environment*. Pearson Education.

International Seed Testing Association (ISTA). (2020). *International rules for seed testing*. https://www.seedtest.org/upload/cms/user/ISTA_Rules_2020.pdf

IRDP (Institute of Research and Dialogue for Peace) (2020). Determinants of inorganic fertilisers and improved seeds along with extension services support for agricultural productivity in Rwanda. Final Policy issues and Recommendations.

Jones, A. B., & Smith, C. D. (2015). The role of intra- and inter-specific competition in regulating seed size variability in *Trifolium repens*. *Journal of Ecology, 103*(4), 934-942. https://doi.org/10.1111/1365-2745.12411

Khan, A. M., Fayyaz, L., Din, R. U., Ali, S., Din, I. U., Ahmad, S., & Ahmad, I. (2022). Genetic variability among rapeseed (*B. napus* L.) genotypes for seed-yield and seed-quality traits. *Sarhad Journal of Agriculture, 38*(1), 68-75.

Louwaars N.P., & de Boef W.S. (2012). Integrated seed sector development in Africa: A conceptual framework for creating coherence between practices, programs, and policies. *J. Crop Improvement*, *26*, 39–59.

Maguire, J.D. 1962. Speed of Germination. Aid in Selection and evaluation of seedling emergence and vigour. *Crop Sci.*, 2: 176-177.

Mdlalose, S., Workneh, T., Sibanda, S., & Laing, M. (2021). Evaluation of a seed storage facility in relation to preserving seed moisture, vigour, and germination. *African Journal of Food, Agriculture, Nutrition and Development*, *21*(7), 18368-18390.

Myles, S. (2019). Understanding genetic variation. *Nature Reviews Genetics, 20*(7), 361-372. https://doi.org/10.1038/s41576-019-0111-8

National Institute of Statistics of Rwanda (NISR), (2021). Agricultural Household Survey 2020 report.

National Institute of Statistics of Rwanda (NISR); (2023). The Fifth Rwanda Population and Housing Census, Main Indicators Report.

Ndinya, C., Dinssa, F., Simon, J. E., Nyabinda, N., Maiyo, N., Weller, S., & Makete, N.

Article DOI : https://doi.org/10.37284/eajab.7.2.2300

(2020). Assessment of seed quality of selected African leafy vegetables produced in western Kenya using informal and semi-formal seed systems. *Journal of Medicinally Active Plants, 9*(4).

Raina, A., Sahu, P. K., Laskar, R. A., Rajora, N., Sao, R., Khan, S., & Ganai, R. A. (2021). Mechanisms of genome maintenance in plants: Playing it safe with breaks and bumps. *Frontiers in Genetics, 12*, 675686.

Ricciardi, V. (2015). Social seed networks: Identifying central farmers for equitable seed access. *Agricultural systems*, *139*, 110-121.

Sattler, S. E., Gilliland, L. U., Magallanes-Lundback, M., Pollard, M., & DellaPenna, D. (2014). Vitamin E is essential for seed longevity and for preventing lipid peroxidation during germination. *The Plant Cell*, *16*(6), 1419-1432.

Sisay, D. T., Verhees, F. J. H. M., & van Trijp, H. C. M. (2017). Seed producer cooperatives in the Ethiopian seed sector and their role in seed supply improvement: A review. *Journal of Crop Improvement*, *31*(3), 323–355. https://doi.org/10.1080/15427528.2017.1303800

Sperling L., & McGuire S. (2010). Understanding and strengthening informal seed markets. Exp. Agric. 46, 119–136.

Walters, C. (1998). Understanding the mechanisms and kinetics of seed aging. *Seed Science Research, 8*(3), 223-244.

Walters, C., Wheeler, L. M., Grotenhuis, J. M., & Jorritsma-Wienk, L. D. (2005). Longevity of seeds stored in a genebank: Species characteristics. *Seed Science Research, 15*(1), 1-20.

Westoby, M., Leishman, M., & Lord, J. (2002). Comparative ecology of seed size and dispersal. *Philosophical Transactions of the Royal Society B: Biological Sciences, 357*(1425), 1309- 1321. https://doi.org/10.1098/rstb.2002.1039

Wijewardana, C., Reddy, K. R., Krutz, L. J., Gao, W., & Bellaloui, N. (2019). Drought stress has transgenerational effects on soybean seed germination and seedling vigor. *PLOS ONE, 14*(9), e0214977. https://doi.org/10.1371/journal.pone.0214977

Zhong, L., Fang, Z., Wahlqvist, M. L., Wu, G., Hodgson, J. M., & Johnson, S. K. (2018). Seed coats of pulses as a food ingredient: Characterization, processing, and applications. *Trends in Food Science & Technology*, *80*, 35-42.

