

Research Article

Proximate and Nutritional Composition of Stored Bulb Onions as Affected by Harvest and Postharvest Treatments

Irene N. Kiura , Bernard M. Gichimu , and Felix Rotich 

Department of Agricultural Resource Management, University of Embu, Embu, Kenya

Correspondence should be addressed to Bernard M. Gichimu; wacikubm@gmail.com

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Productivity of bulb onions (*Allium cepa* L.) is largely constrained by postharvest losses. There are several postharvest strategies applicable to onions, but they are mostly applied singularly and therefore their combined effects have not been well studied. This study was set out to evaluate the effects of harvesting stage, curing period, and time of topping on postharvest quality of stored red bulb onions. The study was carried out in Yatta Subcounty, Machakos County, Kenya. The experimental design was split-split plot laid out in a $3 \times 3 \times 2$ factorial arrangement. The treatments consisted of harvesting stage (25%, 50%, and 75% top fall), curing period (none, 1 week, and 2 weeks after harvesting), and time of topping (before and after curing). All the treatments were replicated three times. After 3 months of storage, the bulbs were analyzed for proximate and nutritional composition. Bulbs that were harvested at 75% top fall and cured for one or two weeks before topping retained higher moisture content, bulb weight, crude protein, vitamin C, zinc, potassium, calcium, and iron but lower sodium content after three-month storage. These practices are therefore recommended for maintaining the nutritional quality of bulb onions after harvesting.

1. Introduction

Onion (*Allium cepa* L.) belongs to the Liliaceae family and is a valuable vegetable crop worldwide [1]. Apart from domestic consumption, onions have high economic value that is depicted by the high global production output of more than 640 million tons [2]. Onions are used in different ways, such as being eaten fresh, used for food flavoring, or included as the main ingredient in many recipes [3]. In addition, onions also have medicinal values [2]. They contain antioxidants which keep lifestyle-related diseases in check; thus, they are a vital component of a balanced diet [4]. By and large, it forms part of food security as it is a source of nutrients required by the human body. Therefore, high production and maintenance of good quality of bulb onions are very critical in the realization of food and nutritional security as well as improved farm incomes among onion farmers.

Demand for onions is likely to increase to satisfy the needs of the projected world population of 9.7 billion people by the year 2050 [5]. Kenya is a net importer of bulb onions

because demand exceeds the supply. Apart from the production constraints, the supply of good-quality onions is limited by postharvest losses [6]. Unfortunately, Kenyan small-scale bulb onion farmers rarely have the capacity to process fresh onion and do not have easy access to efficient and structured markets [7]. However, with good postharvest management, onions can keep for up to nine months [8], enabling the farmer to withhold the produce to time the best market prices. Recent studies have sought to improve the quality of bulb onions using different strategies such as curing and delayed topping. Curing is a drying process carried out to remove excess moisture from the outer skins, roots, and neck tissues of harvested onion bulbs [9]. It improves the keeping quality of onion bulbs and reduces the chance of infection by disease-causing organisms during storage [10]. The cured surface scales provide a dry barrier around the onion bulb and a sealing against internal water loss [9]. On the other hand, topping refers to the removal of top foliage from the bulbs after harvest. Some farmers top their onions immediately after harvesting, while others top after curing. However, topping after curing is recommended

because the chances of wounding and water loss occurring when removing desiccated foliage are minimal [11].

Being a semiperishable crop, onion undergoes deterioration during storage. Proper harvest and postharvest conditions are crucial for onion bulb storability, visual quality, and physicochemical composition. For instance, curing of onions has been shown to improve the content of anthocyanins and flavonols [12], while time of harvesting (age of onion) has been found to affect enzyme activity and accumulation of sugar in bulb onion [13]. It is estimated that 40–60% of total bulb onion produced worldwide is lost during storage through poor postharvest practices which further lower marketable yield [14]. Although onion bulb yield and quality could be improved by proper application of postharvest practices, their singular application might not be suitable in the Kenyan smallholder farmers' context who primarily depend on rain-fed agriculture characterized by low-input systems [7]. It is therefore important that different postharvest strategies such as curing, topping, and harvesting stage be integrated to explore their interactive effect on onion bulb quality. Therefore, this study evaluated the singular and interactive effects harvesting stage, curing period, and time of topping on proximate and nutritional composition of bulb onions.

2. Materials and Methods

2.1. Description of the Experimental Site. The study was conducted in Yatta Subcounty (1°28'00.0" S, 37°50'00.0" E), Machakos County, Kenya. Yatta Subcounty lies within an altitude range of 1000–2100 m above sea level characterized by semiarid climate. The area receives unreliable rainfall patterns, flush floods, and sporadic droughts that are a constant challenge to food security in the region [15]. The predominant soil type is vertisols. Apart from the loose top 4 cm, the soils are generally compacted [16] and exhibit high variances in parameters like cation exchange capacity (CEC), pH, nutrients, and organic carbon [17]. Annual rainfall is estimated to be 250–500 mm. The monthly soil temperatures range from 11.1 to 27.3°C, while atmospheric daily temperature ranges between 6°C and 29°C [6].

Actual weather data at the experimental site showed that the first season (October to December 2019) received more cumulative rainfall of 320 mm than the second season (January to March 2020) which received cumulative rainfall of 239 mm. However, the two seasons received equal average temperature of 27°C and relative humidity of 64% and 66% for seasons one and two, respectively. The onions produced in the first season were cured at an average temperature of 26°C and 67% relative humidity, while those produced in the second season were cured at an average temperature of 27°C and 74% relative humidity. After curing, the storage temperature and humidity were maintained the same in both seasons at 25°C and 70%, respectively.

2.2. Experimental Design and Layout. The experiment was laid out in a split-split plot arranged in a 3 × 3 × 2 factorial design. The treatments consisted of harvesting stage (25%,

50%, and 75% top fall), curing period (none, 1 week, and 2 weeks after harvesting), and time of topping (before and after curing). Harvesting stage was assigned as the main treatment; curing period assigned as subtreatments while time of topping was assigned as sub-subtreatments. The treatments were replicated three times, and the experiment was carried out in two cropping seasons. The land was ploughed to a depth of 40 cm and then harrowed to a medium tilth. Experimental plots measured 4.20 m × 3.15 m consisting of double rows which were 20 cm apart and 50 cm between the double rows. The spacing between plants was 9 cm along rows, corresponding to 21 plants per square meter.

2.3. Agronomic and Management Practices. Red creole variety of bulb onion was used where seeds were first sown in a nursery and later transplanted to the experimental plots two months after sowing. At planting, all the plots were fertilized with well-decomposed chicken manure at a rate of 10 tons ha⁻¹, 70 kg N ha⁻¹ as ammonium sulphate, 80 kg P₂O₅ ha⁻¹ as superphosphate, and 130 kg K₂O ha⁻¹ as potassium sulphate. Other agronomic and management practices including supplemental irrigation, weeding, and pest and disease control were applied as recommended [13].

2.4. Data Collection. Plants from the two middle double rows in each plot were selected for data collection according to the plots layout as determined by different levels of the three treatments, namely, harvesting stage, curing period, and time of topping. Fresh weight of harvested bulbs was recorded immediately after harvesting and before topping. During curing, the topped and untopped bulb samples were spread out on a dry surface under a grass thatched roof shade. Temperature and relative humidity were recorded daily throughout the curing period. After curing, unspoiled and regular-shaped bulbs with diameter larger than 50 mm were classified as marketable and were stored for three months awaiting nutritional composition analysis.

Topping involved removal of foliage by cutting with a sharp knife leaving 2 inches of neck on the bulb. The bulbs that were cured before topping were resized after curing before being stored for three months in a well-ventilated room on wooden benches spread to a layer of 15 cm high. After storage, 30 samples of marketable onions from each treatment were randomly pick, and their residual weight was taken. They were then taken to the laboratory for proximate and nutritional analysis. The outer skin of the sampled bulbs was peeled off before the bulbs were washed and then ground into sample pastes. The paste was put in plastic containers and appropriately labeled according to treatment and replicate. The samples were then analyzed for moisture content, crude protein content, vitamin C, iron (Fe), potassium (K), phosphorus (P), calcium (Ca), and sodium (Na). The moisture content was measured according to AOAC [18]. The crude protein was determined using the procedure described by Nerdy [19]. The contents of Fe, Ca, K, P, and Na were determined using the procedure outlined by Bettoni et al. [20]. Vitamin C content was estimated

titrimetrically using 2,6-dichlorophenol dye as described by Dinesh et al. [21].

2.5. Statistical Analysis. The data on proximate and nutritional variables was subjected to analysis of variance (ANOVA) using XLSTAT version 2020 to determine whether there were significant differences between treatments and their interactions. Significant means were separated using Student–Newman–Keuls (SNK) test at 95% level of confidence. Pearson's correlation was carried out to determine the relationship between different physico-chemical variables.

3. Results

3.1. Effects of Postharvest Treatments on Bulb Moisture Content. The results showed that there was highly significant ($P < 0.0001$) variation in the moisture content of the stored bulb onions after three months in storage. Although the moisture content at the time of harvesting was not taken, it was evident that the bulbs suffered some postharvest moisture loss, which resulted in significant weight loss as shown in Table 1. The bulbs that were harvested at 75% top fall retained significantly higher moisture content (81.89%) during storage as compared to those harvested at 50% top fall (76.70%) and those harvested at 25% top fall (72.09%). Curing of bulbs was also found to have a highly significant ($P < 0.0001$) effect on the moisture content of stored bulbs. The bulbs that were cured for 2 weeks retained significantly higher moisture content (81.19%) in storage as compared to those cured for only 1 week (76.66%) and those that were not cured at all (72.84%). Time of topping was also found to have a significant ($P < 0.0001$) effect on the moisture content retained by the bulbs in storage. The bulbs that were topped after curing retained significantly higher moisture content (78.06%) compared to those that were topped before curing (72.84%). Seasonal variations were also significant as the onions produced in the first season of October to December 2019 recorded higher moisture content than those produced in the second season of January to March 2020 (Table 1).

3.2. Effects of Postharvest Treatments on Weight of Stored Bulb Onions. The weight loss from the bulbs varied significantly ($P < 0.0001$) according to harvesting stage, curing period, and time of topping (Table 1). The bulbs that were harvested at 25% top fall lost significantly more bulb weight (173.82 g) in storage as compared to those harvested at 50% top fall (86.07 g) and those harvested at 75% top fall (72.06 g). The bulbs that were not cured lost significantly more bulb weight (138.51 g) in storage as compared to those cured for 1 week (114.54 g) and those that were cured for 2 weeks (78.90 g). The bulbs that were topped before curing lost significantly more bulb weight (117.50 g) compared to those that were topped after curing (103.81 g). Seasonal variations were also significant with the onions produced in the first season recording higher weight loss than those produced in the second season (Table 1).

3.3. Effects of Postharvest Treatments on Crude Protein. The content of crude protein in stored bulb onions varied significantly ($P < 0.0001$) at different harvesting stages, curing periods, and time of topping (Table 1). The bulbs that were harvested at 75% top fall contained significantly higher crude protein content (0.75 g) compared to those harvested at 50% top fall (0.57 g) and those harvested at 25% top fall (0.39 g). The bulbs that were cured for two weeks before storage contained significantly higher crude protein content (0.86 g) compared to those cured for only one week (0.45 g) and those that were not cured at all (0.40 g). The bulbs that were topped after curing contained significantly higher crude protein content (0.70 g) compared to those that were topped before curing (0.43 g). Seasonal variations were not significant ($P > 0.05$) for crude protein content (Table 1).

Treatment effects were highly significant ($P < 0.0001$) on the moisture content, weight loss, and crude protein content of the stored bulb onions (Table 2). The highest moisture content (86.66%) was retained at harvesting stage of 75% top fall combined with 2-week curing and topping after curing (75% TF-2WC-TA). The same treatment recorded the lowest weight loss of 44.37 g and the highest protein content of 1.02 g which was not significantly different from the protein content recorded at harvesting stage of 50% top fall combined with 2-week curing and topping after curing (50% TF-2WC-TA). The lowest moisture content (66.79%) was retained at harvesting stage of 25% top fall combined with no curing and topping before curing (25% TF-NC-TB). The same treatment recorded the highest weight loss of 219.93 g and the lowest protein content of 0.16 g which was not significantly different from the protein content recorded in treatments 50% TF-NC-TB and 25% TF-1WC-TB (Table 2).

3.4. Effects of Postharvest Treatments on Nutritional Content of Bulb Onions. Different harvesting stages, curing periods, and time of topping were found to have highly significant ($P < 0.0001$) effects on the levels of vitamin C, phosphorus, potassium, and calcium, but harvesting stage had no effect on the level of sodium in bulb onions. Only the harvesting stage had a significant ($P < 0.05$) effect on the level of zinc, while curing period had no significant ($P > 0.05$) effect on the level of iron in the stored bulbs (Table 3). The bulbs that were harvested at 75% top fall contained significantly higher levels of vitamin C, potassium, calcium, and iron compared to those harvested at 50% top fall and 25% top fall (Table 3). However, bulbs harvested at 75% top fall did not vary significantly in their levels of zinc and phosphorus with those harvested at 50% top fall. A similar trend was observed for curing where the bulbs that were cured for 1-2 weeks before storage contained significantly higher levels of vitamin C, potassium, and calcium but lower levels of sodium compared to those that were not cured. Similarly, the bulbs that were topped after curing contained significantly higher levels of vitamin C, phosphorus, potassium, calcium, and iron but lower levels of sodium compared to those that were topped before curing (Table 3). Seasonal variations were also highly significant ($P < 0.0001$) for all the nutrient elements except zinc whose levels did not vary across seasons and iron

TABLE 1: Proximate analysis of stored bulb onions as affected by postharvest treatments.

| Factors | Treatments | Moisture content (%) | Bulb weight loss (g) | Crude protein (g/100g) |
|---------------------|----------------|----------------------|----------------------|------------------------|
| Harvesting stage | 75% top fall | 81.89 A | 72.06 C | 0.75 A |
| | 50% top fall | 76.70 B | 86.07 B | 0.57 B |
| | 25% top fall | 72.09 C | 173.82 A | 0.39 C |
| | <i>P</i> value | <0.0001 | <0.0001 | <0.0001 |
| | Standard error | 0.067 | 0.816 | 0.004 |
| Curing period | 2-week curing | 81.19 A | 78.90 C | 0.86 A |
| | 1-week curing | 76.66 B | 114.54 B | 0.45 B |
| | No curing | 72.84 C | 138.51 A | 0.40 C |
| | <i>P</i> value | <0.0001 | <0.0001 | <0.0001 |
| | Standard error | 0.067 | 0.816 | 0.004 |
| Topping time | Topping after | 78.06 A | 103.81 B | 0.70 A |
| | Topping before | 75.72 B | 117.50 A | 0.43 B |
| | <i>P</i> value | <0.0001 | <0.0001 | <0.0001 |
| | Standard error | 0.054 | 0.666 | 0.004 |
| Seasonal variations | Season 1 | 80.03 A | 116.01 A | 0.56 |
| | Season 2 | 73.75 B | 105.30 B | 0.57 |
| | <i>P</i> value | <0.0001 | <0.0001 | 0.477 |
| | Standard error | 0.054 | 0.666 | 0.012 |

Means followed by the same letter within the column are not significantly different based on SNK at $\alpha = 0.05$, $n = 108$.

TABLE 2: Treatment effect on proximate analysis of stored bulb onions

| Treatments | Moisture content (%) | Weight loss (g) | Protein (g/100 g) |
|----------------|----------------------|-----------------|-------------------|
| 75% TF-NC-TB | 77.48 E | 89.63 GH | 0.31 GH |
| 75% TF-NC-TA | 79.29 DE | 85.19 HI | 0.65 CD |
| 75% TF-2WC-TB | 84.67 B | 58.16 K | 0.76 BC |
| 75% TF-2WC-TA | 86.66 A | 44.37 L | 1.02 A |
| 75% TF-1WC-TB | 80.35 D | 80.14 IJ | 0.50 EF |
| 75% TF-1WC-TA | 82.92 BC | 74.87 J | 0.57 DE |
| 50% TF-NC-TB | 70.62 G | 118.70 F | 0.20 HI |
| 50% TF-NC-TA | 73.79 F | 110.03 F | 0.74 BC |
| 50% TF-2WC-TB | 80.76 CD | 60.17 K | 0.78 BC |
| 50% TF-2WC-TA | 82.78 BC | 52.10 K | 1.00 A |
| 50% TF-1WC-TB | 75.18 F | 96.20 GH | 0.44 EFG |
| 50% TF-1WC-TA | 77.10 E | 79.26 IJ | 0.54 DE |
| 25% TF-NC-TB | 66.79 H | 219.93 A | 0.16 I |
| 25% TF-NC-TA | 69.09 G | 207.61 B | 0.37 FG |
| 25% TF-2WC-TB | 74.64 F | 142.92 E | 0.54 DE |
| 25% TF-2WC-TA | 77.63 E | 115.70 F | 0.86 B |
| 25% TF-1WC-TB | 71.01 G | 191.63 C | 0.23 HI |
| 25% TF-1WC-TA | 73.37 F | 165.14 D | 0.44 EFG |
| <i>P</i> value | <0.0001 | <0.0001 | <0.0001 |
| Standard error | 0.645 | 2.671 | 0.036 |

Means followed by the same letter within the column are not significantly different based on SNK at $\alpha = 0.05$, $n = 108$. TF = top fall; WC = weeks of curing; NC = no curing; TA = topping after; TB = topping before.

which recorded slightly significant ($P < 0.05$) variations between seasons. The levels of vitamin C, potassium, calcium, and sodium were higher in the first season than in the second season. On the other hand, the level of phosphorus and iron was high in stored bulbs produced in the second season than in those produced in the first season (Table 3).

Treatment interactions on different proximate and nutritional variables are shown in Table 4. All the treatment interactions were significant ($P < 0.05$) for the variable weight loss except harvesting stage \times curing period \times topping time. For protein, significant ($P < 0.05$) interactions were observed between curing period \times topping

time and between harvesting stage \times curing period \times topping time. For vitamin C, all the treatment interactions were significant ($P < 0.05$) except harvesting stage \times topping time. For phosphorus, potassium, and sodium, significant ($P < 0.05$) treatment interactions were observed between harvesting stage \times curing period only. There were no significant ($P > 0.05$) treatment interactions for moisture content and zinc and calcium levels in stored bulbs (Table 4).

Treatments effects were highly significant ($P < 0.0001$) on the levels of vitamin C, potassium, calcium, sodium, and iron in stored bulb onions (Table 5). The treatments effects were also slightly significant ($P < 0.05$) on the level of zinc

TABLE 3: Nutritional composition of stored bulb onions as affected by postharvest treatments.

| Factors | Treatments | Vitamin C (mg/100 g) | Zinc (mg/100 g) | Phosphorus (mg/100 g) | Potassium (mg/100 g) | Calcium (mg/100 g) | Sodium (mg/100 g) | Iron (mg/100 g) |
|---------------------|----------------|----------------------|-----------------|-----------------------|----------------------|--------------------|-------------------|-----------------|
| Harvesting stage | 75% top fall | 5.20 A | 0.14 A | 19.91 A | 111.71 A | 14.00 A | 4.46 | 0.182 A |
| | 50% top fall | 4.32 B | 0.13 A | 20.17 A | 109.13 B | 12.23 B | 4.33 | 0.177 B |
| | 25% top fall | 2.85 C | 0.06 B | 17.39 B | 104.81 C | 10.97 C | 4.36 | 0.176 B |
| | <i>P</i> value | <0.0001 | 0.004 | <0.0001 | <0.0001 | <0.0001 | 0.098 (NS) | 0.0005 |
| | Standard error | 0.031 | 0.017 | 0.238 | 0.487 | 0.258 | 0.122 | 0.001 |
| Curing period | 2-week curing | 4.97A | 0.13 | 19.70 A | 110.89 A | 13.14 A | 3.48 B | 0.179 |
| | 1-week curing | 4.16 B | 0.13 | 19.27 A | 109.49 B | 12.42 A | 4.34 A | 0.179 |
| | No curing | 3.24 C | 0.08 | 18.50 B | 105.28 C | 11.63 B | 4.48 A | 0.177 |
| | <i>P</i> value | <0.0001 | 0.068 (NS) | 0.002 | <0.0001 | 0.0004 | <0.0001 | 0.177 (NS) |
| | Standard error | 0.031 | 0.017 | 0.238 | 0.487 | 0.258 | 0.012 | 0.001 |
| Topping time | Topping after | 4.38 A | 0.11 | 19.71 A | 110.11 A | 13.16 A | 4.24 B | 0.180 A |
| | Topping before | 3.87 B | 0.12 | 18.61 B | 106.10 B | 11.64B | 4.62 A | 0.176 B |
| | <i>P</i> value | <0.0001 | 0.609 (NS) | 0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.010 |
| | Standard error | 0.025 | 0.014 | 0.194 | 0.398 | 0.211 | 0.034 | 0.051 |
| Seasonal variations | Season 1 | 4.24 A | 0.10 | 16.44 B | 112.20 A | 12.85 A | 4.61 A | 0.180 A |
| | Season 2 | 4.00 B | 0.12 | 21.87 A | 104.91 B | 11.95 B | 4.25 B | 0.177 B |
| | <i>P</i> value | <0.0001 | 0.233 (NS) | <0.0001 | <0.0001 | 0.003 | <0.0001 | 0.040 |
| | Standard error | 0.031 | 0.014 | 0.194 | 0.398 | 0.211 | 0.037 | 0.001 |

Means followed by the same letter within the column are not significantly different based on SNK at $\alpha = 0.05$, $n = 108$.

TABLE 4: *P* values of interactions between different treatment factors.

| Factor interactions | MC | Weight loss | Protein | Vitamin C | Zn | P | K | Ca | Na | Fe |
|---------------------|-------|--------------|--------------|--------------|-------|--------------|--------------|-------|--------------|-------|
| HS*CP | 0.101 | 0.000 | 0.820 | 0.000 | 0.194 | 0.006 | 0.010 | 0.063 | 0.002 | 0.087 |
| HS*TT | 0.830 | 0.000 | 0.334 | 0.318 | 0.641 | 0.885 | 0.372 | 0.127 | 0.223 | 0.899 |
| CP*TT | 0.985 | 0.015 | 0.000 | 0.010 | 0.538 | 0.581 | 0.691 | 0.134 | 0.331 | 0.497 |
| HS*CP*TT | 0.751 | 0.078 | 0.000 | 0.019 | 0.226 | 0.807 | 0.381 | 0.511 | 0.776 | 0.302 |

Values in bold represent significant interactions at $\alpha = 0.05$. HS = harvesting stage. CP = curing period. TT = topping time.

but were not significant ($P < 0.05$) on phosphorous levels in the stored bulbs. The treatment 75%TF-2WC-TA combining the late harvesting stage at 75% top fall, 2-week curing, and topping after curing recorded the highest levels of vitamin C and calcium but the lowest levels of sodium. The lowest ($P < 0.0001$) levels of vitamin C were observed in treatment 25% TF-NC-TB, which also recorded the highest levels of sodium. The other nutrients did show a very clear trend on how they were affected by different harvest and postharvest treatments (Table 5).

There was a significant ($P < 0.05$) negative correlation between moisture content and weight loss of the bulbs indicating that moisture loss contributed significantly to the weight loss in the bulbs (Table 6). The weight loss also correlated negatively to crude protein and all the nutrients except sodium which was the only element that was found to be positively correlated to weight loss. Moisture content was positively correlated to crude protein, vitamin C, potassium, calcium, and iron but negatively correlated to sodium. There was also significant positive correlation between vitamin C and the nutritional elements potassium, calcium, and iron, all of which were negatively correlated to sodium. There was no significant ($P > 0.05$) correlation between zinc and all the other nutritional and proximate components except vitamin C. Similarly, the level of phosphorus in stored bulbs had no significant ($P > 0.05$) correlation with all the other factors

except sodium and weight loss with which it was negatively correlated (Table 6).

4. Discussion

Physiological maturity at harvest and subsequent postharvest treatments are known to have profound influence on postharvest quality of many horticultural crops. This study sought to determine the effects of physiological maturity of bulb onion at harvesting, period of curing, and timing of topping (foliage removal) on some proximate and nutritional composition of stored bulbs. The data was taken at three months after harvesting, representing two initial weeks of postharvest treatments and ten weeks of undisturbed storage. This period coincides with the average time taken by most farmers to sell their onions after harvest although bulb onions can keep for up to nine months under good storage conditions [8]. Onion is a seasonal crop which attracts very high prices during off-season and very low prices during peak seasons [22]. Extending the storage period of onions enables the farmers to time for higher prices thus ensuring more profit [23].

The harvesting stage of the bulb onions was found to have a profound effect on proximate and nutritional composition of bulb onions. This observation corroborated earlier reports by Biswas et al. [24] and Nabi et al. [23] who

TABLE 5: Treatment effect on nutritional composition of stored bulb onions.

| Treatments | Vitamin C (mg/100 g) | Zinc (mg/100 g) | Phosphorus (mg/100 g) | Potassium (mg/100 g) | Calcium (mg/100 g) | Sodium (mg/100 g) | Iron (mg/100 g) |
|----------------|-------------------------|--------------------|--------------------------|-------------------------|-----------------------|----------------------|--------------------|
| 75% TF-NC-TB | 3.87 F | 0.18 AB | 18.86 | 104.85 BE | 13.60 BCD | 4.98 CDE | 0.176 AB |
| 75% TF-NC-TA | 4.53 DE | 0.09 AB | 20.33 | 109.29 AE | 14.04 BC | 4.70 DEF | 0.184 AB |
| 75% TF-2WC-TB | 5.95 B | 0.13 AB | 19.80 | 113.19 ABC | 12.83 BCD | 3.19 J | 0.188 A |
| 75% TF-2WC-TA | 6.45 A | 0.17 AB | 20.56 | 113.82 AB | 16.36 A | 2.60 K | 0.185 A |
| 75% TF-1WC-TB | 4.95 CD | 0.11 AB | 19.17 | 114.00 AB | 12.34 BE | 4.13 GH | 0.179 AB |
| 75% TF-1WC-TA | 5.45 C | 0.14 AB | 20.77 | 115.10 A | 14.82 AB | 3.58 IJ | 0.181 AB |
| 50% TF-NC-TB | 3.24 G | 0.05 AB | 19.55 | 103.97 CDE | 10.81 DEF | 4.98 CDE | 0.176 AB |
| 50% TF-NC-TA | 3.74 F | 0.07 AB | 20.88 | 107.76 AE | 12.53 BE | 4.87 CDE | 0.177 AB |
| 50%TF-2WC-TB | 4.94 CD | 0.14 AB | 19.68 | 110.27 AE | 11.38 CF | 3.70 HIJ | 0.175 AB |
| 50%TF-2WC-TA | 5.34 C | 0.15 AB | 20.83 | 113.84 AB | 13.70 BCD | 3.33 IJ | 0.178 AB |
| 50%TF-1WC-TB | 4.14 EF | 0.25 A | 19.88 | 107.21 AE | 11.91 BF | 4.45 EFG | 0.174 AB |
| 50%TF-1WC-TA | 4.54 DE | 0.13 AB | 20.23 | 111.77 AD | 13.04 BCD | 4.28 FG | 0.182 AB |
| 25%TF-NC-TB | 1.72 I | 0.03 B | 14.92 | 101.42 E | 9.17 F | 6.50 A | 0.171 B |
| 25%TF-NC-TA | 2.37 H | 0.04 B | 16.48 | 104.37 BE | 9.65 EF | 5.60 B | 0.176 AB |
| 25%TF-2WC-TB | 3.15 G | 0.08 AB | 18.50 | 104.58 BE | 11.73 CF | 4.33 FG | 0.174 AB |
| 25%TF-2WC-TA | 3.97 EF | 0.09 AB | 18.83 | 109.63 AE | 12.87 BCD | 3.74 HI | 0.177 AB |
| 25%TF-1WC-TB | 2.85 G | 0.06 AB | 17.10 | 103.47 DE | 10.99 CF | 5.34 C | 0.178 AB |
| 25%TF-1WC-TA | 3.00 G | 0.07 AB | 18.50 | 105.42 BE | 11.42 CF | 5.09 CD | 0.180 AB |
| P value | <0.0001 | 0.027 | 0.132 (NS) | <0.0001 | <0.0001 | <0.0001 | 0.004 |
| Standard error | 0.155 | 0.041 | 1.345 | 2.016 | 0.661 | 0.138 | 0.003 |

Means followed by the same letter within the column are not significantly different based on SNK at alpha = 0.05, n = 108. TF = top fall; WC = weeks of curing; NC = no curing; TA = topping after; TB = topping before.

TABLE 6: Pearson's correlation matrix between nutritional variables in stored bulb onions.

| Variables | MC* | | | | | | | | | |
|-------------|---------------|---------------|---------------|---------------|--------|---------------|---------------|---------------|---------------|--|
| Weight loss | -0.703 | Weight loss | | | | | | | | |
| Protein | 0.681 | -0.663 | Protein | | | | | | | |
| Vitamin C | 0.856 | -0.880 | 0.724 | Vitamin C | | | | | | |
| Zn | 0.191 | -0.363 | 0.177 | 0.316 | Zn | | | | | |
| P | -0.163 | -0.496 | 0.215 | 0.252 | 0.213 | P | | | | |
| K | 0.833 | -0.502 | 0.496 | 0.631 | 0.107 | -0.264 | K | | | |
| Ca | 0.600 | -0.559 | 0.428 | 0.547 | 0.201 | 0.177 | 0.573 | Ca | | |
| Fe | 0.479 | -0.286 | 0.338 | 0.450 | -0.007 | -0.110 | 0.447 | 0.199 | Fe | |
| Na | -0.678 | 0.831 | -0.796 | -0.829 | -0.274 | -0.425 | -0.446 | -0.468 | -0.329 | |

Values in bold are different from 0 with a significance level alpha = 0.05. * Moisture content.

reported that retention of onion bulb quality during storage depends majorly on the bulb maturity. Delayed harvesting (at 75% top fall) was found to retain significantly higher nutrients and moisture content and suffered minimal weight loss from stored bulbs than early harvesting. Moisture retention was attributed to reduced rates of transpiration while higher content of mineral nutrients was attributed to translocation of these minerals from the drying leaves to the bulbs during the period of delayed harvesting. Moisture content of the bulb is a major factor associated with spoilage of onion during storage [24]. Moisture loss during storage results in wilting and shrinking of onion bulbs and subsequent postharvest quality losses [25]. Our study showed that bulbs that were harvested at 75% top fall had a higher residual weight, took significantly longer time to sprout during storage, had lower incidences of skin rots, more enhanced skin colour, and higher percentage of marketable bulbs [6]. This observation corroborated the earlier report by Woldetsadik and Workneh [26] that harvesting of onions at 75% top fall produced marketable bulbs with better dry matter

content, reduced rotting, sprouting, and weight loss. In our study, bulbs harvested at 75% top fall retained 13.6% higher moisture content than those harvested at 25% top fall after 45 days of storage. Although we did not take the moisture content of the bulbs at harvesting, it was apparent that the onions harvested at 25% top fall lost significantly more moisture than those harvested at 50% and 75% top fall.

Curing of bulbs was also found to have a significant effect on the proximate and nutritional composition of stored bulbs. The bulbs that were cured for two weeks retained significantly higher moisture content and recorded significantly lower weight loss in storage than those cured for only 1 week and those that were not cured at all. The longer period of curing also resulted in delayed sprouting in storage, reduced incidences of skin rots, more enhanced skin colour, and higher percentage of marketable bulbs [6]. According to Opara [27], both curing and drying remove excess moisture from the outer layers of the bulb prior to storage. Bulb curing hardens the outer skin which subsequently acts like a protective coat against loss of internal

moisture, thus maintaining quality [28]. The dried skin provides a surface barrier to water loss and microbial infection, thereby preserving the main edible tissue in a fresh state [27]. Drying also reduces bulb weight, and since bulb onions are sold mostly on weight basis, achieving the desired level of dehydration is critical [27]. Our study showed that longer period of curing (2 weeks) significantly increased the retained levels of protein, vitamin C, phosphorus, potassium, and calcium but decreased the content of sodium in the bulbs. This was attributed partly to reduced moisture loss from the cured bulbs following the formation of the surface barrier and partly to translocation of some nutrients from the drying outer scale to the inner bulb tissue during curing. Curing of onions is therefore highly desirable considering that onion contains relatively low levels of nutrients and minerals but higher moisture content compared to other vegetables [29].

Time of topping was also found to have a significant effect on the proximate and nutritional composition of stored bulbs. The bulbs that were topped after curing retained significantly higher moisture content and lost significantly lesser weight than those that were topped before curing. We noted that topping the bulbs immediately after harvesting caused excessive bleeding, which resulted in moisture loss, subsequent weight loss, and shrinkage of the bulbs. Topping before curing also reduced the keeping time before sprouting, increased the incidences of skin rots, and resulted in lower percentage of marketable bulbs although it had no significant effect on the skin colour [6]. Nabi et al. [23] also observed higher moisture content and lesser weight loss on onion bulbs that were cured with their foliage intact than in those whose foliage was cut off before curing. They concluded that onion bulb quality can be maintained longer by curing with foliage intact. The bulbs that were topped after curing were also found to retain significantly higher protein, vitamin C, phosphorous, potassium, calcium, and iron than those that were topped before curing. For protein and vitamin C, this observation may be attributed to moisture loss while for the mineral nutrients, it was attributed to translocation of the nutrients from the drying leaf tissues to the bulbs during curing. However, the content of sodium in stored bulbs was found to be higher in bulbs that were topped before curing than those that were topped after curing. This was attributed to high moisture loss that increased the concentration of sodium in the bulbs. From the literature, there are very few publications on the effects of time of topping on physicochemical properties of onion bulbs in storage.

Our study observed significant interactions between the three treatment factors (harvesting stage, curing period, and time of topping) for some of the quality parameters that were measured, majorly weight loss, protein content, and levels of vitamin C. The levels of phosphorous, potassium, and sodium also portrayed significant interactions between harvesting stage and curing period. In addition, interaction between harvesting stage and curing period had a significant effect on days to sprouting, incidence of skin rots, and percent of marketable grade [6]. This was an indication that effective maintenance of quality during storage may be an

interplay of the recommended harvest and postharvest practices. Apparently, mature bulbs respond better to curing, which hardens the outer skin of the bulbs and subsequently prevents internal moisture loss, weight loss, and nutrients loss. Wright et al. [10] also reported that onions that are harvested early when the tops are green and succulent take longer to cure than those with desiccated tops. On the other hand, topping of bulbs before curing causes excessive bleeding which causes significant weight loss, reduction of total soluble solids, and possibly loss of nutrients [30]. These previous observations explain the significant deterioration in bulb quality observed in our study among those onions that were harvested at 25% top fall, topped immediately after harvesting and then either not cured or cured for only one week.

Bulb onions reportedly contain 0.17 mg/100 g zinc, 29 mg/100 g phosphorus, 146 mg/100 g potassium, 23 mg/100 g calcium, 3.75 mg/100 g sodium, 0.21 mg/100 g iron, 7.4 mg/100 g vitamin C, and 1.1 g/100 g protein among other nutrients [25]. The physicochemical levels observed in our study were lower than expected levels except for zinc and sodium. However, the difference between the expected and observed levels was relatively smaller under treatments 75% TF-1WC-TA and 75% TF-2WC-TA combining the late harvesting stage at 75% top fall, 1- or 2-week curing, and topping after curing. This was an indication that delayed harvesting combined with proper curing and topping after curing are a good bet towards ensuring postharvest quality of bulb onions. There was significant positive correlation between moisture content and levels of potassium, calcium, iron, vitamin C, and crude protein in raw stored bulbs indicating that moisture loss was associated with loss of these nutrients. Armand et al. [31] noted that the major challenge during drying of food materials is to reduce the moisture content of the material to the desired level without substantial loss of nutrients. However, it was not expected that loss of moisture would result in loss of nutrients that are not water-soluble, but their mobility in plant tissues may offer a better explanation. Probably, there was some translocation of minerals from the outer scales and drying leaf tissues to the inner fleshy bulbs during curing. Sharma et al. [32] also reported that postharvest conditions play an important role in the physiology of onions, which ultimately affects their physicochemical and phytochemical properties.

Significant seasonal variations that were observed for all parameters except for crude protein and zinc content were attributed to different weather conditions that were experienced in the two seasons as described in Section 2.1 of this paper. Although there was supplemental irrigation which was done whenever it was deemed necessary, the bulbs grown in the first season accumulated higher moisture content than those grown in the second season. Soil moisture levels are reportedly influential in soil nutrients availability, nutrients uptake, and tissue nutrient concentration. The seasonal variations may also result from differences in weather conditions prevailing during curing and subsequent storage [23]. In our study, the storage temperature and humidity were maintained the same in both seasons, but there were variations in the curing temperature

and humidity as described in Section 2.1 of this paper. Wright et al. [10] also reported that prevailing weather conditions during field-curing affect the postharvest quality of harvested bulb onions.

5. Conclusion and Recommendations

This study concludes that harvesting stage, curing period, time of topping, and their interactions have a significant influence on postharvest quality of onions. Curing is the major factor that helps to maintain the quality of bulbs in storage but its effectiveness is dependent on the physiological maturity of the bulbs and proper timing of foliage removal. The prevailing environmental conditions before, during, and after harvesting may also have a significant influence on the effectiveness of curing and subsequent deterioration of quality during storage. The study recommends that onions produced in Machakos County and other areas with similar climatic conditions be harvested at 75% top fall, cured for 2 weeks, and topped after curing to ensure higher postharvest bulb quality. However, similar studies need to be performed under different environmental conditions. There is also need to conduct optimization studies to precisely determine the optimum harvesting stage and curing period at different environmental conditions.

Data Availability

Some of the data used to support the findings of this study are included in the article. Additional data are available from the corresponding author upon request.

Conflicts of Interest

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

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