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Yield Assessment and Responsiveness of Shallot (*Allium cepa ascalonicum* L.) Landraces to Storability Relevant Traits in a Controlled Environment in Mali

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Abstract

Shallots (*Allium cepa ascalonicum* L.) are an important crop primarily due to their likely culinary and economic value. However, its production comes with specific challenges. In addition, effective post-harvest management is critical to ensure the quality and availability of shallot bulbs for extended periods. This study assessed the yield performance and storability relevant traits of five shallot cultivars (Saboula Jaba, Espagne Jaba, Daou Jaba, Tata Jaba, and N'galamandjan Jaba) under controlled storage conditions. Field experiments were conducted in 2021 to evaluate growth and yield in terms of bulb quantity, size, and weight. Storability traits such as firmness, weight loss, and Total Soluble Solids (TSS) were also measured for each entry. The five ecotypes of shallots were evaluated on-station with a total rainfall of 810 mm in 2021. The results revealed statistically significant variations ($p > 0.01$) in storability traits and yield among the tested entries. Furthermore, the weight loss of stored bulbs varied, indicating genetic differences among the cultivars that can influence their moisture retention abilities, leading to differences in weight loss rates. Indeed, Daou jaba showed less weight loss and superior firmness. The top highest-ranking entry for yield was shown by N'galamandjan jaba with 40 T/ha, followed by Saboula jaba with 39 T/ha. These highest productivity entries also showed significantly higher bulb quantity and individual bulb size. While there was a significant correlation between weight loss and firmness, a correlation between weight loss and TSS was also observed. The weight loss and firmness of N'galamandjan jaba were significantly correlated ($r = 0.52$) on the one hand, and on the other hand, the weight loss and visual quality of Espagne Jaba were highly and significantly correlated (r = 0.69). N'galamandjan Jaba and Saboula Jaba can be used to improve the yield and the storability relevant traits and prevent post-harvest losses.

Keywords

Horticulture, Productivity, Post-Harvest Management, Bulbs Losses, Mali

1. Introduction

Shallot (*Allium cepa ascalonicum L.*) is a widely cultivated vegetable belonging to the Alliaceae family [1]. It is a close relative of the common onion (*Allium cepa*) but is characterized by its smaller bulbs arranged in clusters. Shallots are known for their distinctive flavor and culinary uses, contributing to the rich diversity of regional cuisines worldwide [2].

Agriculture is highly dependent on weather conditions, and Mali, like many other countries, faces challenges related to unpredictable climate patterns, droughts, or excessive rainfall, affecting shallot production [3]. Post-harvest management of shallots faces several significant challenges that impact their economic value and marketability. Shallots have a high moisture content, making them susceptible to dehydration during storage. Poor storage conditions can lead to accelerated weight loss, which diminishes quality and market value.

Improper temperature and humidity levels can trigger sprouting in shallots. [4]

Major challenges that impact the shallot's success include limited access to modern agricultural technologies and inadequate infrastructure, which may hinder efficient shallot cultivation, storage, and transportation [5]. Also, shallot crops are susceptible to various pests and diseases, as well as various fungal infections that cause decay and rot, especially if they are stored in damp conditions. The use of fungicides during both the planting and storage phases has been shown to significantly reduce losses due to rot [6]. Therefore, farmers need proper knowledge, resources, and good agriculture practices to implement effective pest and disease management practices [7]. To enhance the storability of shallots and mitigate post-harvest losses, several strategies can be implemented. Conduct training sessions for farmers on best practices for harvesting, curing, and storing shallots. Emphasizing the importance of removing damaged bulbs before storage can significantly reduce overall losses. Establish a routine for checking temperature and humidity levels within storage facilities. This proactive approach can help prevent conditions that lead to sprouting or decay [8].

Shallot cultivation can offer farmers an opportunity to diversify their income sources, especially if they integrate it with other crops or agricultural activities. If shallot production can meet quality standards, there may be export opportunities, contributing to economic growth and providing better returns for farmers. Adding value to shallot products through processing, packaging, and branding can enhance their market value, opening up new avenues for profit [9].

In Mali, shallot yields generally range from 5 to 15 tons per hectare [10], which is much lower than the potential yield of shallot. In addition, physical damage and moisture evaporation are critical factors in the cultivation of shallots, influencing their economic value and marketability [11]. Landraces, locally adapted varieties developed through traditional farming practices, play a significant role in shallot cultivation. Different varieties of shallots exhibit varying rates of weight loss due to inherent genetic traits. Some cultivars may have thicker skins or higher moisture content, which can influence their susceptibility to dehydration and spoilage

Temperature and humidity play a crucial role in weight loss. Higher temperatures accelerate metabolic processes and moisture evaporation, leading to increased weight loss. Relative humidity significantly affects moisture retention in stored shallots [12].

Understanding the responsiveness of shallot landraces to storability-relevant traits is essential for sustainable agriculture and food security. This study assessed the shallot bulb yield and the storability of relevant traits under a controlled environment.

2. Methodology

2.1. Plant Material

The genetic material was composed of five landraces of shallot, namely Saboula Jaba, Tata Jaba, Espagne Jaba, Daou Jaba, and N'Galaman Jaba. **Table 1** shows the characteristics of these landraces.

Table 1. Characteristics of the five landraces.

Genotype	Origin	Cycle	Color	Nb. of bulbs	Storability
Saboula Jaba	Mali	90	Red	2	high
Tata Jaba	Mali	90	Yellow	2	Low
Espagne Jaba	Mali	90	Golden	2	Low
Daou Jaba	Mali	90	Deep Yellow	2	Medium
N'Galaman Jaba	Mali	90	Golden	2	Medium

2.2. Site and Experimental Design

The assessment was carried out during the 2021 rainy season in Mali, with an annual rainfall of 810 mm, specifically in one environment at the World Vegetable Center experimental station at Samanko. This station features clay soil, which is nutrient-rich and has high water retention capacity but can be difficult to work with, especially when dry. The average temperature at the site is 27.7˚C. **Figure 1** illustrates the location of the experimentation site and the general distribution of rainfall in this area.

A set of five landraces were evaluated in this single environment using a randomized complete block design with four replications. Randomization of the experimental design facilitated using the breeding Management System (BMS) software. Each of the experimental plots consisted of lines measuring 5 meters in length. Planting densities were set at 20cm x 15cm between and within rows, respectively.

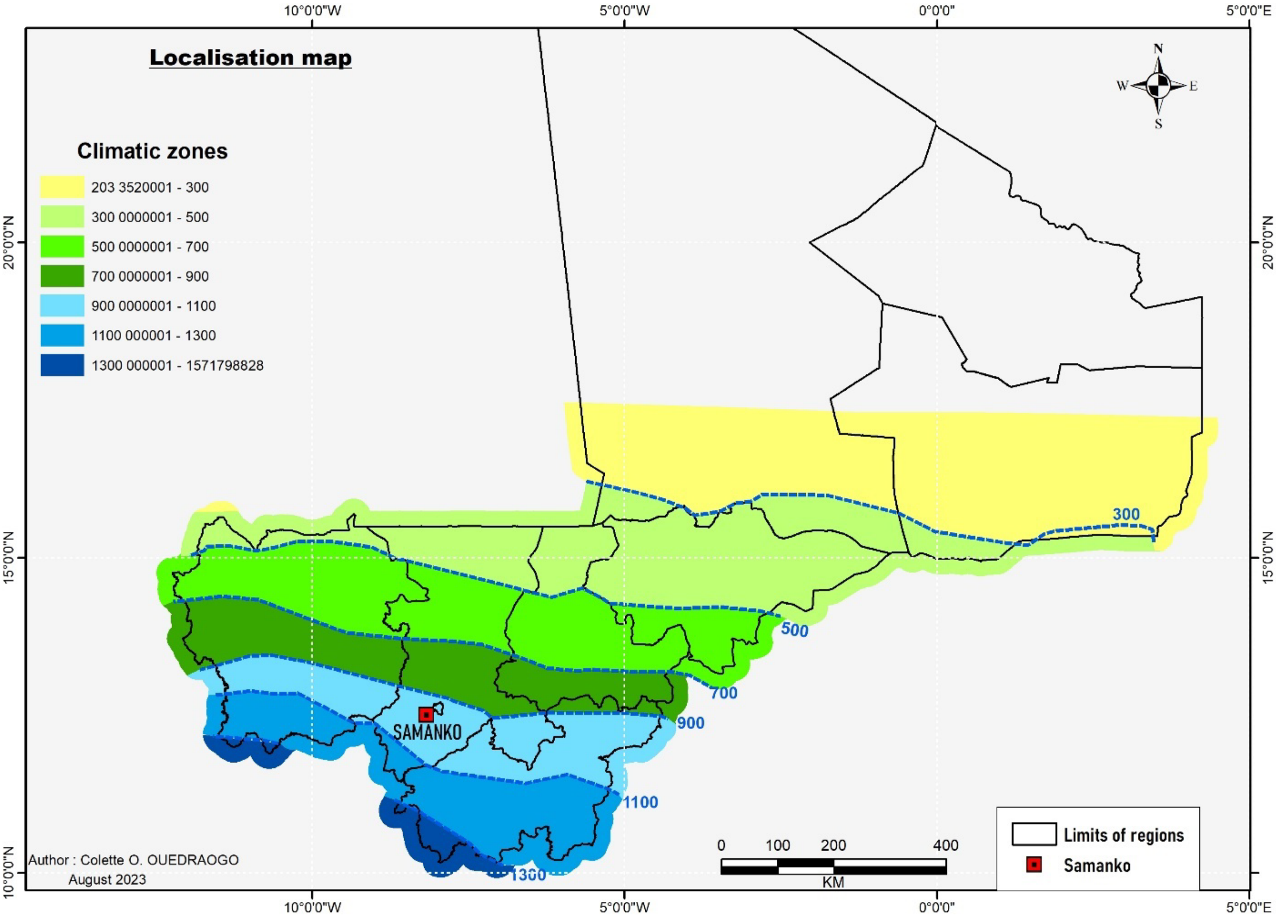

Figure 1. Location of the experimentation site and the distribution of rainfall.

2.3. Seedling Germination and Yield Evaluation Management

Before sowing, seeds were treated with the fungicide Thiram (2 g/kg of seed) to prevent damage from the damping-off disease. Seeds were sown thinly in lines spaced at 5 - 7 cm intervals, at a depth of 2 - 3 cm, and covered with a fine layer of soil, followed by light watering using a watering can. Dry straw grass was then used to cover the beds to maintain the required temperature and moisture levels. Watering was performed as needed until germination was complete, after which the grass cover was removed. Seedlings were ready for transplanting 45 days after planting. The seedlings from each line were transplanted into rows. Three weeks after emergence, seedlings were thinned to one plant per hill. Fertilizer was applied according to standards recommendations: 20 t/ha of decomposed organic matter was applied as background manure before the planting, followed by DAP at a rate of 100 kg/ha 15 days after plating, and 200 kg/ha of Urea split into two applications (half 30 days after planting and the other half 45 days after plating) [13]. Regular hoeing was performed to remove weeds and allow plants to access water and mineral elements. The assessment was carried out for agronomic traits such as bulb yield, which was obtained by weighing the bulbs and components of the five landraces.

2.4. Bulb Storability Traits Experiment

The storage trial was carried out in the Horticulture laboratory of the World Vegetable Center WCA Dry Region. The experiment followed a factorial scheme utilizing five landraces' shallots. Storage durations of 45, 90, and 135 days were implemented in a randomized design with four repetitions.

Before storage, several initial characteristics of the bulbs were measured, including weight, visual quality, water content, pH, total soluble solids, and firmness. The bulbs were then stored in a controlled chamber. **Figure 2** shows the temperature and relative humidity conditions during the storage period. The storage was 18 weeks, and monitoring was carried out once in six weeks. A total of four measurements were taken during this period. To assess firmness, five bulbs from each replication were randomly selected. Dry scales were removed before measuring bulb firmness. Firmness was measured using an objective method described by [14], employing a durometer. Durometer readings are based on the bulb's resistance to compression relative to the resistance of steel, with values ranging from 0 to 100. Bulbs were placed on a flat metal plate for firmness testing, with a constant contact pressure of 5 atm maintained by adjusting the height of the metal plate to accommodate bulbs of various sizes.

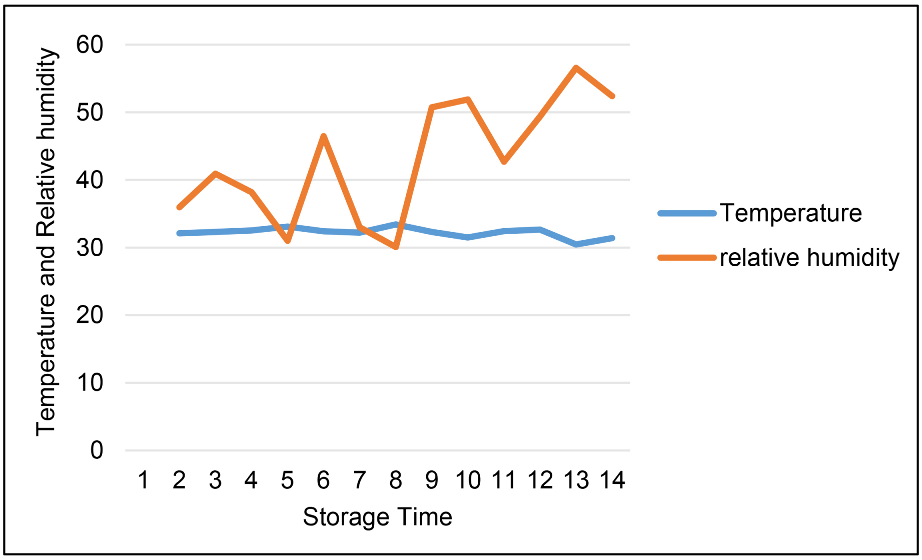

Figure 2. Temperature and relative humidity Variation over storage time.

Two single-point durometer readings were taken equatorially on each bulb and the mean was calculated and used as the measure of firmness.

Since dry matter is highly correlated to the total soluble solids (TSS), TSS was measured using digital refractometry as described by [15]. This method involved placing 2 or 3 drops of clear onion juice on the prism of the refractometer, and the results were expressed as degree brix (˚Bx).

The weight loss of onions was measured and expressed as a percentage by comparing the initial and final bulb weights after each storage interval. Similarly, the pH was also measured after each storage period. A visual quality assessment was conducted by a panel of 10 farmers. Each farmer evaluated one shallot from each landrace at each storage time. The assessment was based on factors such as color, shape, and bulb splitting, and ratings were given on a scale of 1 to 5, where 1 indicated a poor-quality bulb, and 5 indicated a high-quality bulb.

2.5. Data Analysis

Single environment analysis was conducted for each trait. The BMS (Breeding View) software was utilized to derive the best linear unbiased estimate (BLUEs) and the best linear unbiased prediction estimate (BLUP). Two models were used for the analysis to obtain the BLUEs and BLUPs. In the first model, the genotype was treated as a random factor. In the second model, the genotype was regarded as fixed.

The following formulas were used: model:

$$Yijk = \mu + Gi + Rj + Eij$$

In this formula, $Yijk$ represents the observed value of the trait;

μ: the population mean;

Gi: the effect due to the i$^{\text{th}}$ genotype tested; Rj is the effect due to the j$^{\text{th}}$ replicate; Eij is the effect due to the random error.

This analysis allowed for the estimation of the genetic and environmental effects on the observed traits.

The genotype factor, treated as a random variable, was utilized to compute predicted values and standard errors for each genotype. Analysis of correlation, variance (ANOVA), and graphical representation were performed using R software. Additionally, the least significant difference between mean values was determined using Duncan's Multiple Range Test (DMRT) at the significance level of 5%. The bulb yield is calculated as follows:

$$\mathrm{Y}\left(\mathrm{g/m^2}\right) = \frac{\mathrm{BW}}{0.2\left(5+0.3\right)}$$

where 0.2 = line spacing; 5 = length of the sowing row; 0.3 = 2 borders corresponding to the inter-hill, Y is the bulb yield and PW is the bulb weight.

Coefficients of genotypic variation (CGV) were calculated according to the method proposed by [16] to allow comparisons of genetic variability of all traits between trials.

$$\mathrm{VG}(\%) = \frac{\sqrt{(\vartheta g2)}}{\mu} \times 100$$

where σg2 is the genotypic variance component, and μ is the overall trial mean.

The broad heritability (H^2) was calculated using the method described by [17]:

$$H^2 = \frac{\mathrm{Vg}}{\mathrm{Vg} + \left(\frac{\mathrm{Vge}}{\mathrm{nE}}\right) + \left(\frac{\mathrm{Ve}}{\mathrm{nE}} \times \mathrm{nR}\right)}$$

where = genotypic variance, nE = number of environments, Vge = variance of the genotype-environment interaction, nR = number of repetitions and Ve = variance error.

The genetic correlation (g) between the different traits was calculated as follows:

$$\mathrm{rg} = \frac{\mathrm{Cov}(\mathrm{caractere1}; \mathrm{caractere2})}{\left[\sigma(\mathrm{caractere1}) \times \sigma(\mathrm{caractere2})\right]}$$

where: Cov (trait1; trait2) is the covariance of the genotype means of trait1 compared to trait2. σ(caractere1) and σ (caractere2) are the genotypic standard deviation of trait1 and trait2, respectively.

3. Results

3.1. Estimates of Genotypic Variability and Heritability

Table 2. Estimates of genotypic variances (σ^2), coefficient of variability (CV) and heritability (h^2).

Traits	Minimum	Mean	Maximum	CV	σ^2	h^2
Yield	31.57	35.97	39.13	11.15	60.33**	0.76
WL1	23.76	25.75	27.46	20.3	30.45	0.45
WL2	18.96	22.42	25.46	12.91	20.1	0.8
WL3	15.77	19.57	22.92	11.47	15.38*	0.88
V1	3	3.9	5	4.6	0.12	0.05
V2	3	4.03	5	10.17	0.3	0.005
V3	3	4.92	5	12.77	0.43	0.005
Firmness1	74.327	75.32	76.32	21.86	201.1	0.3
Firmness2	58.59	59.48	60.66	8.56	28.6	0.29
Firness3	54.58	55.59	56.59	20.52	112.6*	0.35
TSS1	18.8	19.55	20.48	2.65	0.63**	0.84
TSS2	19.2	19.668	20.18	2.9	0.47*	0.66
TSS3	18.4	19.408	20.33	6.58	2.83*	0.66

*= p-value > 0.05; **= p-value > 0.01; 1 = 45 days; 2 = 90 days; 3 = 135 days.

From the analysis of variance for bulb yield and storability traits (**Table 2**), it is observed that genotype significantly influences bulb yield, firmness, weight loss, and Total Soluble Solids (TSS) at 135 days of storage. Significant variation was found for yield ($p > 0.01$), weight loss, firmness, and the total soluble solid at 18 weeks of storage ($p > 0.05$) and the total soluble solid at 6 weeks of storage ($p > 0.01$).

Estimates of heritability indicate that bulb yield, weight loss, and TSS at all stages exhibit high heritability, ranging from 0.45 to 0.88. Conversely, heritability for firmness and visual quality is notably low. Genotypic coefficients of variation for landraces are particularly elevated for bulb yield, weight loss at 135 days, and firmness at both 45 and 135 days and significant, respectively, $p > 0.001$, $p > 0.05$, $p > 0.05$, and $p > 0.01$, while moderate and significant for TSS at all stages ($p > 0.05$ and $p > 0.01$). The coefficient of variation (CV) was found to be high for weight loss and firmness at 45 days of storage and firmness at 90 days of storage (CV > 20%).

3.2. Relationship among Storability Traits

Figure 3 and **Figure 4** show the correlation between weight loss and firmness, as well as weight loss and TSS for landraces. A significant correlation was observed between weight loss and firmness, as well as between weight loss and TSS.

Specifically, the analysis revealed a significant correlation coefficient (r) of 0.52 ($p > 0.001$) between weight loss and firmness at N'galamandjan Jaba landrace. Additionally, the correlation between weight loss and TSS for the Espagne Jaba landrace was notably high and significant ($p > 0.05$), with an r-value of 0.69.

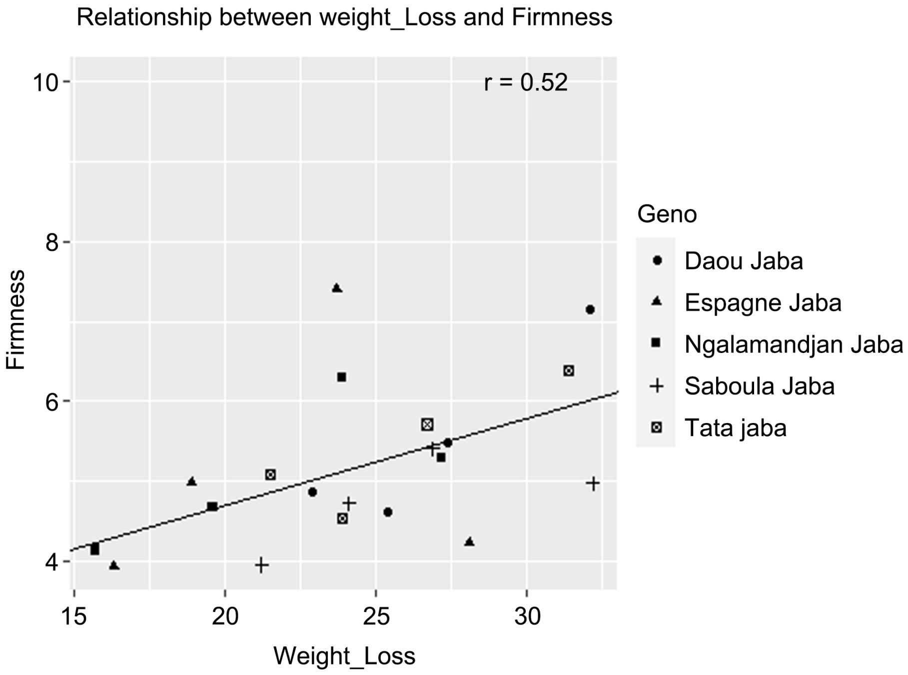

Figure 3. Relationship between weight loss and firmness.

Figure 4. Relationship between weight loss and total soluble solids.

3.3. Shallot Landraces Performance

N'galamandjan jaba emerged as the highest-ranking genotype for yield, boasting an impressive yield of 40 T/ha, closely followed by Saboula jaba with 39 T/ha, but there is no significant difference between them (LSD = 5.84). However, as shown in **Table 3**, there was a significant difference between N'galamandjan Jaba and Daou Jaba (LSD = 5.84). These top-ranking entries not only exhibited higher productivity in terms of bulb quantity but also showcased larger individual bulb sizes. In terms of firmness, Espagne jaba demonstrated noteworthy firmness levels at both 45 and 90 days after storage, while N'Galaman Jaba exhibited superior firmness towards the end of the storage period. Regarding the TSS Tata Jaba and N'Galaman Jaba displayed exceptional performance at 135 days after storage. It's important to note that the TSS levels tended to decrease consistently across all the genotypes from the beginning toward the end of the storage period. There was a significant difference between N'galamandjan Jaba and Espagn Jaba for firmness at 135 days of storage (LSD = 8.19).

3.4. Weight Loss of the Five Shallot Bulbs

Figure 5 illustrates the weight loss of bulbs during the storage period. There was a high coefficient of variation (CV) and a significant genotypic variation for weight loss (see **Table 2**). The weight of bulbs from five different landraces changed over time, generally decreasing towards the end of the storage period. The weight loss varied among the landraces, suggesting genetic differences. The weight loss varied among the landraces, suggesting genetic differences.

At the end of the storage period, Daou Jaba exhibited the least weight loss, followed by Tata Jaba. However, Espagne Jaba experienced a significant weight loss, losing nearly 45% of its initial weight.

Table 3. Shallot genotypes performance.

Genotypes	Yield	WL1	WL2	WL3	Firm1	Firm2	Firn3	TSS1	TSS2	TSS3
Saboula Jaba	39.12*	28.28	24.52	21.47	74.68	57.35	52.32	19.74	19.4	18.52
Espagne Jaba	34.5	21.37	18.13	15.93	81.09	63.5	47.02	19.45	18.98	17.93
Tata jaba	35.93	27.83	24.26	21.8	75.79	57.48	53.43	21.26	20.42	20.17*
Daou Jaba	30.18	29.52	26.19*	23.34*	74.22	62.65	56.24	20.65	19.29	18.54
N'galamandjan Jaba	40.12**	21.76	19.02	15.3	70.82	56.44	58.92**	20.66	19.53	19.26*
LSD	5.84	9.02	4.99	3.87	28.41	8.79	8.19	0.89	0.98	1.2

*= $p > 0.05$; **= $p > 0.01$.

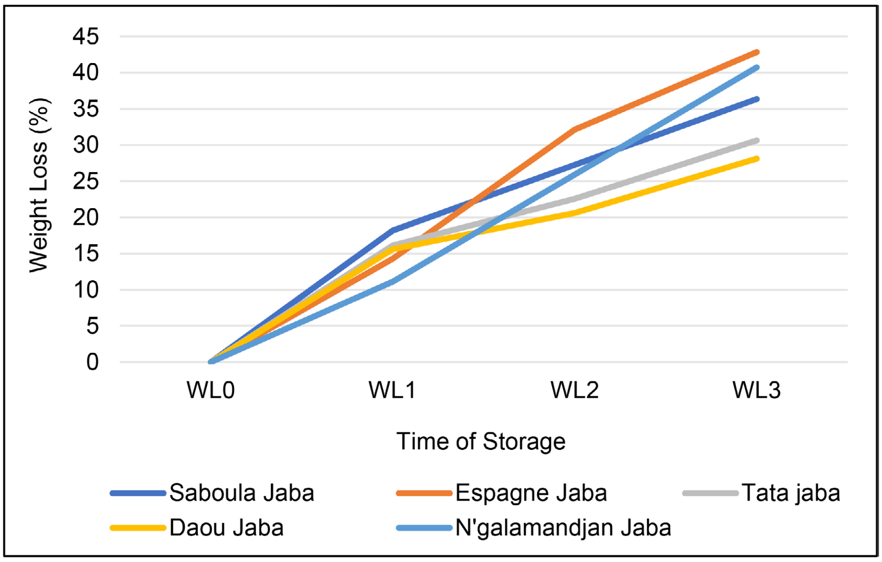

Figure 5. Shallot bulbs weight loss during the storage time for the five landraces.

4. Discussion

Post-harvest management plays a crucial role in determining storability traits and can impact overall yield. As noted by [18], significant losses post-harvest stem from the physiological processes within the bulbs, such as sprouting and rooting, which contribute to mass losses, visual deterioration, and alterations in quality.

All five landraces exhibited changes during the storage, highlighting the dynamic nature of post-harvest storage conditions.

A highly significant effect ($P \leq 0.01$) of the landraces on bulb yield was observed, aligning with findings from various authors [19] [20], who reported substantial differences in bulb production among shallot lines, particularly in marketable yield.

Significant genotypic variability was noted in bulb yield, firmness, weight loss, and TSS. The significant level of genetic variation confirms the diversity present among the shallot landraces.

Understanding genetic variability is crucial to the selection of varieties [21]. Demonstrating this variability for specific morphological traits represents the initial essential step in characterizing genetic resources [22]. The broad sense of heritability was observed to be high for most of the traits. According to [23], higher values of broad-sense heritability indicate greater effectiveness in selecting for these traits. They categorized heritability values as low if below 30%, average if between 30% - 60%, and very high if above 60%.

Considering this, it's essential to note that values of broad-sense heritability above 60% signify substantial genetic control over the trait expression, facilitating more precise selection processes. Conversely, heritability values below 30% suggest lower genetic influence and may require additional considerations or approaches in variety selection.

Weight loss serves as a critical quality parameter reflecting the freshness of bulbs. It was observed that the weight loss of shallot gradually increased with prolonged storage duration. This phenomenon can be attributed to various factors such as vaporization, decay, and physical damage occurring during storage. Long-term storage exacerbated various weight loss, as indicated by [24]. Furthermore, [25] found that onion bulbs experienced the highest weight loss under ambient storage conditions in mitigating weight loss and preserving bulb quality.

TSS encompasses all solids present in water, including reduced sugars, sucrose, organic acids, and water-soluble vitamins [26]. Throughout storage, TSS tends to decrease from the beginning toward the end of the storage. This is in line with the statement of [27] [28], which noted that changes in dissolved solids correlate with moisture content variations, where a reduction in water content leads to an increase in TSS levels. Weight loss is found to be correlated to TSS. Contrary to this, [29] reported results that diverge from the correlation. They found a negative association between TSS content and ambient storage loss, suggesting a more nuanced relationship between TSS levels and storage conditions.

Bulb firmness exhibited a decrease across all tested landraces as storage time increased, indicating that the storage process alone cannot prevent changes in firmness. This observation aligns with findings by [30] suggesting that storage conditions may inadequately preserve bulb firmness over time. Furthermore, the distinct behaviors of the five shallot genotypes in terms of bulb firmness support the notion that different genotypes possess unique characteristics during storage. This is consistent with the assertion made by Ferreira and [31], who noted significant firmness differences between bulbs of different genotypes, underscoring the genotype-specific nature of bulb characteristics during storage.

The observed differences in the bulb's firmness among the five shallot genotypes are consistent with [29] assertion regarding the variability in firmness between bulbs, indicating distinct characteristics exhibited by different genotypes during storage.

Interestingly, while our study found a positive correlation between weight loss and bulb firmness, [32] reported a negative correlation.

It's important to note that our research was conducted in Mali, under specific climatic conditions during shallot bulbs production. In contrast, the research by Lari *et al.* was conducted in a different geographic area and possibly during a different growing season. These contextual variations may have influenced how shallot bulbs responded to the treatments, leading to differing correlations between weight loss and bulb firmness

5. Conclusion

This study highlighted the potential of shallot landraces to contribute to breeding efforts leading to identifying superior genotypes, particularly for long-term storage purposes. The characterization revealed significant phenotypic variability in yield and storability traits among landraces. Among the tested landraces, Daou jaba demonstrated notably less weight loss during storage, indicating its potential suitability for extended storage durations. Notably, N'galamandjan jaba emerged as the top-ranking entry for yield, boasting a yield of 40 T/ha, closely followed by Saboula jaba at 39 T/ha. These entries exhibit higher productivity, both in terms of bulb quantity and individual bulb size. Furthermore, N'galamandjan jaba displayed high TSS levels after 135 days of storage, underscoring its potential for maintaining quality attributes over extended storage periods.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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