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Evaluation of the Production and Preservation Ability of Four Varieties of Onions (*Allium cepa* L., *Alliaceae*) in Korhogo, Northern Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. Author SK designed the study, performed the analyses and wrote the first draft of the manuscript. Author KNY performed the statistical analysis and assisted the draft conception. Authors KEBZ and YSDM contributed to study design and interpretation of the results. Author CM supervised the full study with Author DN. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The study was investigated the ability of producing and preserving fresh onion bulbs from various varieties to fit sustainable onion culture in Ivorian agroclimatic conditions.
Study Design: Four onion varieties, namely *Dayo*, *Safari*, *Red Star* and *Red Jewel*, were cultivated, and their fresh bulbs harvested and stored for the investigation of both physical and environmental parameters during the storage.

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Place and Duration of Study: The onion culture and the physical and environmental measures were carried out from the experimental field and at the laboratory of Peleforo GON COULIBALY University, Korhogo, Côte d'Ivoire, over a period from December 2021 to September 2022.
Methodology: Onion bulbs of different varieties were cultivated on the experimental site. Thus, 10 kg of onion fresh bulbs per variety were collected in bags and stored in the store under ambient conditions, and then environmental (temperature and humidity) and physical (sprouting, rotting and loss rate, physiological weight loss and dry matter) parameters were determined at 30 days intervals stages for four months storage period. The statistical processing consisted of the comparison of means according to the ANOVA test, the study of correlation between parameters and the multivariate PCA analysis.
Results: The production yield varies between 17.16 and 23.69 t/Ha with the best production rates observed from *Red Jewel* and *Red Star* varieties. The average temperature was recorded between 26°C and 27.9°C while the average humidity increases from 77% (June) to 85% (September). *Red Star* and *Red Jewel* varieties assumed the highest bulbs loss rates with respective values of 81.58% and 90.38%, while *Dayo* and *Safari* varieties displayed losses of 19.88% and 14.29% over the four months storage. Sprouting represents the main causes of the losses of both red onion varieties. Furthermore, the weight loss and the dry matter vary according to the onion variety and the storage duration. After 4 months storage, the physiological weight loss of preserved onion bulbs remains minimal for *Dayo* and *Safari* varieties, while it's more significant from red onions reaching 14.83% for *Red Jewel*. The dry matter content of the onion bulbs decreases with the storage during with *Dayo* and *Safari* provided higher values.
Conclusion: The red onion varieties *Red Jewel* and *Red Star* display more production potential for onion bulbs. But *Dayo* and *Safari* onion bulbs seem to have good preservation abilities compared to the red varieties under the storage conditions studied.

Keywords: Onion varieties culture; bulbs production; four months storage; post-harvest losses.

1. INTRODUCTION

Onion is the vegetable crops belonging to the *Alliaceae* plant family. It's a vegetable originating from Central Asia, with species name of *Allium cepa* L. (Bindu B and Podikunju B, 2015). Onion is generally cultivated as an annual crop for its bulbs which display white, yellow or red appearances with different flavors from slightly sweet to spicier (Massiha S et al, 2001). Onion bulbs contain numerous biochemical molecules. It is a source of phytonutrients such as flavonoids, organosulfur compounds, fructo-oligosaccharides and saponins which assume various technological and therapeutic properties.

In terms of production, onion is the second most important horticultural crop over the world after tomatoes, with an annual production around 105 million tons in 2020 (FAOSTAT, 2020). China, India and the United States represent the main onion producers. The African continent ranks second in terms of production with Egypt, Algeria, Nigeria, Niger and Morocco as major producers (FAOSTAT, 2020). Unfortunately, Côte d'Ivoire remains far in this ranking with an annual production of 7.980 t gathered in 2020. This production is significantly lower compared to the increasingly growing consumption demand over 200.000 t/year since 2020 (FAOSTAT, 2020). Consequently, 95% of the onion consumption in the country result from large volumes of imports from various onion-producing countries.

The Ivorian onion sector is very under-exploited despite the availability of large areas of suitable arable lands for this crop. One of the reasons to the low onion production deals with the use of inappropriate varieties by climate seasons. In addition, the post-harvest management remains of the significant concerns for the tropical crops storage so that onion bulbs are subject to significant deterioration at fresh form. Therefore, the investigations of suitable varieties favorable to be cultivated from different lands are important for mitigating the trade deficit of the onions. Such searches must consider the preservation potential of these varieties as sustainable factor for the extension strategy. Indeed, Aidoo et al**.** (2014) noted that fresh vegetables suffer higher post-harvest losses than cereals due to their highly perishable nature involved by the greater moisture content. Furthermore, many studies have been carried out on the intensity of post-harvest losses in onion production and their financial involvements for farmers (Emana B et al, 2017, Gorrepati K et al, 2018). The losses are

of both quantitative and qualitative natures, impeding the marketability, dropping the volume of bulbs available, and affecting the nutritional composition of onion bulbs (Hodges RJ et al, 2011).

According to Biswas et al. (2010), post-harvest quantitative losses can reach a considerable value of 66% of harvested bulbs, causing a major problem for onion producers. The current study investigates the production yield and the preservation ability of bulbs deriving from some onion varieties experimented for cultivation in northern Côte d'Ivoire.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was carried out on the experimental site of the Peleforo GON COULIBALY University (UPGC) in Korhogo, northern Côte d'Ivoire (Fig. 1). Korhogo is located 633 km from Abidjan between 5°15 and 6°20 west longitude and 8°30 and 10°25 north latitude. Korhogo is the capital city of Poro region, accounting about 441000 inhabitants (National Institute of Statistics, 2021). This region assumes a dry tropical climate of bimodal Sudano-Sahelian type with a long dry season extending between November and April and a rainy season from May to October. During the rainy season, the rainfall peaks are recovered in June and September. The average annual temperature is 27°C with an average rainfall of 1200 mm/year.

2.2 Plant Material

The plant material was constituted of bulbs from four onion varieties, including two red onions (*Red Star* and *Red Jewel*), and purplish ones (*Dayo* and *Safari*). The bulbs were grown at field from the UPGC experimental lands using onion seeds purchased on the local and sub-regional markets.

2.3 Methods

2.3.1 Growing onion bulbs

The onion production was carried out over a period of six (6) months from December 2021 to May 2022 according to the nursery production system followed by transplanting.

For nursery, 3 m² boards were made and 12 g of seeds were distributed in furrows drawn on boards. After 45 days of growth, the plants were transplanting onto 6 m² beds previously prepared for this purpose. The bulbs were harvested 3 months after transplanting and the production yield was evaluated according to the following expression (Koffi EBZ et al, 2022):

$$y = \frac{Q}{S} \times 10^{-7}$$

With : y = production yield (t/Ha) ; Q = quantity of bulbs obtained per bed (Kg) ; S= surface harvested (m²) et 10^{-7} = conversion factor.

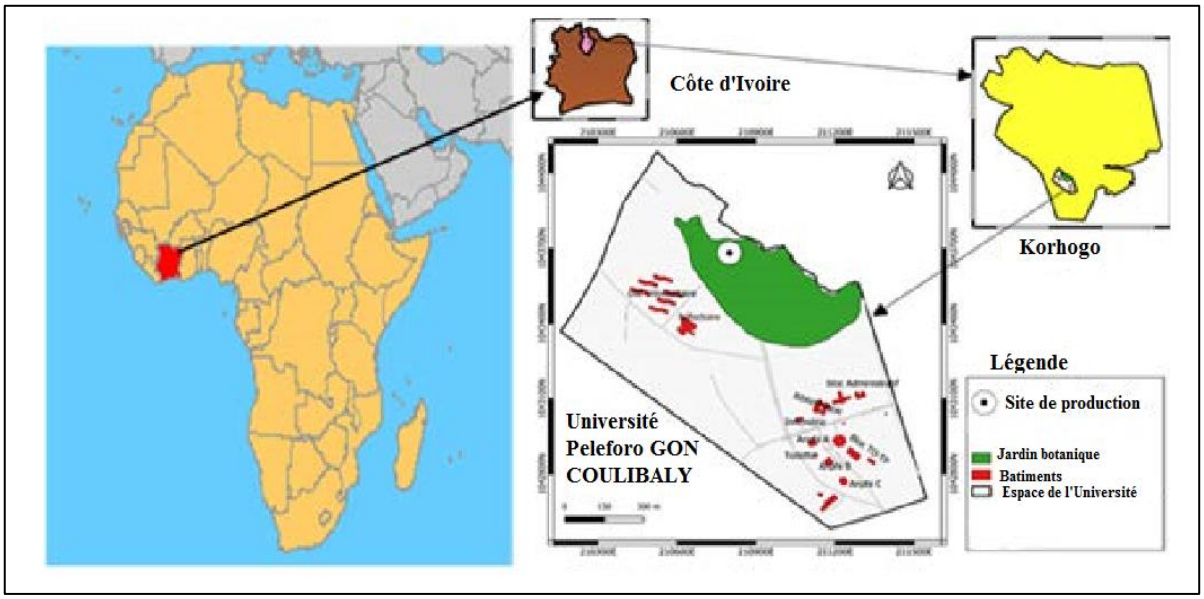

Fig. 1. Study site (Koffi EBZ et al, 2022)

2.3.2 Harvest, packaging and storage of onion bulbs

The onion bulbs harvested at maturity were dried in the shade for two weeks then sorted to eliminate injured bulbs and constitute a batch of samples of uniform size. Thus, batches of 10 kg of onion bulbs of each variety were made. The bulbs were packaged in large-mesh commercial net bags and stored on a wooden rack in the store under ambient conditions. The period of storage was 120 days (4 months) from June 2022 to September 2022 corresponding to study period.

2.3.3 Measurement of environmental parameters of store

The store temperature and relative humidity were measured by placing an electronic hygro-thermometer in the middle of onion bags in storage. The temperature and humidity values were recorded four (04) days in the week and at three (03) times of the day (6:00 a.m., 12:00 p.m. and 6:00 p.m.) until the onion bulbs were removed from storage.

2.3.4 Evaluation of losses during storage

The onion bulbs showing signs of sprout and rot were considered losses. They were counted and removed from batches of healthy bulbs. This operation was carried out at a frequency of 30 days until the end of storage. The percentages of sprout, rot and total loss rate during storage were then calculated using the following formulas (Endalew W et al, 2015):

Percentage of sprout:

$$\mathrm{SPR}\ (\%) = \frac{\mathrm{N_{sb}}}{\mathrm{N_{total}}} \times 100$$

With: SPR = Sprouting Rate (%); N_{sb} = sprouted bulbs number; N_{total} = total bulbs number

Percentage of rot:

$$\mathrm{RTR}\ (\%) = \frac{\mathrm{N_{rb}}}{\mathrm{N_{total}}} \times 100$$

With: RTR = rotting rate (%); N_{rb} = rotted bulbs number; N_{total} = total bulbs number

Total loss rate:

$$\mathrm{TLR}\ (\%) = \frac{\mathrm{N_{bl}}}{\mathrm{N_{total}}} \times 100$$

With: TLR = Total loss rate (%) ; N_{bl} = bulbs lost ; N_{total} = total bulbs number

2.3.5 Determination of physiological weight loss

The physiological weight loss of the bulbs was determined by taking the difference in the mass of the bulbs before storage (initial instant) and any instant corresponding to a given length of days. To do this, the mass of 30 onion bulbs (10 bulbs × 3 batches) randomly chosen and labeled were taken just before storage. Next, the mass of these same bulbs was taken at a frequency of 30 days until the end of the experiment. The mass loss is determined from the following formula (Falayi FR and Yusuf HA, 2014):

$$\mathrm{PWL}\ (\%) = \frac{\mathrm{W_i - W_n}}{\mathrm{W_i}} \times 100$$

With: PWL = Physiological weight losses (%) ; Wi = mass (g) of bulbs before storage ; Wn = mass (g) of bulbs after n days of storage.

2.3.6 Determination of dry matter content

The dry matter content was determined according AOAC (1990) gravimetric method. For this, 5 g of onion were dried at 105°C in oven (Memmert) till constant weight. Dry matter content was deduced by the following relation:

$$\mathrm{DMC} = \frac{\mathrm{W_d}}{\mathrm{W_f}} \times 100$$

With: DMC = dry matter content (g/100g fresh bulb); Wd = weight in gram of onion after drying; Wf= weight in gram of raw onion.

2.4 Statistical Analysis

The weight losses and dry matter content were achieved in triplicate. All data in this study were statistically processing using Statistical Package for Social Sciences (SPSS 22.0, USA) and STATISTICA (7.1, France) software at 5% significance. The means were compared using analysis of variances (ANOVA-1) test, followed by means comparison using Student Newman Keuls (SNK) post-hoc test for weight losses and dry matter content. The correlation between the parameters analyzed was assessed using the Pearson r correlation indices. Then, Principal Component Analysis (PCA) was carried out to check the correlation between parameters studied and the overall onion samples using STATISTICA software.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Production yield

Fig. 2 shows the production yield of different onion varieties. Statistical processing shows a significant difference in yields between onion varieties. The yield obtained varies between 17.16 and 23.69 t/Ha. Thus, *Red Jewel* variety made it possible to obtain the greatest yield equivalent to 23.69 ± 10.27 t/Ha, followed by the *Red Star* variety with a rate of 22.46 ± 8.33 t/Ha. *Dayo* et *Safari* varieties produced fewer bulbs with respective yields of 19.51 ± 7.86 and 17.06 ± 6.09 t/Ha.

3.1.2 Environmental parameters

Table 1 shows environmental data (temperature and relative humidity) recorded during storage. During storage, the minimum temperature recorded is 22°C (September) and the maximum value is 32.4°C recorded in the month of June. Likewise, the lowest humidity is recorded in June (52%) and the highest, in July with a value of 99%. The average daily temperatures recorded are around 26°C in the months of July, August and September. However, this average value is higher in the month of June (27.9 ± 1.7°C). The average daily humidity gradually increases each month from 77 ± 8% obtained in June to 85 ± 3% in September.

3.1.3 Evolution of losses during storage

Fig. 3 shows the evolution of the sprouting rates of onion bulbs during storage. The bulb sprouting rate is low after 30 days of storage with a maximum value of 3.50% observed for the *Red Star* variety. Up to 30 days, there is almost no significant difference in losses between varieties. In the other hand, after the first 30 days, a differentiation of sprouting rates is observed between varieties. Thus, low germination rates are recorded for *Dayo* and *Safari* varieties which go from 0.62% to 6.21% and from 0% to 3.89% respectively at the end of 120 days. On the other hand, the germination rates are higher for the two red varieties (*Red Star* and *Red Jewel*). These rates expanded from day 30 to reach values of 76.32% germination for *Red Star* and 86.29% for *Red Jewel* at the end of storage.

Regarding rotting rates, the number of rotten bulbs increases with the duration of storage (Fig. 4). However, the rotting rate of onion bulbs from *Red Star* and *Red Jewel* varieties is lower with a respective percentage of 5.26% and 4.03% compared to the two other varieties which show rates of 13.66% (*Dayo*) and 10.39% (*Safari*) after 120 days of storage.

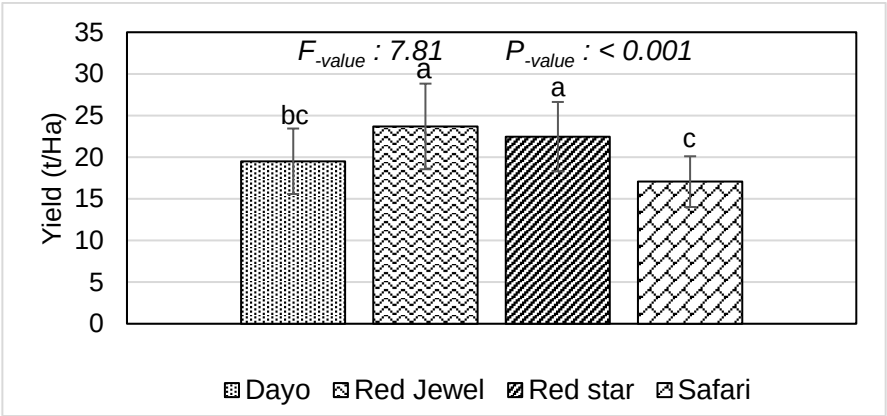

Fig. 2. Bulb production yield of different onion varieties
Histograms with different letters are statistically different at P < 0.001

Table 1. Value of temperature and relative humidity recorded during storage

Month	Temperature (°C)			Relative Humidity (%)		
	Min	**Max**	**Average**	**Min**	**Max**	**Average**
June	23.4	32.4	**27.9 ± 1.7**	52	97	**77 ± 8**
July	22.3	31	**26.0 ± 1.3**	63	99	**84 ± 4**
August	22.8	30.7	**26.1 ± 1.3**	63	97	**84 ± 5**
September	22.0	30.0	**26.1 ± 0.4**	63	98	**85 ± 3**

In terms of overall bulb loss, the results show that *Red Star* and *Red Jewel* onion bulbs are the most lost with loss rates of 81.58% and 90.32% respectively (Fig. 5). These loss rates increased rapidly from the 30th day of storage. On the other hand, in the *Dayo* and *Safari* varieties, bulb losses are relatively low compared to the other two varieties. Throughout storage, these increased from 0 to 19.88% for the *Dayo* variety and from 0 to 14.29% for the *Safari* variety.

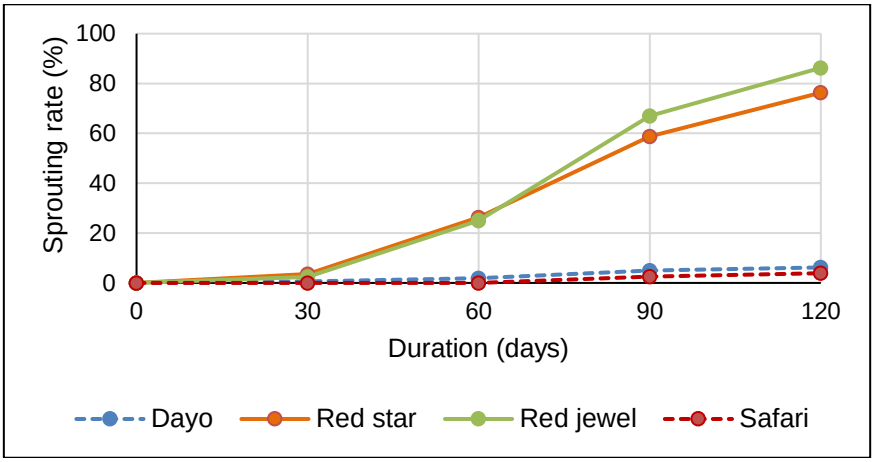

Fig. 3. Evolution of sprouting rate of bulbs during storage

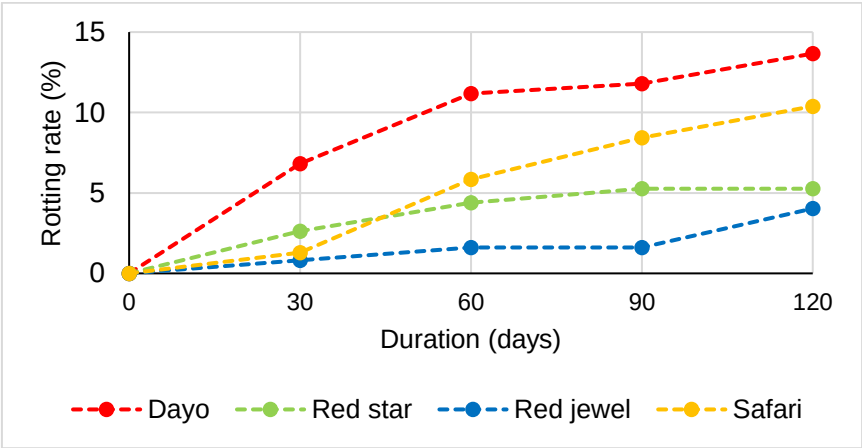

Fig. 4. Evolution of bulbs rotting rate during storage

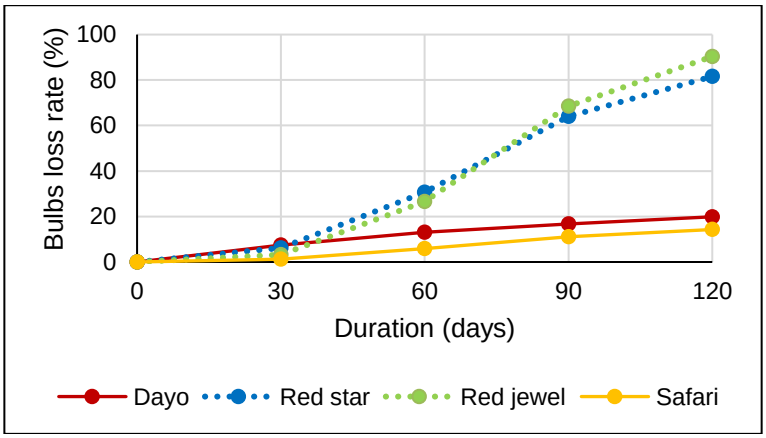

Fig. 5. Evolution of total losses of bulbs during storage

3.1.4 Evolution of onion bulbs mass during storage

The evolution of onion bulbs mass from the four varieties during storage is presented by Fig. 6. For all varieties, the mass of the bulbs gradually decreases during storage with a maximum mass loss of less than 15%. Thus, after four months of storage, the bulbs of *Dayo* and *Safari* varieties lost respectively 9.59 ± 1.68% and 10.19 ± 1.03% of their initial mass. The loss of physiological mass is greater in the *Red Star* and *Red Jewel* varieties. Indeed, the mass loss rates recorded for these two varieties are respectively 13.41 ± 0.52% (*Red Star*) and 14.83 ± 0.88% (*Red Jewel*) after 120 days of storage.

3.1.5 Evolution of dry matter content

Fig. 7 shows the variation in dry matter levels of onion bulbs during the 4 months of storage. The interaction of variety and storage duration constitutes a source of variation ($p < 0.001$) in dry matter contents during storage. *Dayo* and *Safari* onion varieties provide bulbs with dry matter contents significantly higher than the values displayed by the red varieties *Red Star* and *Red Jewel* during 120 days of storage. The average dry matter contents of *Dayo* and *Safari* oscillate respectively between 11.59 ± 0.18 and 12.07 ± 0.21 g/100 g and between 11.67 ± 0.14 and 13.19 ± 0, 13 g/100 g of fresh onion. Those of *Red Star* and *Red Jewel* (red onions) fluctuate between 9.70 ± 0.26 and 11.32 ± 0.10 g/100 g and from 10.05 ± 0.11 to 10.61 ± 0.25 g /100 g of fresh onion. In addition, a slight decrease in dry matter content is observed in the bulbs of onion varieties except for the *Safari* variety where an increase is seen at the end of 120 days of storage.

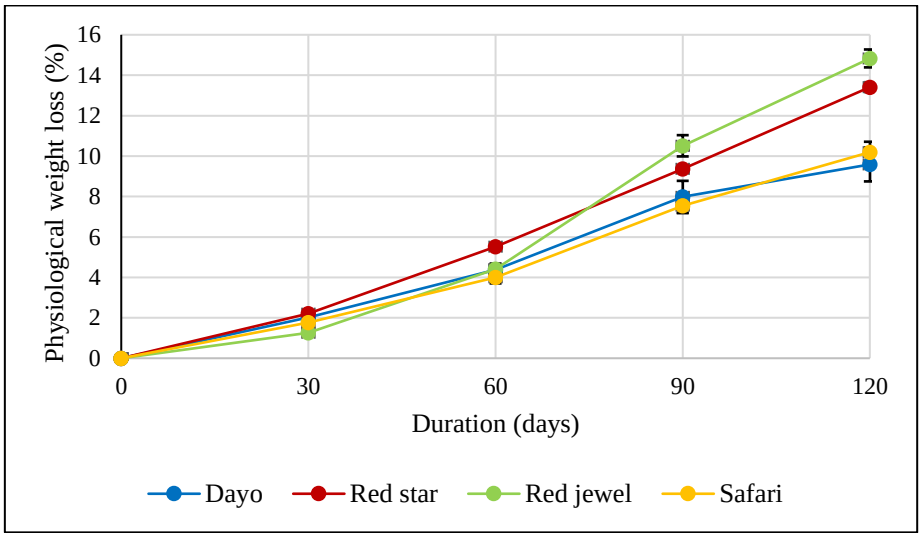

Fig. 6. Evolution of bulbs weight during storage

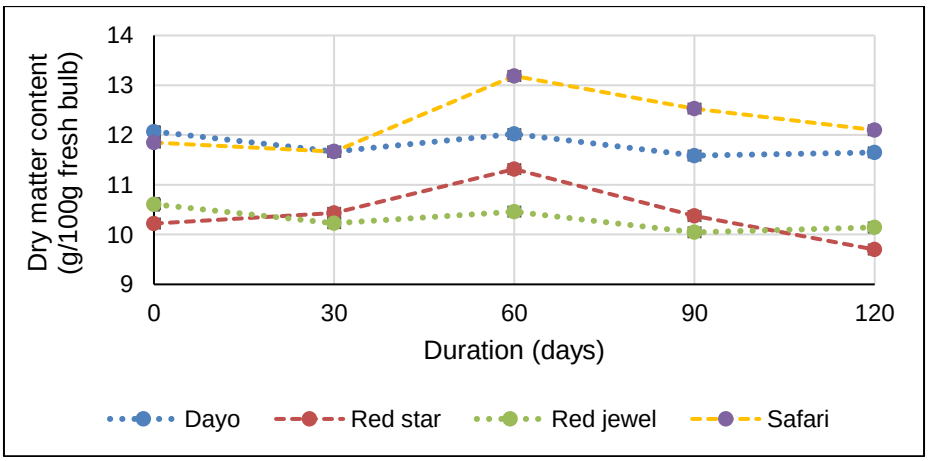

Fig. 7. Evolution of bulbs dry matter content during storage

3.1.6 Correlation between the studied parameters

The Pearson's r correlation indices between the parameters analyzed during storage are recorded in Table 2. Thus, positive and significant correlations ($p < 0.001$) are recorded between the sprouting rate and the total loss of bulbs (0, 99) on the one hand; and between the germination rate and the loss of physiological mass (0.77) on the other hand. However, there is a negative correlation between sprouting rate and dry matter content during storage (-0.63). In addition, the total loss rate increases significantly with loss of bulb mass (0.85). Also, a reduction in the dry matter rate induces an increase in the percentage of loss of onion bulbs during storage (-0.56).

3.1.7 Variability between parameters determined during storage

According to the results, parameters analyzed are significantly divided into five (05) factors or main components (Table 3). However, factors F1 and F2 with eigenvalues greater than 1 better express variability according to Kaiser's rule.

For correlation, sprouting rate, total loss rate and physiological weight loss are negatively correlated with the F1 component while the dry matter rate is positively associated with this factor. For the F2 component, only the rot rate is negatively correlated.

Fig. 8 presents the projection of parameters analyzed and onion samples during storage in the plane formed by the F1 and F2 factors of ACP which express 92.86% of the variability. Thus, onion varieties samples at different conservation times are divided into four (04) groups. The first group includes individuals *Dayo* D (day) 0, D30 and *Safari* D0 on D60. These individuals are characterized by high dry matter contents during storage. The second group is made up of *Red Star* and *Red Jewel* D90 and D120. This group is characterized by individuals with the highest rates of sprouting, total bulb loss and weight loss. *Dayo* D60 to D120 and *Safari* D90 and D120 individuals constitute the third group characterized by high rotting rate. As for the fourth group, it brings together individuals *Red Star* D0 to D30 and *Red Jewel* D0 to D60. This group presents different characteristics from other groups.

3.2 Discussion

Temperature and relative humidity are important environmental factors in the preservation of fruits and vegetables. Indeed, high temperature and humidity promote the growth of microorganisms and the degradation of internal tissues (Lidiya T, 2020). Thus, Endaley et al. (2015) recommends an optimal temperature range between 22 and 30°C and a range of 55 to 70% for relative humidity. Temperatures obtained in this study are similar to these recommendations. However, humidity values are higher than the recommended values. This fact could result in an increased in respiration rate, deterioration and loss of water in fresh produce, leading to reduction in their market value and nutritional value (Kitinoja L and AlHassan H, 2012).

Table 2. Matrix of Pearson correlation indexes between parameters studied during storage

	SPR	RTR	TLR	PWL	DMC
SPR	1				
RTR	-0.07	1			
TLR	**0.99****	0.08	1		
PWL	**0.77****	0.51	**0.85****	1	
DMC	**-0.63****	0.43	**-0.56****	-0.24	1

*** Significatif correlation at P < 0,001*

With: SPR= sprouting rate; RTR= rotting rate; TLR= total loss rate; PWL= physiological weight loss, DMC= dry matter content

Table 3. Matrix of eigen-values of factors resulting from the principal components analysis

	F1	F2	F3	F4	F5
Eigen- values	**3.09**	**1.56**	0.31	0.05	0.00
Variance (%)	61.74	31.12	6.18	0.95	0.00
Cumulative variance (%)	61.74	92.86	99.05	100.00	100.00

With: SPR= sprouting rate; RTR= rotting rate; TLR= total loss rate; PWL= physiological weight loss, DMC= dry matter content; F= factor

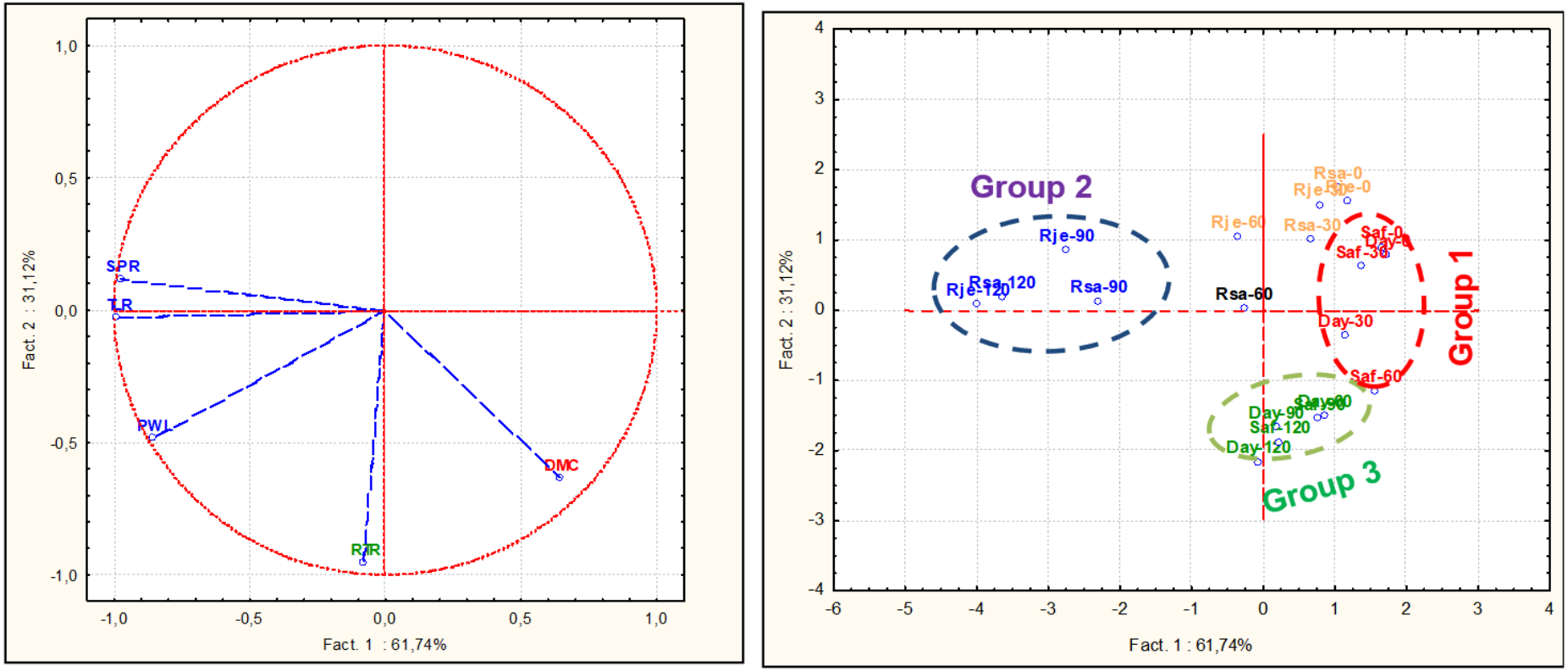

Fig. 8. Correlation between the F1-F2 factorial of principal components analysis (PCA) deriving from the stored onion bulbs

With: Day: Dayo; Rje: Red jewel; Rsa: Red star; Saf: Safari; 0 to 120: Storage duration from 0 to 120 days

After harvesting, bulbs conservation represents one of the difficulties for producers due to the losses recorded. These losses mainly consist of weight loss, sprouting and rotting which cause enormous economic losses (Seid HM, 2022).

The low germination rate observed during the first 30 days of storage could be explained by low relative humidity in the store. Indeed, germination of bulbs is a process that takes place when the dormancy of bulbs is lifted. This emergence is favored by high humidity levels. Also, the length of the dormancy period depends on the cultivar (Petropoulos SA et al, 2016). The results could suggest that the two red onion varieties (*Red Star* and *Red Jewel*) with largely high germination rates (> 70%) have shorter dormancy periods than the other two varieties. These germination rates obtained these two varieties are much higher than those obtained (46 to 56%) by Kukanoor L. (2005). The rates of 3.9 to 6.2 % perceived at Dayo and Safari after 4 months of storage are less than those observed by Tripathi and Lawande (2005), where the values oscillate between 8 and 10 % after 4 to 5 months of storage.

The observation of signs of rot from the first days of storage would indicate contamination of the bulbs from the field by microorganisms mainly mold. Also, relative humidity increasing during storage from 77% in June to 85% in September can justify the gradual increase in the rot rate during storage. Indeed, excess humidity promotes the growth of fungi and other alteration microorganisms (Lidiya T, 2020).

Concerning total bulb losses, the Dayo and Safari varieties presents rates lower than that obtained by Housseini et al. (2020) which is 21.5% in conditions almost identical to our study (28 and 34 ° C / 60 and 87% HR). According to Biswas et al. (2010), internal factors such as the physiological and metabolic activity of onion bulbs as well as the cultivar can influence losses. Thus, the results suggest that the *Dayo* and *Safari* bulbs are potentially conservable over a long time.

For weight loss, the average values obtained are lower than those found in the study of Ayalew (2018) carried out at a temperature of 25°C. The authors obtained a loss of 21.8% of the fresh weight. Weight loss is due to the action of desiccation, respiration and sprouting which are linked to storage temperature. Thus, this observation can justify the loss rates for *Red Star* and *Red Jewel* varieties, as these bulbs recorded high sprouting rates. It is therefore suggested to control the storage conditions of bulbs in order to minimize water losses and extend the shelf life (Yoo KS et al, 2012).

The dry matter contents found in this experience are lower than those reported by Ayalew (2018). where contents were between 12.5 and 15.3%. The reduction in dry matters during storage could be due to the mobilization of nutrients, particularly sugars, during germination and microbial growth phenomena. *Red Star* and *Red Jewel* varieties have low dry matter contents values at the start of storage (<11%) thus showing their high-water content. This humidity would promote on the one hand the growth of microorganism and germination on the other hand, justifying the great losses in these two varieties.

4. CONCLUSION

The study assessed the production and storage potential of bulbs of four onion varieties.

According to this study, Red Jewel has the highest production yield. But, it appears that post-harvest losses of the Red star and Red jewel varieties are greater. For these varieties, germination is the main cause of losses. They are also characterized by high mass losses and a low dry matter content during storage. The Dayo and Safari varieties with relatively low quantitative losses, has good conservation skills but the two Red varieties have good production yields.

A study on the effect of the conservation time on the nutritional quality of these bulbs would be ideal for the choice of favorable varieties.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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