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Research Article

Visual and Keeping Quality of Stored Bulb Onions as Affected by Harvest and Postharvest Treatments

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Productivity of onion (*Allium cepa* L.) in Kenya is constrained by postharvest losses. Most postharvest strategies applicable to onions are applied singularly, and therefore, their combined effects have not been well studied. This study evaluated the combined effects of harvesting stage, curing period, and time of topping on postharvest visual and keeping quality of red bulb onions. The study was carried out in Yatta Sub-County, Machakos County, Kenya. The experimental design was a split-split plot laid out in $3 \times 3 \times 2$ factorial arrangement. The treatments consisted of harvesting stage (25%, 50%, and 75% top fall), curing period (none, 1 week, and 2 weeks) and time of topping (before and after curing). After three months of storage, the bulbs were assessed for visual and keeping quality using incidences of skin rots, skin colour, percent of marketable bulbs, residual weight of the bulbs after curing, and days to 50% sprouting. Bulbs that were harvested at 75% top fall and cured for one or two weeks before topping were found to have significantly better visual and keeping quality. Although seasonal variations were significant for some of the parameters assessed, a similar trend was observed in both seasons. The study recommends harvesting of onions at 75% top fall and curing for at least one week before topping for enhanced visual and keeping quality of harvested bulb onions.

1. Introduction

Onion (*Allium cepa* L.) belongs to the Alliaceae family and is a valuable vegetable crop worldwide [1]. In addition to being consumed as a vegetable, onions also have medicinal values [2]. Bulb onion contains antioxidants which keep lifestyle-related diseases in check, and thus it is a vital component of a balanced diet [3]. By large, it forms part of food security as it is a source of nutrients required by the human body. In Kenya, onion is an important commercial vegetable crop among smallholder farmers but the national average production and quality are highly compromised by poor agronomic and postharvest practices [4]. 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].

Postharvest losses in onions in Kenya are estimated at 40–60% thus contributing highly to reduction of marketable yield [4]. Therefore, proper postharvest handling is perquisite in order to meet food demand for the growing population in Kenya. Proper postharvest conditions are crucial for onion bulb storability but could also affect its quality and marketability traits such as weight, texture and colour, and chemical and nutritional composition [6]. Although onion bulb quality could be improved by proper application of postharvest practices, their singular application might not be suitable in the context of Kenyan smallholder farmers [7] whose production is usually below average. It is therefore important that different postharvest practices such as harvesting stage, curing, and time of topping are properly integrated to explore their interactive effect on onion bulb quality.

Quality characteristics of harvested onions include bulbs that have intact, unblemished, and clean skin that is free of diseases and have the appropriate colour expected for that cultivar [8]. These characteristics are achieved by harvesting of properly mature bulbs and then proper maintenance after harvest through application of various postharvest practices [2]. Owing to the sensitivity of onion consumers to quality, the commercial value of onions is largely determined by their visual quality including the skin colour. For red bulb onions, the most desirable colour is pinkish-red to deep red and onions with blemished, pale, or greenish skins are considered inferior [9].

Harvesting stage is one of the cultural practices being presently explored in management of postharvest quality of bulb onions and other related species. When bulb onions start to mature, the tops (foliage) become yellow and begin to fall over. The percentage top fall is the best indicator of maturity of bulb onions. Woldetsadik and Workneh [10] reported a significant increase in the bulb yield and increased dry matter content in shallot bulbs when harvesting was delayed to 100% top fall. In the same study, the authors observed low incidences of skin rot, lower weight loss, and more marketable grades of bulbs when harvested at 75% top fall. Akrofi et al. [11] also found that postharvest diseases of bulb onion can be significantly reduced by altering the harvesting stage thus improving the quality of the bulbs. Eshel et al. [12] also observed that onion bulbs harvested at 80–100% leaf drop while accommodating roughly 10 cm of neck above the bulb resulted in less skin cracks, leading to a durable tunic below the murky outer skin of the onions.

Curing is a drying process carried out to remove excess moisture from the outer skins, roots, and neck tissues of harvested onion bulbs. It enhances the skin colour, reduces bulb susceptibility to harmful microorganisms, and allows the production of aroma enhancing volatile compounds [13]. It also creates a tunic which averts extreme water being lost from the bulb and lessens disease occurrence [14]. Additionally, onion curing dehydrates outer bulb skin which peels off leaving behind a cleaner finished skin that improves the bulb appearance. Proper curing has also been shown to modify the biochemical quality of onions [15]. For example, field curing was found to increase the quercetin content of white and red Portuguese onion varieties by 33–40% [16].

Together with curing, time of topping has also been explored in improving the storage quality of bulb onion. Topping of bulb onions refers to removal of foliage from the bulb by cutting back at 2–5 cm above the bulb [9]. Most onion farmers practice field topping. However, Schroeder et al. [17] reported that field topping can be detrimental as it might create an avenue for pathogen infection. High occurrence of skin rots and splitting were observed in bulb onions lifted three weeks after 50% top-down and topped before curing [9]. It is therefore important to document the effects of time of topping in relation to curing.

From the above literature, it is evident that proper harvesting stage coupled with proper curing and topping may have a significant contribution to the postharvest quality of bulb onions. However, many onion farmers in Kenya have not embraced integrated application of these postharvest practices instead of singular application. Other farmers may have adopted the practices but lack proper guidance on the optimal levels or duration of application. Storage conditions including relative humidity and temperature may also play a pivotal role in the management of postharvest quality [18]. The objective of this study was therefore to evaluate the interactive effects of harvesting stage, curing period, and time of topping on postharvest visual and keeping quality of red bulb onion under controlled conditions.

2. Materials and Methods

2.1. Experimental Site. The study was conducted in Yatta Sub-County (1°28′00.0″S 37°50′00.0″E), Machakos County, Kenya. Yatta Sub-County lies within altitude range of 1000–2100 m above sea level characterized by arid and semi-arid climate. The study area receives unreliable rainfall patterns, flush floods, and sporadic droughts that are a constant challenge to food security in the region [19]. The predominant soil type is Vertisols. Apart from the loose top 4 cm, the soils are generally compacted and are low in organic matter and fertility [20]. Soils exhibit high variances in parameters like cation exchange capacity (CEC), pH, nutrients, organic carbon, and moisture content as influenced in part by farm management [21]. 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 [22].

2.2. Experimental Design and Field Layout. The experimental design was split-split plot arranged in a $3 \times 3 \times 2$ factorial design. The experiment consisted of three harvesting stages (25, 50, and 75% top fall), three curing periods (none, 1 week, and 2 weeks after harvesting), and two topping times (topping before and topping after curing). Harvesting stage was assigned as the main treatment, curing period assigned to sub-treatments, while time of topping was assigned to sub-sub treatments (Table 1). The treatments were replicated three times and the experiment was carried out in two cropping seasons. Although the actual application of treatments started at harvesting, the experimental layout was adopted right from planting time and not after harvesting. This ensured avoidance of bias thus increased the precision of data collected.

2.3. Experimental Material and Seasons. In this experiment, "Red Creole" bulb onion was used as plant material because of its superiority in anthocyanin content and commercial values [1, 23]. The experiment was conducted in two seasons. The first season production took place between October and December, 2019, while the second season took place between January and March, 2020. The onion seedlings were established in a nursery two months prior to the start of each season for transplanting in the experimental plots when they were two months old.

2.4. Land Preparation and Planting. The land was ploughed at 40 cm depth and harrowed to medium tilth. The experimental plots measured 4.20 m × 3.15 m and consisted of double rows which were 20 cm apart and 50 cm between the double rows. 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 P_2O_5 ha^{-1} as superphosphate, and 130 kg K_2O ha^{-1} as potassium sulphate. The spacing between plants was 9 cm corresponding to 21 plants per square meter. Other management practices including control of pests and diseases, supplemental irrigation,

Table 1: Treatment combinations.

Main plot (harvesting stage)	Sub-plot (curing period)	Sub-sub plot (time of topping)
At 75% top fall	No curing	Topped at harvesting Topped 2 weeks after harvesting
	1-week curing	Topped at harvesting Topped 2 weeks after harvesting
	2 weeks' curing	Topped at harvesting Topped 2 weeks after harvesting
At 50% top fall	No curing	Topped at harvesting Topped 2 weeks after harvesting
	1-week curing	Topped at harvesting Topped 2 weeks after harvesting
	2 weeks' curing	Topped at harvesting Topped 2 weeks after harvesting
At 25% top fall	No curing	Topped at harvesting Topped 2 weeks after harvesting
	1-week curing	Topped at harvesting Topped 2 weeks after harvesting
	2 weeks' curing	Topped at harvesting Topped 2 weeks after harvesting

and weeding were conducted uniformly in all plots using recommended practices [4]. Temperature and rainfall data were recorded daily throughout the growing period.

2.5. Harvesting and Curing. Harvesting was done by holding the onion's neck, gently pulling it up, and shaking off excess soil. The two middle double-rows in each plot were sampled for data collection. The fresh weight of harvested bulbs was taken immediately after harvesting using a weighing balance before topping while the residual bulb weight was taken after two months of storage after topping. Curing was achieved by spreading out the topped and un-topped bulb samples on a dry surface under a thatched roof shade. Temperature and relative humidity were recorded daily throughout the curing period. 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. The bulbs that were cured before topping were topped after curing before storage.

2.6. Storage. After curing, unspoiled and regular-shaped bulbs with diameter bigger than 50 mm were classified as marketable and were stored for three months, after which the data was taken on the visual and keeping quality of the bulbs. The three-month storage period represented 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 [24]. The onions were stored in a well ventilated room with a thatched roof and they were spread on wire mesh benches in a layer of 15 cm. The storage temperature averaged 25°C and the mean relative humidity varied between 70 and 74% in both seasons.

2.7. Quality Assessment. After three-month storage, a sample of 30 onions was randomly taken from each treatment and scored for postharvest quality. The keeping quality was assessed using the residual weight after curing, net weight loss, and days to 50% sprouting. The weight was taken using a digital weighing scale (Adam Equipment, UK). Days to 50% sprouting was determined by counting the number of days from the date of harvesting up to when 50% of the bulbs sprouted. The visual quality was assessed by scoring the incidences of skin rots (counts of the rot spots), skin colour (using a score scale of 1–3 described as 1 = light red, 2 = pinkish-red, and 3 = dark red), and percent of marketable bulbs (excluding rotten and sprouted bulbs).

2.8. Statistical Analysis. The variable data was subjected to analysis of variance (ANOVA) using XLSTAT version 2020 (https://www.xlstat.com/en/news/xlstat-version-2020-1) to determine whether there were significant differences between treatments and their interactions. Significant means were separated using Student's Newman–Keuls (SNK) test at 95% level of confidence. Pearson correlation was carried out to determine the relationship between different visual and keeping quality parameters.

3. Results

3.1. Weather Data. 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.

3.2. Effects of Harvest and Postharvest Treatments on Keeping Quality of Bulb Onions. This study demonstrated significant ($p < 0.05$) effects of harvest and postharvest treatments on keeping quality of bulb onions. The harvesting stage had a highly significant ($p < 0.0001$) effect on fresh weight, residual

weight, weight loss, and days to 50% sprouting. Harvesting at 75% top fall recorded the highest fresh and residual weight, the lowest weight loss, and the longest time to 50% sprouting. This was followed in a similar trend by harvesting at 50% top fall and at 25% top fall (Table 2). The curing period and topping time also had a highly significant ($p < 0.0001$) effect on residual weight, weight loss, and days to 50% sprouting. Curing for 2 weeks recorded higher residual weight, lower weight loss, and longer time before sprouting as compared to one week curing and no curing (Table 2). Topping after curing also reduced the net weight loss from the bulbs, thus recording a higher residual weight and longer time before sprouting. Seasonal variations were also highly significant ($p < 0.0001$) for fresh weight, residual weight, and weight loss but not significant ($p > 0.05$) for days to 50% sprouting (Table 2).

Analysis of variance with all the factors combined showed that there were highly significant ($p < 0.0001$) treatment effects on bulb residual weight, weight loss, and days to 50% sprouting. The treatment 75%TF-2WC-TA that combined harvesting stage of 75% top fall with two weeks curing and topping after curing recorded the lowest weight loss and the longest time to 50% sprouting. However, all bulbs that were harvested at 75% top fall did not vary significantly in their residual bulb weight regardless of other postharvest treatments (Table 3). Therefore, the best keeping quality was achieved under treatment 75%TF-2WC-TA.

3.3. Effects of Harvest and Postharvest Treatments on Visual Quality of Bulb Onions. This study demonstrated significant ($p < 0.05$) effects of harvest and postharvest treatments on visual quality of bulb onions. Harvesting stage had a highly significant ($p < 0.0001$) effect on the incidences of skin rots, skin colour, and percent of marketable bulbs. Harvesting at 75% top fall recorded the lowest incidences of skin rots and most of bulbs had desirable skin colour ranging from pinkish to dark red (score 2.58). This treatment also recorded the highest percentage of marketable onions of 97.75% (Table 4). The curing period also had a highly significant ($p < 0.0001$) effect on the incidences of skin rots, skin colour, and percent of marketable bulbs. Curing for two weeks significantly reduced the incidences of skin rots, improved the skin colour, and increased the percentage of marketable bulbs as compared to one week curing and no curing (Table 4). Similarly, time of topping had a highly significant effect on the incidences of skin rots ($p < 0.0001$), skin colour ($p < 0.01$), and percent of marketable bulbs ($p < 0.0001$). Topping after curing recorded significantly lower incidences of skin rots, more pronounced skin colour, and higher percentage of marketable bulbs (Table 4). Seasonal variations were also highly significant ($p < 0.0001$) for percent marketable grade but were not significant ($p > 0.05$) for skin rot incidences and skin colour (Table 4).

Analysis of variance with all the factors combined showed that the treatments that combined harvesting stage of 75% top fall with one or two weeks curing and either topping after curing or before curing (75%TF-2WC-TB, 75% TF-2WC-TA, 75%TF-1WC-TB, and 75%TF-1WC-TA) recorded the highest percentage of marketable bulbs. However, skin colour and the incidences of skin rots were not significantly different in most of the bulbs harvested at 75% top fall and 50% top fall but subjected to different curing and topping treatments (Table 5).

3.4. Interactions between Treatment Factors on Visual and Keeping Quality Parameters. There were significant harvesting stage *x* curing period interactions for weight loss, days to 50% sprouting, skin rots, and percent marketable grades (Table 6). Harvesting *x* topping time interaction was significant for weight loss, sprouting time, and percent marketable grades. Interaction between curing period and time of topping was significant only for the variable weight loss while interaction between harvesting stage *x* curing period *x* topping time was significant only for sprouting time (Table 6).

3.5. Pearson Correlation between Visual and Keeping Quality Parameters. There was significant ($p < 0.05$) negative or positive correlations between different variables as shown in Table 7. The variables weight loss and skin rots were found to be negatively correlated to all the other variables, namely, fresh weight, residual weight, days to 50% sprouting, skin colour, and percent marketable grades, all of which were positively correlated to each other. The weight loss was also positively correlated to skin rots.

4. Discussion

Physiological maturity at harvest and subsequent postharvest treatments are known to have profound influence on postharvest quality of many crops including shallots [10], yams [18] tomatoes [25], apricots [26], and different types of onions [6, 8, 9, 13]. 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 postharvest quality of stored bulbs. Since onion attracts very high prices during off-season [27], extending the storage period of onions would enable the farmers to time for higher prices thus ensuring more profit [28]. According to Wright et al. [9], the physiological maturity of onions at harvesting, the prevailing weather conditions during curing, and the method of curing all affect the visual and keeping qualities of harvested bulbs. Therefore, the quality characteristics of bulb onions are achieved by harvesting at appropriate maturity stage and then maintained after harvest through application of various postharvest practices [2].

This study showed that the harvesting stage of bulb onions is an important factor in determining the ultimate yields. Delayed harvesting (at 75% top fall) resulted in the highest bulb fresh weight and hence higher yields than early harvesting. This shows that, even after 50% top fall, the onion bulbs continue to expand and to gain more weight. This observation was in support of some previous studies that reported that harvesting stage has a significant effect on yields of onions and related plants [10, 29, 30]. When studying the effect of harvest date on onion yield in a

Table 2: Keeping quality of bulb onions subjected to harvest and postharvest treatments.

Factors	Treatments	Fresh weight (kg)	Residual weight (kg)	Weight loss (kg)	Days to 50% sprouting
Harvesting stage	75% top fall	1081.22 A	1009.16 A	72.06 C	79.56 A
	50% top fall	893.05 B	806.97 B	86.07 B	67.97 B
	25% top fall	656.03 C	482.20 C	173.82 A	60.08 C
	p value	<0.0001	<0.0001	<0.0001	<0.0001
	Standard error	8.159	8.277	1.079	0.419
Curing period	2 weeks' curing	N/A	797.39 A	78.90 C	84.00 A
	1-week curing	N/A	760.58 B	114.54 B	72.00 B
	No curing	N/A	740.37 B	138.51 A	51.61 C
	p value	N/A	<0.0001	<0.0001	<0.0001
	Standard error	N/A	8.277	1.079	0.419
Topping time	Topping after	N/A	773.17	103.81 B	72.11 A
	Topping before	N/A	759.05	117.50 A	66.30 B
	p value	N/A	<0.0001	<0.0001	<0.0001
	Standard error	N/A	6.758	0.881	0.342
Seasonal variations	Season 1	926.43 A	810.42 A	116.01 A	68.96
	Season 2	827.10 B	721.80 B	105.30 B	69.44
	p value	<0.0001	<0.0001	<0.0001	0.322^{NS}
	Standard error	6.662	6.758	0.881	0.342

Means followed by the same letter within the column for each treatment factors are not significantly different at alpha = 0.05; N/A: not applicable; NS: not significant.

Table 3: Treatment effects on keeping quality of bulb onions.

Treatments	Residual weight (kg)	Weight loss (kg)	Days to 50% sprouting
75%TF-NC-TB	**989.70 A**	89.63 GH	50.00 IJ
75%TF-NC-TA	**995.63 A**	85.19 HI	59.50 H
75%TF-2WC-TB	**1021.58 A**	58.16 K	95.00 B
75%TF-2WC-TA	**1038.45 A**	44.37 L	102.83 A
75%TF-1WC-TB	**1002.76 A**	80.14 IJ	83.50 C
75%TF-1WC-TA	**1006.81 A**	74.87 J	86.50 C
50%TF-NC-TB	774.51 B	118.70 F	48.33 JK
50%TF-NC-TA	782.93 B	110.03 F	53.17 I
50%TF-2WC-TB	832.30 B	60.17 K	79.67 D
50%TF-2WC-TA	841.00 B	52.10 K	86.33 C
50%TF-1WC-TB	797.50 B	96.20 G	65.67 G
50%TF-1WC-TA	813.60 B	79.26 IJ	74.67 E
25%TF-NC-TB	437.50 D	219.93 A	46.33 K
25%TF-NC-TA	461.94 CD	207.61 B	52.33 I
25%TF-2WC-TB	520.14 C	142.92 E	69.50 F
25%TF-2WC-TA	530.85 C	115.70 F	70.67 F
25%TF-1WC-TB	455.51 CD	191.63 C	58.67 H
25%TF-1WC-TA	487.28 CD	165.14 D	63.00 G
p value	<0.0001	<0.0001	<0.0001
Standard error	20.274	2.643	1.025

Means followed by the same letter within the column for each treatment factors are not significantly different at alpha = 0.05. TF = top fall; WC = week(s) of curing; NC = no curing; TA = topping after; TB = topping before.

Table 4: Visual quality of bulb onions subjected to harvest and postharvest treatments.

Factors	Treatments	Skin rots	Skin colour	% marketable grade
Harvesting stage	75% top fall	0.44 C	2.58 A	97.75 A
	50% top fall	2.06 B	1.89 B	71.14 B
	25% top fall	5.33 A	1.36 C	13.92 C
	p value	<0.0001	<0.0001	<0.0001
	Standard error	0.164	0.073	0.365
Curing period	2 weeks' curing	1.28 C	2.44 A	68.89 A
	1-week curing	2.25 B	1.89 B	61.47 B
	No curing	4.31 A	1.50 C	52.44 C
	p value	<0.0001	<0.0001	<0.0001
	Standard error	0.164	0.073	0.365

Table 4: Continued.

Factors	Treatments	Skin rots	Skin colour	% marketable grade
Topping time	Topping after	2.19 B	2.06 A	62.85 A
	Topping before	3.04 A	1.83 B	59.02 B
	p value	<0.0001	0.010	<0.0001
	Standard error	0.134	0.060	0.298
Seasonal variations	Season 1	2.72	1.91	60.07 B
	Season 2	2.50	1.98	61.80 A
	p value	0.243^{NS}	0.383^{NS}	<0.0001
	Standard error	0.134	0.060	0.298

Means followed by the same letter within the column for each treatment factors are not significantly different at alpha = 0.05; NS: not significant.

Table 5: Treatment effect on keeping quality of stored bulb onions.

Treatments	Skin rots	Skin colour	% marketable grade
75%TF-NC-TB	1.83 DE	2.00 BCDE	92.67 C
75%TF-NC-TA	0.50 EF	2.17 BCD	95.67 B
75%TF-2WC-TB	0.17 EF	3.00 A	100.00 A
75%TF-2WC-TA	0.00 F	3.00 A	100.00 A
75%TF-1WC-TB	0.17 EF	2.67 AB	98.83 A
75%TF-1WC-TA	0.00 F	2.67 AB	99.33 A
50%TF-NC-TB	4.00 C	1.17 F	54.83 I
50%TF-NC-TA	3.33 C	1.50 DEF	62.67 H
50%TF-2WC-TB	0.67 EF	2.33 ABC	81.00 E
50%TF-2WC-TA	0.17 EF	2.67 AB	86.00 D
50%TF-1WC-TB	2.50 CD	1.67 CDEF	68.00 G
50%TF-1WC-TA	1.67 DEF	2.00 BCDE	74.33 F
25%TF-NC-TB	8.50 A	1.00 F	3.33 N
25%TF-NC-TA	7.67 A	1.17 F	5.50 N
25%TF-2WC-TB	4.00 C	1.67 CDEF	20.67 K
25%TF-2WC-TA	2.67 CD	2.00 BCDE	25.67 J
25%TF-1WC-TB	5.50 B	1.00 F	11.83 M
25%TF-1WC-TA	3.67 C	1.33 EF	16.50 L
P value	<0.0001	<0.0001	<0.0001
Standard error	0.401	0.179	0.893

Means followed by the same letter within the column for each treatment factors are not significantly different at alpha = 0.05. TF = top fall; WC = week(s) of curing; NC = no curing; TA = topping after; TB = topping before.

Table 6: p values of interactions between different treatment factors.

Factor interactions	Fresh weight	Residual weight	Weight loss	Sprouting time	Skin rots	Skin colour	Marketable bulbs (%)
HS * CP	0.984	0.711	**0.000**	**0.000**	**0.000**	0.186	**0.000**
HS * TT	0.998	0.829	**0.000**	**0.018**	0.198	0.369	**0.000**
CP * TT	0.930	0.972	**0.015**	0.368	0.787	1.000	0.627
HS * CP * TT	0.980	0.984	0.078	**0.002**	0.404	0.965	0.108

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

Table 7: Pearson correlation between keeping and visual quality of stored bulbs.

Variables	FW					
Residual weight (RW)	0.987	RW				
Weight loss (WL)	−0.719	−0.822	WL			
Sprouting time (ST)	0.441	0.525	−0.702	ST		
Skin rots (SR)	−0.710	−0.788	0.887	−0.692	SR	
Skin colour (SC)	0.589	0.655	−0.741	0.759	−0.729	SC
% marketable bulbs	0.893	0.945	−0.915	0.592	−0.851	0.722

All the values are different from 0 with a significance level of alpha = 0.05. FW = fresh weight.

northern climate, Suojala [29] reported that early harvesting leads to some loss in bulb yield. Similarly, a study conducted using shallot bulb in University of Kwa-Zulu Natal found that the bulb yield increased significantly when harvesting was delayed until 100% top fall [10]. Elsewhere, delaying harvesting by 60 to 120 days after planting led to significant yield boost of bunching onion (*Allium fistulosum* L.) [31].

The harvesting stage of the bulb onions had a profound effect on visual and keeping quality of bulb onions. This observation corroborated earlier reports by Nabi et al. [28] and Biswas et al. [32] who reported that retention of onion bulb quality during storage depends majorly on the bulb maturity. In this study, delayed harvesting (at 75% top fall) resulted in the highest bulb residual weight, lowest weight loss from stored bulbs, longest time to sprouting, reduced rotting, enhanced skin colour, and increased percent of marketable onions as compared to medium (50% top fall) and early (25% top fall) harvesting. The relatively higher bulb residual weight and lower weight loss at delayed harvesting was attributed to reduced respirational losses while faster sprouting observed in early harvested bulbs was attributed to activation of growth during storage [30].

Reduced rotting at delayed harvesting stage was attributed to reduced moisture in the bulb, thus a less conducive environment for moisture-requiring bacterial and fungal pathogens [9]. Woldetsadik and Workneh [10] also showed that harvesting of onions at 75% top fall produced marketable bulbs with better dry matter content, reduced rotting and sprouting, better skin colour, and lower weight loss. Wright et al. [9] also reported that the stage of bulb maturity at harvest may affect the incidence and severity of bulb rotting during storage. Wright et al. [33] observed higher incidence of bulb storage rots in onions harvested at 50–70% top-down compared to those harvested at 90% top-down. Akrofi et al. [11] also found that pests and diseases that cause postharvest losses can be controlled by altering harvesting stage of bulb onions thus improving the quality of bulb onions.

This study demonstrated that curing of bulbs after harvesting combined with time of topping (either before or after curing) had a significant effect on keeping and visual quality of bulb onions. Two weeks' curing combined with topping after curing rather than before curing maintained higher residual weight, lower weight loss, longer time before sprouting, reduced incidences of skin rots, improved skin colour, and higher percentage of marketable bulbs as compared to one week curing and no curing. Comparable results were reported by Nega et al. [34] where bulbs cured for 10 days without topping had less moisture loss, fewer rotten and sprouted bulbs, less weight loss, and ultimately more marketable bulbs. However, Wright et al. [9] did not find any significant effect of time of foliage removal on mean skin colour of the bulbs although onions that were topped before curing had slightly more bulb skins than onions topped after curing. They concluded that the curing duration depends on the time taken for the bulb necks to dry which is mainly influenced by the weather conditions, physiological maturity at harvest, cultivar, and the amount of foliage. Onions that are harvested early when the tops are green and succulent obviously take longer to cure than those with desiccated tops [9].

Higher residual weight and reduced weight loss in cured bulbs were attributed to hardening of the outer skin which subsequently provides a surface barrier to water loss [35]. Reduced rotting was attributed to removal of excess moisture from the onion neck and skin, which reduced the bulb susceptibility to disease causing pathogens [34]. Wright et al. [9] also reported that curing reduces moisture levels in the neck tissue and outer skins of harvested bulbs making them less susceptible to infections and deactivates the growth thus preventing sprouting. Poor skin colour on onion bulbs that are not properly cured may arise from stains and blemishes, mainly caused by fungi on the surfaces of bulbs [9]. Ultimately, curing increases the percentage of marketable bulbs by reducing weight loss, sprouting, rotting, and improving the skin colour. Proper curing has also been shown to modify the biochemical quality of onions [15]. For example, field curing was found to increase the quercetin content of white and red Portuguese onion varieties by 33–40% [16].

Significant seasonal variations that were observed for all the keeping and visual quality parameters were attributed to different weather conditions that were experienced in the two seasons as described in Section 2.4 of this publication. Although there was supplemental irrigation which was done whenever it was deemed necessary, the first season received more cumulative rainfall than 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 that prevailed during curing [28] since the storage temperature and humidity were maintained the same in both seasons. Wright et al. [9] also reported that prevailing weather conditions during field-curing affects the postharvest quality of harvested bulb onions.

Significant interactions between different treatment factors observed on different variables were an indication that most variables responded differently to different treatment factors. Similar observation was made by Wright et al. [9] and Nega et al. [34]. This indicates that although onion bulb quality could be improved by proper application of postharvest practices, their singular application might not be the best strategy for quality improvement. The effects of one postharvest practice may be significantly influenced by application of another postharvest practice. It is therefore important for onion farmers to adopt integrated application of different postharvest strategies such as harvesting stage, curing, and topping in order to benefit from their interactive effects on bulb quality.

Pearson correlation showed that the variables weight loss and skin rots were negatively correlated to fresh weight, residual weight, days to 50% sprouting, skin colour, and percent marketable grades, all of which were positively correlated to each other. This was an indication that weight loss and incidences of skin rots are the major causes of postharvest loss of visual and keeping quality of bulb onions. Similar observation was made by Woldetsadik and Workneh

[10] on shallot bulbs. The desired quality can be achieved by harvesting the bulbs at the right stage [9, 11, 33] followed by good postharvest management such as curing and proper removal of foliage [2]. These previous observations were confirmed by our study which recorded low incidences of skin rot, lower weight loss, and more marketable grades of bulbs when harvested at 75% top fall. Our study also confirmed that curing of onions for one or two weeks before topping enhanced skin colour, reduced skin rots and weight loss, delayed the sprouting, and increased the proportion of marketable bulbs.

5. Conclusion and Recommendations

This study concludes that harvesting stage, curing period, time of topping (before or after curing), and their interactions have significant influence on postharvest visual and keeping quality of bulb onions. A combination of delayed harvesting at 75% top fall, curing for two weeks, and removing the foliage after curing was identified as the best integrated approach to ensure sustained postharvest quality of bulb onions in Machakos County. These practices are also recommended for other areas with similar climatic conditions as Machakos County. However, there is 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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