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Effect of Post-Harvest Handling and Ripening Methods on Quality and Shelf-Life of Banana

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Abstract

Banana (*Musa* spp.) is a highly perishable fruit that requires special handling. In Eritrea, post-harvest handling practices are characterized to be poor and as a result, poor fruit quality and high post-harvest loss are common. Thus, the purpose of this study was to evaluate the effect of different post-harvest handling and ripening methods on quality and shelf-life of banana. A Complete Randomized Design (CRD) was used for evaluating a combination of two levels of post-harvest handling and four ripening methods in a factorial combination conducted in the laboratory of Horticulture at Hamelmalo Agricultural College. Peel colour change, physiological weight loss, pulp to peel ratio, total soluble solids (TSS), pulp pH, ripening period and shelf life were parameters studied. The results showed fruits treated with ripened tomato showed improved characteristics in all parameters compared to those treated with smoke from kerosene burning or mixed with moringa leaf. Similarly, fruits brought directly from the farm were better than those collected from the ripening room after passing the conventional post-harvest handling. Based on the results of this study, it can be concluded that ripening of banana with the help of tomato improves fruit quality and shelf life. Thus, it can be a safe and better alternative to smoking from kerosene burning. While moringa leaf has no potential as an alternative.

Keywords

Post-Harvest Handling, Banana, Ripening, Quality, Shelf Life

1. Introduction

Banana is one of the most economical and important fruits of the world, which undergoes rapid physiological deterioration after harvest [1]. Globally, it is the fourth most important crop in food market next to rice, wheat, and maize [2].

Banana constitutes significant roles in food security, employment, economic development, and nutrition for many developing countries [3]. In Eritrea, the banana is one of the most important fruit crops. It is mainly grown in the western lowlands of the country and it covers the highest area than any other fruit crop predominantly harvested year-round [4]. In 1964 banana production in Eritrea was at its highest level and was exported to Europe, the Middle East, and neighboring East African countries. However, it ceased in 1974 [5] because of the war for independence, drought, low-quality production, and failure to compete with other exporting countries [6].

Bananas are highly perishable climacteric fruits usually harvested at their mature green stage and artificially ripen in a ripening room [7]. As the fruit is harvested at its green mature stage artificial ripening is a very important aspect at commercial levels [8]. The ripening process of banana fruits involves numerous biochemical and physiological changes [8]. Under natural fruit ripening conditions, ethylene gas is auto-stimulated by the ripening fruits. However, the fruits ripen slowly and unevenly, leading to high weight loss and failure to develop good colour and aroma [9]. Thus unripe bananas need to be exposed to an exogenous source of ethylene gas for the assurance of firm pulp texture, good flavour, and bright peel colour [10].

In Eritrea, the post-harvest handling of banana is very poor, with few treatments being given to control damage, diseases, and quality, as a result, poor-quality bananas with external bruising are sold in the local markets [5]. Results of a survey carried out in 2017/2018 (unpublished data) showed, majority of the harvested fruits are transported to wholesaler markets located mainly in Asmara and other major cities of the country which are far from the production areas. Fruits are transported long distance using inappropriate means of transportation on mostly rough roads and are stored under poor storage conditions. Bunches are loaded on open trucks and then covered with banana leaves for transportation [11]. Such kind of transportation system leads to mechanical damages and post-harvest losses in banana supply chains [12] [13] and [14]. During loading and unloading of bunches, laborers usually stand, sit, or walk on the fruits. As a result, most of the fruits get damaged leading to reduced fruit quality, and shelf life is also affected [11]. Then they are stored under poor storage conditions for ripening purposes with less attention is given to control the temperature, relative humidity, and air circulation of ripening rooms. The farmers and sellers also have limited knowledge of post-harvest handling practices of bananas. All these have aggregated negative impacts on the post-harvest losses and delivery of poor quality and external bruised fruits to the local markets [4]. This poor handling reflects lack of awareness in the whole post-harvest handling system including lack of appropriate harvesting technology, transportation, storage, and ripening facilities [11].

The 2017/2018 survey results (unpublished data) also show that the ripening system followed in Eritrea in which smoke generated from kerosene burning

systems are mainly used is very poor. In this smoke-based system, banana fruits are separated from the bunch during unloading and packed into wooden boxes and kept in air-tight rooms where kerosene stove is burned for about 24 to 48 hrs depending on the external environmental conditions. Less attention is given to controlling temperature, relative humidity and air circulation inside the ripening rooms. All these will have a cumulative effect on the fruit quality and shelf life of bananas. On the other hand, lack of infrastructure facilities has limited the implementation of improved ripening systems and storage practices.

Banana ripening with ethylene is a well-known process; while the effectiveness of the traditional ripening methods practiced in Eritrea has not yet been evaluated from the fruit quality and shelf life point of view [11]. Under the current economic situation and lack of improved technologies in Eritrea, ethylene-based ripening methods are unlikely to be expanded. In addition to that, cheaper alternatives such as ethephon and acetylene which are widely used in many other poor countries have been banned due to the negative effects on human health [15]. Therefore, it is important to search for better alternative methods that have no negative effect on human health and at least can be applied at a small-scale ripening system which may have collective contribution towards improving the quality of banana fruits displayed in local markets. Thus, this study was designed to assess the currently practiced post-harvest handling method and the smoke from kerosene burning-based ripening methods compared to other methods and find out a better and safer alternative for improving the quality and shelf life of banana.

2. Materials and Methods

2.1. Site Description

The experiment was conducted in the Horticulture Laboratory of Hamelmalo Agricultural College (HAC), located 13 km north of Keren, Eritrea. Average daily temperature and relative humidity in the laboratory were recorded using a digital Thermo hygrometer (Model IM397, Temp Tec). The temperature and relative humidity ranged from 20.01˚C to 25.79˚C and 58.25% to 71.5% respectively during the ripening period.

2.2. Banana Fruit

Banana fruits of Dwarf Cavendish were collected from two sources. The first group of fruits (PH1) was harvested by the researcher directly from the farm and was handled properly until it has reached the laboratory in the college in a way that post-harvest damage was avoided or kept as minimum as possible. The second group of fruits (PH2) was of the same variety and from the same farm, but harvested by the farmer and transported by the wholesalers to the ripening room in Keren (the nearest city to the laboratory). This allowed the fruits to pass all the common post-harvest handling practices applied in Eritrea. As soon as the fruits reached the ripening room, samples were collected and transported to

the laboratory in HAC. For avoiding variation due to time factors between the two groups; it was arranged to be harvested, transported, and reach the laboratory at HAC on the same day.

2.3. Grading, Packaging and Storage of Banana in the Laboratory

When the banana fruits reached the laboratory, they were carefully unloaded, and to remove the field heat they were stored in a cool place (at 20˚C) for about two hours. Then fruits were graded based on size, maturity stage, and level of damage. Following that, damaged fruits were removed to avoid spoilage of the other fruits, and the remaining good fruits were assigned to the treatments.

2.4. Experimental Design

The trial was set up in the laboratory in a Complete Randomized Design (CRD) with a combination of two factors and three replications. The two factors were two levels of post-harvest handling (PH1 and PH2) and four levels of ripening methods (M1 = Smoking from burning kerosene, M2 = Mixed with ripened tomato, M3 = Packing in plastic bag, and M4 = Mixed with moringa leaf). The two factors and three replications formed a total of 24 experimental units. The four ripening methods were selected based on previous studies carried out in different countries on banana fruit ripening. The ratio of tomatoes to bananas used in this experiment was three fruits of tomato (average weight of 50 gram per one tomato fruit) to four hands of bananas (with an average of twelve fruits per hand).While the ratio of moriga leaf was 200 grams of moriga leaf to four hands of banana fruits (Figure 1).

2.5. Data Collection

Observations were recorded three times from three sample fingers during the storage period. They were collected on the first, seventh, and fourteenth day starting from the first storage date to determine the quality parameters of fruits as follows:

Peel colour change: The number of days taken to reach different stages of colour during storage and ripening was recorded daily and total days taken to reach the sixth stage of peel colour were counted to determine the progress. A

(a) (b) (c) (d)

Figure 1. Treatments for ripening of banana (a) smoking from kerosene burning, (b) mixed with ripened tomato, (c) packing in plastic bag and (d) mixed with moringa leaf.

standard banana ripening chart with colour plates ranging from 1 - 7 was used. Where: 1 = green; 2 = green with yellow tracks; 3 = more green than yellow; 4 = more yellow than green; 5 = yellow with green tips; 6 = all yellow and 7 = yellow flecked with black spots [16].

***Physiological Weight Loss* (*PWL*):** Randomly selected hands of fruits from each treatment were weighted on day one to determine the initial weight, then the same hands of fruits were weighted again after seven and fourteen days of storage to determine the percentage of weight losses due to storage which was calculated as the difference between initial and final weight determined by [17]. A digital balance (Model Adventurer Pro Av4101, BLANC-LABO S.A.) was used for weighing the fruits.

***Pulp to peel ratio*:** The pulp to peel ratios of bananas were recorded by weighting the pulp, and peel of the fruits separately at days one, seven and 14 after storage. The ratio was determined by dividing pulp weight to the peel weight [16].

***Total Soluble Solids* (*TSS*):** Total soluble solids of banana pulp were measured three times at days one, seven and 14. According to [18], banana juice was prepared by adding 30ml of distilled water to 30 g of pulp extracted with a juice extractor machine. Then TSS was determined by dropping a juice into the prism of hand refractometer (MASTER-M, Model No 2313) and reading was recorded as ˚Brix.

***Pulp pH*:** The pH of the fruit juice sample was measured using a digital pH meter (Precisa pH 900, BLANC-LABO S.A.) at one, seven, and 14 days after storage. The pH meter was calibrated with buffer at pH 4.0 and 7.0 before taking the measurements.

***Ripening period*:** Ripening period was determined based on the changes in colour and firmness of bananas. It was recorded as the number of days taken until the fruit attained full ripe stage (colour stage 4).

***Shelf life*:** Shelf life of fruits was determined by visual inspection of fruits at alternate days. Then, it was calculated as the number of days between the day of harvesting and the end of consumption level of the fruit.

2.6. Data Analysis

Data recorded for the different variables from the experiment was subject to the analysis of variance (ANOVA) using GENSTAT Discovery Edition 4 software, version 4.10.3.0 (VSN International Ltd., 2011).

3. Results and Discussion

3.1. Peel Colour Change

Peel colour change from green to yellow is a result of chlorophyll degradation and is the most important eating criterion used by consumers to determine fruit ripening [1] and [19]. The results of the current study showed significant differences ($p < 0.001$) among the different ripening methods for attaining stage 6, the

acceptable stage of peel colouration for consumers (**Figure 2**). Fruits ripened using smoking from kerosene burning attained the acceptable peel colour change after six days of storage followed by bananas treated with moringa leaf with a mean of 6.17 days after storage. The difference between the smoking and moringa treatments was not significant. Fruits ripened using ripened tomato was the slowest (7.67 days) to reach stage six (**Table 1**). The results are in agreement with [20] and [10] who used smoke from kerosene and straw respectively. Similarly, [2] reported faster peel colour change (7 days after storage) of fruits treated with kerosene smoking compared to ethrel treated. [20] related the faster colour change in smoke-treated banana fruits to increased temperature from the kerosene burner in addition to ethylene. However, this is in contrast to the known fact that chlorophyll degradation slows or stops at high temperature [1]. [21] also found no effect of temperature and applied ethylene on colour change.

During ripening, there is a link between chromoplast development and ethylene. This is due to the carotenoid pathway being under positive control of ethylene [22]. The amount of ethylene required to start ripening is as little as 0.01 uL/L, however; the magnitude varies by the amount applied [19] and [23]. Therefore, the faster colouration observed on smoking from kerosene is probably due to the higher amount of ethylene combusted from kerosene burning compared to the other sources. On the other hand, [24] reported that an increased amount of moringa leaf mixed with banana fruits resulted in higher starch and chlorophyll hydrolysis which probably lead to faster colouration of bananas treated with moringa leaf. Fruits treated with ripe tomatoes developed

Figure 2. Banana fruits ripened with (a) smoking from kerosene burning, (b) mixed with ripe tomato, (c) packing in plastic bag and (d) mixed with moringa leaf five days after storage.

Table 1. Effect of post-harvest handling and ripening methods on peel colour change of banana.

Ripening Method	Peel colour change (days)		
	Post-harvest handling		
	PH1	PH2	Mean
Smoking using kerosene burning	6.00	6.00	6.00
Mixed with ripened tomato	8.67	6.67	7.67
Packing in plastic bag	7.33	6.33	6.83
Mixed with moringa leaf	6.33	6.00	6.17
Mean	7.08	6.25	6.67
p-value	<0.001[a]	<0.001[b]	0.011[c]
C.V. (%)	6.9		
L.S.D. (5%)	0.405[a]	0.573[b]	0.811[c]

Note: a = p-value and L.S.D. for post-harvest handling, b = p-value and L.S.D. for ripening methods, c = p-value and L.S.D. for Interaction effect of post-harvest handling and ripening methods, PH1 = fruits brought directly from the farm with applying post-harvest handling that minimize damage to the possible minimum, PH2 = Fruits brought from the ripening room after passing commonly practiced post-harvest handling.

acceptable peel colour compared to fruits treated with kerosene smoke which exhibited deep yellow colour with black spots on the surface leading to over-softening of the fruits at the end of the ripening period. This is similar to the results of [2] that compared smoking from kerosene with an ethrel-based system for ripening banana.

There was a significant difference ($p < 0.001$) in peel colour change between the two post-harvest handling methods (Table 1). Fruits collected from the ripening room (PH2) were faster to reach the 6th stage of colour (6.25 days) compared to fruits brought directly from the farm with reduced post-harvest damage (PH1) which reached the 6th colour stage in an average of 7.08 days from storage (Table 1). The difference is due to post-harvest handling of bananas in Eritrea which includes few treatments to control damage resulting in fruits reaching ripening room with external bruising [5]. Since fruits collected from the ripening room (PH2) passed the conventional handling conditions, they normally are subject to more physical damage compared to those handled with care (PH1). Consequently, fruits from PH2 are expected to produce more ethylene during the climacteric phase leading to earlier coloration.

The interaction effect of post-harvest handling and ripening methods on peel colour change was significant ($p = 0.011$). Banana fruits treated with smoking from kerosene burning and moringa leaf in both post-harvest handling system (PH1 and PH2) reached the sixth stage of peel colour within 6 to 6.33 days after storage. While banana fruits treated with ripened tomato and brought directly from the farm (PH1) were much slower and reached the sixth stage of peel co-

lour in 8.67 days after storage (Table 1). This indicates that limited amount of ethylene is produced by the natural ethylene generating fruits like tomato to initiate ripening process.

3.2. Physiological Weight Loss (PWL)

The result in Table 2 shows both ripening and post-harvest handling methods had significant effects on physiological weight loss recorded at 7th ($p < 0.001$ and $p = 0.007$) and 14 days ($p < 0.001$) after storage. Table 2 also shows the interaction between the ripening method and post-harvest handling had significant effect ($p < 0.001$) on physiological weight loss at14 but not at seven days after storage. We observed ripening with smoking using kerosene burning with mean values of 11% and 16.15% at seven and 14 days after storage respectively was the highest in physiological weight loss among all ripening methods in both post-harvest handling methods tested in this study. While fruits ripened with the help of ripened tomato with a mean value of 7.8% at seven days after storage and 11.83% at 14 days after storage was the lowest (Table 2). Physiological weight loss of fruit is a direct result of water loss which is due to external and internal factors such as temperature, relative humidity, and peel permeability [1]. [21] reported an increase in weight loss in banana due to the interaction effect of applied ethylene and increased temperature. This may interpret the highest weight losses recorded by the kerosene burning ripening method of the current study

Table 2. Effect of post-harvest handling and ripening methods on physiological weight loss of banana.

Ripening Method	Physiological weight loss 7 days after storage (%)			Physiological weight loss 14 days after storage (%)		
	Post-harvest handling			Post-harvest handling		
	PH1	PH2	Mean	PH1	PH2	Mean
Smoking from kerosene burning	10.58	11.42	11	16.13	16.17	16.15
Mixed with ripened tomato	7.49	8.10	7.8	10.52	13.15	11.83
Packing in plastic bag	9.51	10.39	9.95	13.79	14.60	14.19
Mixed with moringa leaf	9.46	9.53	9.5	13.44	14.09	13.77
Mean	9.26	9.86	9.56	13.47	14.50	13.99
p-value	0.007[a]		<0.001 [b] 0.423[c]	<0.001[a]		<0.001[b] 0.001[c]
C.V. (%)	4.8			3.3		
L.S.D. (5%)	0.403[a]		0.570[b] NS[c]	0.398[a]		0.563[b] 0.796[c]

Note: a = p-value and L.S.D. for post-harvest handling, b = p-value and L.S.D. for ripening methods, c = p-value and L.S.D. for Interaction effect of post-harvest handling and ripening methods, PH1 = fruits brought directly from the farm with applying post-harvest handling that minimize damage to the possible minimum, PH2 = Fruits brought from the ripening room after passing commonly practiced post-harvest handling.

where burning of kerosene resulted in higher temperature. In addition to that amount of ethylene from combusting kerosene is higher than tomato and moringa leaf. Besides, kerosene combusting might have increased ethylene production and ethylene gas intern triggered the initiation of ripening and senescence [7]. However, the effect of smoking from kerosene burning on physiological weight loss percentage in this study was different from previous studies. It was much lower than [20] who reported 15% at seven days and 20% at 14 days, but higher than the 8.10% after seven days of storage reported by [2].

Except for fruits treated with moringa leaf at seven and smoking from kerosene burning at 14 days after storage, fruits collected from the ripening room (PH2) had significantly higher weight loss in all treatments. Accelerated weight loss is due to the breakdown of cellular walls and increased permeability of the outer tissues to water vapour as a result of mechanical injuries [1]. This explains the higher loss in PH2 in which fruits had higher probability of mechanical damage between harvest and reaching the ripening room in city [5]. Similarly, [13] reported that inappropriate transportation, loading, and unloading methods cause mechanical damages and subsequently PWL.

3.3. Pulp to Peel Ratio

Significant difference ($p < 0.001$) was observed among the different ripening methods after 7th and 14 days of storage. The highest pulp to peel ratio (1.96 and 3.18) measured at 7 and 14 days respectively was on fruits treated with smoking from kerosene burning. The lowest ratio after 7 and 14 days of storage (1.67 and 2.50 respectively) was recorded on fruits treated with ripened tomato (**Table 3**). Similar results were reported by [20] who found a higher pulp to peel ratio of bananas ripened with smoking from kerosene burning. The increase in pulp to peel ratio during ripening is related to an increased sugar concentration of the pulp tissues [25] and losses of water from the peel to the air and moving towards the fruit pulp [26] [27] and [28].

Post-harvest handling methods showed significant difference ($p < 0.001$) only at 14 days after storage in which the ratio was higher in the PH2 treatment (3.01) compared to a ratio of 2.63 in PH1 (**Table 3**). The interaction between ripening methods and post-harvest handling also had significant effect on pulp to peel ratio at 7th ($p < 0.001$) and 14 ($p = 0.017$) days after storage. The highest pulp to peel ratio (3.22) was obtained after 14 days of storage in fruits treated with smoking from kerosene burning and brought from the ripening room (PH2) followed by fruits treated by the same method and brought directly from the farm (PH1) which scored a ratio of 3.14. While the lowest pulp to peel ratio on each of the two post-harvest handling practices (2.31 and 2.70) was obtained from fruits treated with ripened tomato after 14 days of storage (**Table 3**).

In the present study, with the advance of ripening the peel weight continued to decrease whereas the pulp weight continued to increase causing an increase in pulp to peel ratio (from 47.58% to 54.10%). This was in agreement with previous

Table 3. Effect of post-harvest handling and ripening methods on pulp to peel ratio of banana.

Ripening Method	Pulp to peel ratio at day 1				Percentage increase in ratio (%)
	Post-harvest handling				
	PH1	PH2	Mean		
Smoking using kerosene burning	1.25	1.23	1.24		
Mixed with ripened tomato	1.23	1.24	1.24		
Packing in plastic bag	1.25	1.25	1.25		
Mixed with moringa leaf	1.25	1.23	1.24		
Mean	1.25	1.24	**1.24**		
p-value	0.343[a]		0.674[b]	0.192[c]	
C.V. (%)			1.3		
L.S.D. (5%)	NS[a]		NS[b]	NS[c]	
	Pulp to peel ratio at day 7				Day1 - Day 7
Smoking using kerosene burning	1.95	1.98	1.96		58.06
Mixed with ripened tomato	1.62	1.72	1.67		34.68
Packing in plastic bag	1.93	1.76	1.84		47.20
Mixed with moringa leaf	1.78	1.87	1.83		47.58
Mean	1.82	1.83	**1.83**		47.58
p-value	0.520 [a]		<0.001[b]	<0.001[c]	
C.V. (%)			2.4		
L.S.D. (5%)	NS [b]		0.054[b]	0.076[c]	
	Pulp to peel ratio at day 14				Day 7 - Day 14
Smoking using kerosene burning	3.14	3.22	3.18		62.24
Mixed with ripened tomato	2.31	2.70	2.50		49.70
Packing in plastic bag	2.66	3.12	2.89		57.07
Mixed with moringa leaf	2.40	2.99	2.70		47.54
Mean	2.63	3.01	**2.82**		54.10
p-value	<0.001[a]		<0.001[b]	0.017[c]	
C.V. (%)			4.3		
L.S.D. (5%)	0.107[a]		0.151[b]	0.213[c]	

Note: a = p-value and L.S.D. for post-harvest handling, b = p-value and L.S.D. for ripening methods, c = p-value and L.S.D. for Interaction effect of post-harvest handling and ripening methods, PH1 = fruits brought directly from the farm with applying post-harvest handling that minimize damage to the possible minimum, PH2 = Fruits brought from the ripening room after passing commonly practiced post-harvest handling.

results obtained by [29], who found an increase in pulp to peel ratio with the advance from ripening stage five to stage seven in which an increase in pulp moisture content was observed indicating to movement of water from peel to

pulp. Several previous studies also indicated that increase in pulp to peel ratio is due to the water lost from the peel by evapotranspiration to the air and moving towards the fruit pulp as a result of change in osmotic pressure due to carbohydrate breakdown [21] [26] [27] [28] and [29]. Higher storage temperature, lower humidity, and applied ethylene were also found to increase pulp to peel ratio [21] and [28]. Bananas treated with smoke from kerosene burning are expected to have higher temperature and ethylene compared to the other treatments. While the conventional post-harvest handling method (PH2) in which banana fruits were subject to various damages during harvesting, loading, unloading and transportation until it reaches the ripening room [5] is expected to have more moisture content loss from the peel [20]. This explains the high pulp to peel ratio in the smoke treated and the conventional post-harvest handling method (PH2) applied in the current study.

3.4. Total Soluble Solids (TSS)

The results in the current study (**Table 4**) show the change in TSS was progressive with the increase of storage period from one to 14 days. The difference among both the ripening methods and post-harvest handling was significant ($p < 0.001$ and $p = 0.002$ respectively) at seven days after storage but not significant ($p = 0.066$ and $p = 0.483$ respectively) at 14 days after storage. While the interaction between the ripening method and post-harvest handling showed no significant difference for both dates (**Table 4**).

The highest reading after seven days of storage was observed on fruits treated with smoke from kerosene burning (15.28 ˚Brix), while the lowest reading was observed on fruits treated with moringa leaf (12.77 ˚Brix). On the other hand, fruits treated with smoking from kerosene burning showed the highest TSS change percentage (58.67%) between the initial and seven days after storage and the lowest (6.74%) during the storage period from the seventh to 14th days of storage compared to the rest three methods (**Table 4**). This is due to the conversion of starch to sugar in banana that occurs during the climacteric phase [1] and the increase in TSS during ripening is a result of an increase in the concentration of organic solutes as a consequence of water loss and hydrolysis of starch into soluble sugars such as sucrose, glucose, and fructose [29]. Therefore, this interprets the higher (initial to seven days after storage) and the lower (between seventh and 14thdays of storage) differences shown by the smoke from kerosene burning ripening method which ripened earlier and it entered the senescence stage where no more starch to be converted to sugar. Similar results were reported by [20] who found TSS values in smoke treated dwarf Cavendish bananas to increase early in the second day and start declining after eight days. The faster change in TSS of the smoke-treated bananas is due to the exogenous ethylene and the heat from kerosene burning [20]. However, other studies showed source of ethylene [30] and temperature and ethylene [21] had no effect on TSS at 6th colour stage.

Table 4. Effect of post-harvest handling and ripening methods on total soluble solids (TSS) of banana.

Ripening Method	TSS (˚Brix) at day 1				Percentage increase in ratio (%)
	Post-harvest handling				
	PH1	PH2	Mean		
Smoking from kerosene burning	9.73	9.53	9.63		
Mixed with ripened tomato	9.40	9.47	9.43		
Packing in plastic bag	9.47	9.03	9.25		
Mixed with moringa leaf	9.37	9.43	9.40		
Mean	9.49	9.37	**9.43**		
p-value	0.352[a]		0.263[b]	0.483[c]	
C.V. (%)	3.4				
L.S.D. (5%)	NS[a]		NS[b]	NS[c]	
	TSS (˚Brix) at day 7				Day 1 - Day 7
Smoking from kerosene burning	14.93	15.63	15.28		58.67
Mixed with ripened tomato	12.67	14.43	13.55		43.69
Packing in plastic bag	12.70	13.07	12.88		39.24
Mixed with moringa leaf	12.47	13.07	12.77		35.85
Mean	13.19	14.05	**13.62**		**44.43**
p-value	0.002[a]		<0.001[b]	0.175[c]	
C.V. (%)	4				
L.S.D. (5%)	0.483[a]		0.683[b]	NS[c]	
	TSS (˚Brix) at day 14				Day 7 - Day 14
Smoking from kerosene burning	16.27	16.37	16.31		6.74
Mixed with ripened tomato	17.27	17.00	17.13		26.42
Packing in plastic bag	16.00	16.43	16.22		25.93
Mixed with moringa leaf	16.17	16.63	16.40		28.43
Mean	16.43	16.61	**16.52**		**21.29**
p-value	0.460[a]		0.066[b]	0.685[c]	
C.V. (%)	3.6				
L.S.D. (5%)	NS[a]		NS[b]	NS[c]	

Note: a = p-value and L.S.D. for post-harvest handling, b = p-value and L.S.D. for ripening method, c = p-value and L.S.D. for Interaction effect of post-harvest handling and ripening methods, PH1 = fruits brought directly from the farm with applying post-harvest handling that minimize damage to the possible minimum, PH2 = Fruits brought from the ripening room after passing commonly practiced post-harvest handling.

3.5. Pulp pH

The effect of ripening methods on pulp pH of banana at both the 7th and 14th days of storage was significant ($p < 0.001$). Post-harvest handling methods and

their interaction with ripening methods had no effect ($p > 0.05$) on pulp pH at both the 7th and 14th days of storage (Table 5). On the seventh day of storage, the highest pH value (5.63) was obtained from fruits treated with plastic cover while

Table 5. Effect of post-harvest handling and ripening methods on pulp pH of banana.

Ripening Method	Pulp pH at day 1			Percentage decrease in ratio (%)
	Post-harvest handling			
	PH1	PH2	Mean	
Smoking from kerosene burning	6.52	6.57	6.55	
Mixed with ripened tomato	6.50	6.65	6.58	
Packing in plastic bag	6.50	6.57	6.54	
Mixed with moringa leaf	6.52	6.60	6.56	
Mean	6.51	6.60	**6.56**	
p-value	0.085[b]		0.935[a]	0.892[c]
C.V. (%)	1.7			
L.S.D. (5%)	NS[a]		NS[b]	NS[c]
	Pulp pH at day 7			**Day 1 - Day 7**
Smoking from kerosene burning	5.20	5.37	5.29	23.82
Mixed with ripened tomato	5.62	5.55	5.58	17.92
Packing in plastic bag	5.62	5.63	5.63	16.16
Mixed with moringa leaf	5.40	5.37	5.38	21.93
Mean	5.46	5.48	**5.47**	19.93
p-value	0.684[a]		<0.001[b]	0.302[c]
C.V. (%)	2.1			
L.S.D. (5%)	NS[a]		0.140[b]	NS[c]
	Pulp pH at day 14			**Day 1 - Day 14**
Smoking from kerosene burning	4.46	4.38	4.42	19.68
Mixed with ripened tomato	4.91	4.82	4.87	14.58
Packing in plastic bag	4.81	4.78	4.79	17.54
Mixed with moringa leaf	4.34	4.39	4.37	23.11
Mean	4.63	4.59	**4.61**	18.66
p-value	0.202[a]		<0.001[b]	0.307[c]
C.V. (%)	1.5			
L.S.D. (5%)	NS[a]		0.087[b]	NS[c]

Note: a = p-value and L.S.D. for post-harvest handling, b = p-value and L.S.D. for ripening method, c = p-value and L.S.D. for Interaction effect of post-harvest handling and ripening methods, PH1 = fruits brought directly from the farm with applying post-harvest handling that minimize damage to the possible minimum, PH2 = Fruits brought from the ripening room after passing commonly practiced post-harvest handling.

the lowest value (5.29) was obtained from fruits treated with smoking from kerosene burning (**Table 5**). On the 14th day of storage, the highest value (4.87) was obtained from fruits treated with ripened tomato, and the lowest value (4.37) was obtained from fruits treated with moringa leaf (**Table 5**). The lower pH of the banana treated with smoking from kerosene could be due to the faster advance in ripening [20] and the effect of temperature [23].

In banana pulp pH quickly declines in response to increasing ripeness, however, the magnitude differs according to variety [16]. The increase in titratable acidity and decrease of pulp pH occurs until peel colour stage three and then acidity drops and pH increases and this coincides with the climacteric respiration [19], however, number of days to reach maximum titratable acidity may vary based on difference in ripening methods. [20] found it to be 4 and 6 days for smoking from kerosene and ethephon treated bananas respectively and more than eight days for other ripening methods, while [2] recorded maximum titrable acidity and lowest pH by treating bananas with smoking from kerosene burning at 7 days after storage. With aging, depletion of sugars as a respiratory substrate and the switch to catabolism of proteins occurs, and this leads to release of free amino groups resulting in a shift to a more alkaline pH in the cell sap [19]. However, in the current study, the pH of the pulp steadily decreased with the increase in storage periods from mean initial pH of 6.58 to 5.58 (17.92%) after seven days and 4.87 (14.58%) after 14 days after storage for fruits treated with ripened tomato (**Table 5**). In agreement with this finding, [31] reported a pulp pH decrease of plantain from 6.18 to 4.92 during the ripening process. The decline in pH with an advance in ripening is in agreement with [2]. Similarly, [27] found in bananas treated with different concentrations of ethrel the pH gradually decreased with the advance in ripening and when the fruit reached optimum ripening six days after storage, the pH was 4.8. [32] found the increase and decrease in pH and titrable acidity to depend on banana variety. They observed different trends, some varieties showed a complete decrease in pH from green stage to fully yellow stage (this is the case of the current study), others showed first decrease and then an increase at full ripe, while the last group increase, decrease and again increase. Some previous studies showed ethylene source has no effect on titrable acidity and pH of banana pulp [23] and [30].

3.6. Ripening Period and Shelf Life

There were significant differences ($p < 0.001$) of ripening period and shelf life among all the ripening methods. The shortest ripening period (3.83 days) and shelf life (9.34 days) were observed on fruits treated with smoking from kerosene burning, while fruits treated with ripened tomato attained full ripening stage after 5.5days of storage and had the highest shelf life of 12.5 days (**Table 6**). Similarly, post-harvest handling methods significantly affected ($p = 0.012$ and $p < 0.001$) both the ripening period and shelf life of the banana fruits respectively.

Banana fruits brought directly from the farm (PH1) required longer number of days to ripen (4.83 days) and achieved longer shelf life (11.50 days) compared to fruits brought from the ripening room (PH2) which required a shorter ripening period (4.25 days) and scored an average shelf life of 10.25 days (Table 6). The interaction effect of post-harvest handling and ripening methods was not significant on the ripening period ($p = 0.610$) however, it was affected significantly for shelf life ($p = 0.045$) (Table 6).

The results of the current study were in agreement with the finding of [20] who found banana fruits treated with smoke from kerosene to have a shorter ripening period and referred that to the effect of exogenous ethylene and high temperature resulted from kerosene burning which may enhance the physico-chemical changes. The smoke from burning kerosene increases the temperature inside the chamber [27] and releases ethylene and other trace gases like acetylene and carbon monoxide [7]. Similarly, [21] found the storage period to decrease with increased temperature and the application of ethylene. This indicates that the difference in the length of both ripening period and shelf life of banana fruits treated with different ripening methods is due to differences in the amount of ethylene and temperature. Fruits treated with ripened tomato produced relatively limited amount of ethylene [19], which is expected to delay the ripening process [15]. [30] also found difference in the effect of sources of exogenous ethylene application on the ripening period of banana, where avocado with higher ethylene releasing capacity had more impact compared to tomato

Table 6. Effect of post-harvest handling and ripening methods on ripening period and shelf life.

Ripening Method	Ripening period (Days)			Shelf life (Days)		
	Post-harvest handling			Post-harvest handling		
	PH1	PH2	Mean	PH1	PH2	Mean
Smoking using kerosene burning	4	3.67	3.83	10	8.67	9.34
Mixed with ripened tomato	6	5	5.5	13.67	11.33	12.5
Packing in plastic bag	5	4.33	4.67	11.33	10.67	11
Mixed with moringa leaf	4.33	4	4.17	11	10.33	10.67
Mean	4.83	4.25	**4.54**	11.50	10.25	**10.88**
p-value	0.012[a]		<0.001[b] 0.610[c]	<0.001[a]		<0.001[b] 0.045[c]
C.V. (%)	10.9			4.8		
L.S.D. (5%)	0.437[a]		0.612[b] NS[c]	0.453[a]		0.641[b] 0.906[c]

Note: a = p-value and L.S.D. for post-harvest handling, b = p-value and L.S.D. for ripening method, c = p-value and L.S.D. for Interaction effect of post-harvest handling and ripening methods, PH1 = fruits brought directly from the farm with applying post-harvest handling that minimize damage to the possible minimum, PH2 = Fruits brought from the ripening room after passing commonly practiced post-harvest handling.

and mango.

Mechanical damage is one of the major factors leading to the post-harvest deterioration of banana. This is a result of poor packaging and handling of packed fruits during loading and unloading, shaking during transportation, and other factors [16]. Post-harvest handling in Eritrea includes few treatments to control damage [5]. Mechanically damaged banana fruits generally ripen earlier than non-damaged fruits [16]. This explains why ripening period and shelf life in the current study was shorter in the commonly followed post-harvest handling practices (PH2) compared to the fruits collected by the researcher from the farm and transported directly to the laboratory with proper packaging and all possible care to reduce mechanical damage (PH1).

4. Conclusion

From the results of this study, it can be concluded that the currently practiced post-harvest handling and smoking-based ripening methods have negative impacts on quality and shelf life of banana. On the other hand, the use of ripened tomato as a ripening agent combined with the application of proper handling that reduces damage on fruits during harvesting, packing, transportation, loading, and unloading can improve both internal and external fruit quality as well as shelf life. Therefore, tomato can serve as a better and safer alternative to the use of kerosene burning in banana ripening at least for small local ripening rooms. In contrast, moringa leaf may not have any potential to serve as an alternative to kerosene burning-based ripening methods.

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Conflicts of Interest

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

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