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The experiment was conducted at Metema District, Northwestern Ethiopia to evaluate and select suitable banana ripening techniques in the 2019 cool and 2020 hot seasons. The treatments consisted of three kerosene smoking durations and two none kerosene smoke treatments such as low-density white polyethylene sheet and banana leaf were arranged in CRD with three replications. Properly matured fruits were treated with 12hrs, 18hrs, and 24hrs kerosene smoke to induce ethylene production in the fruits and commence ripening inside an air-tight and dark room. Immediately after the treatment application, fruits were subjected to an ambient temperature for ventilation. Similar properly matured fruits were wrapped with low-density white polyethylene sheet and banana leaf until ripening. The result revealed that fruits treated with kerosene burn for 12 hr gave uniform color development, desirable firmness and acceptable quality, and better shelf life within 4 and 5 days under hot and cool season conditions, respectively. Subsequently, uniform color development was attended within short days when fruits were treated with kerosene burn for 18 and 24hr smoking durations, however, the majority of the fingers were detached from the hands of the banana bunch. On the other hand, fruits treated with polyethylene sheets and banana leaves did not indicate any color change or firmness loss for 7 days. Therefore, it is concluded that kerosene smoke for 12 hours under cool and hot season conditions was found optimum for ripe bananas at Metema and similar environmental conditions.

**Key words:** ripening

Banana ( *Musa sapientum* ) belongs to the genus *Musa* and *Musaceae* family. It is native to Southeast Asia and is diversified in warmer regions. It has multipurpose uses compared to other horticultural fruit crops. Banana is the fourth most stable food crop in the world next to rice, wheat, and maize (Salvador et al., 2004). It is a good source of fiber, potassium, vitamins A, B6, C, and D, and various antioxidants and phytonutrients (Kumar et al., 2012).

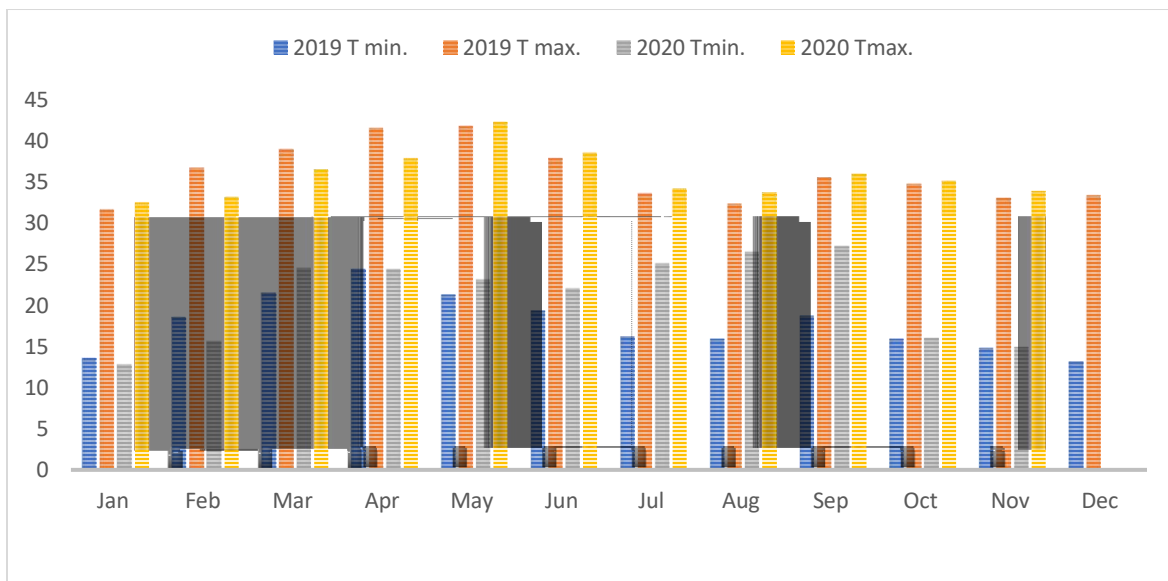
Ethiopia has a favorable diverse agro-ecology for the production of temperate, subtropical, and tropical fruits. In Ethiopia, bananas have been cultivated for several years as a garden plant, boundary of fields and farms. Recently cultivation of banana in orchards was started with the introduction of different high yielding varieties such as Dwarf Cavendish, Giant Cavendish, Poyo, Williams (I and II), and Grande Nain. Currently, banana production in Ethiopia covers about 66,800 hectares of land and total production at present is estimated to be 539,000 tons. Amhara region ranks third next to SNNP and Oromia region in banana production (Derbew et al., 2023). In Metema, district banana production covers an area of 500 hectares (Metema Worda Office of Agriculture annual report 2024-unpublished). Metema is a prevailing area for sustainable banana production in terms of temperature, soil, water sources, and market proximity. Although farmers have been allocating a parcel of land for banana production in the study areas, there are several production constraints as limiting factors. Among these factors, lack of fruit ripening technique, improved variety, and improved production knowledge and skills are the main ones. Despite the fact that banana cultivation in study, a large volume of banana has transporting from Southern, part of the country and sold with high market prices at Metema. The presence of high demand of banana in the study areas is consider as a good opportunity for banana value chain actors to fully exploit the benefit potential of the commodity.

Ripening is a process that includes physiological, biochemical, and organoleptic changes in fruits that attain the desirable color, aroma, and texture that are unique to the optimum eating quality (Prasanna et al., 2010). Banana is ripened locally using various practices, such as covering fruits with grass, straw, banana leaf, and plastic sheet (Berhe et al., 2008). Due to the high temperature in Metema condition, traditional banana ripening techniques are ineffective and cause fruit browning which is unattractive to customers and negatively affects producers to fetch premium prices. Moreover, these techniques are not suitable for bulk fruit ripening collected by the wholesalers. Unless improved banana ripening techniques is adopted mass production of bananas is not expected in the study areas by following traditional way of ripening techniques.

The most popular banana ripening method practiced in developed countries is the application of ethylene gas in ripening rooms. Modern banana ripening rooms are designed with techniques to control temperature, humidity, and ethylene gas concentration and are equipped with proper ventilation and exhausting systems (Maduwanthi & Marapana, 2019). This is a very expensive ripening method to adopt in Ethiopia as well as in the study area. Rather cheaper and easier methods are required for the desirable color development during ripening. . In many developing countries, food producers use several artificial ripening methods to speed up the ripening process. Smoking is one of these methods used in banana ripening in which harvested banana bunches are exposed to smoke generated by a kerosene burner in an airtight room. The smoke

produced by kerosene combustion is known to contain traces of ethylene as well as other gases (Kulkarni et al., 2011). Therefore, this study was conducted to evaluate banana-ripening techniques at Metema condition to maintain the desirable color of banana in the market.

The study was conducted in the 2019 cool season (November) and 2020 hot season (May) at Metema district, Gendewuha town. It is located at 12° 46' 45.26"N and 36°42' 20.68"E with altitude of 745 m.a.s.l. The temperature range of the area is 22 - 43°C, while night minimum annual temperatures are between 22 and 28°C. Daily temperature becomes very high during March to May and reaches as high as 43°C and night temperature reaches 28°C (Figure 1).



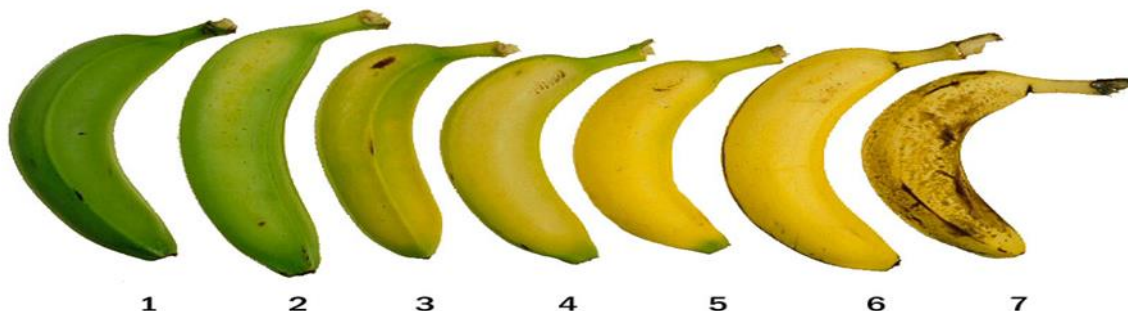
Annual monthly min. and max. Temperature of Metema in 2019 and 2020(Data source: NASA Power)

The treatments consisted of three kerosene smoking durations (12, 18, and 24hrs) and two none kerosene smoke treatments such as low-density white polyethylene sheet and banana leaf arranged with factorial combinations in CRD with three replications.

Properly matured 'Giant Cavendish' banana fruits collected from Metema, 'Meder' 6 were treated with 12hrs, 18hrs, and 24hrs kerosene smoke to induce ethylene production in the fruits and commence ripening inside a 12m<sup>2</sup> airtight room used kerosene burners. Immediately after the treatment application, fruits were subjected to an ambient temperature for ventilation. Similar properly matured fruits were wrapped with low-density white polyethylene sheet and banana leaf until ripening. For each treatment, 200kg green banana bunches were used.

### ***Fruit color change***

Fruit skin color change was recorded using a standard ripening chart having 1 to 7 scales where 1 is dark green; 2 is light green; 3 is more green than yellow; 4 is more yellow than green; 5 is yellow with green tips; 6 is fully yellow and 7 is yellow flecked with brown and compared with the chart visually (Figure 2) (Dadzie & Orchard, 1997).



Color stage of banana ripening

#### ***Fruit weight loss***

Fruits physiological weight loss was calculated using the following formula as suggested by Mohammed et al. (1999).

$$\text{Weight Loss (percentage)} = \frac{\text{Weight initial} - \text{Weight final}}{\text{Weight initial}} \times 100$$

#### ***Fruit pulp-to-peel ratio***

The pulp-to-peel ratio (PPR) was determined by dividing the pulp weight by the peel weight. Pulp and peel were separated and weighed separately using a sensitive balance having two decimals' places and expressed as the pulp-to-peel ratio at the full ripening stage (fully yellow color-stage 6 (Dadzie & Orchard, 1997).

#### ***Fruit total soluble solids (TSS)***

The total soluble solids (TSS) of pulp juice were determined using a digital handheld refractometer at 20 °c (Kad & Dhemre, 2017). The juice was prepared by blending 30 g of pulp tissue from the fruit's transverse portion for two minutes with 90 ml of distilled water and filtered with filter paper. A single drop of the filtrate was placed on the prism of a handheld refractometer to determine the percentage of total soluble solids (°Brix).

#### ***Fruit Titrable acid (TA)***

The total Titrable Acidity (TA) of the pulp was determined by titration of the filtrate to the phenolphthalein end and calculation of acid present as malic acid (NaOH). After transferring 25 milliliters of the filtrate into a 125-milliliter conical flask, 4 drops of phenolphthalein indicator and 25 milliliters of distilled water were added. The mixture was then titrated with 0.1N sodium hydroxide until the indicator just turned pink or red. Titrable acidity (% malic acid) was calculated according to the following formula:

$$\text{TA (\%)} = \frac{\text{Normality of base} \times \text{volume of base} \times 0.067 \times \text{dilution factor}}{\text{Volume of sample}} \times 100$$

The ripening period was determined based on the changes in color and firmness of bananas (Dadzie and Orchard, 1997).

### **Temperature**

The temperatures of the storage rooms, and the ambient condition, were recorded starting from day one onwards on a daily interval until the full ripened stage was attended.

Ripening/room and ambient conditions for daily temperature records in November 2019 and May 2020.

	Day	Ripening	Ambient	Day	Ripening	Ambient
	2019 (November)			2020 (May)		
12 hr.	7	28.8	25.1	16	32.5	28.5
18 hr.	8	29.6	24.8	17	33.0	27.8
24hr.	9	30.8	25.3	18	32.3	27.5
Polyethylene	10	-	24.7	19		28.1
Banana-leaf	11	-	24.7	20		28.0

The collected data for each parameter was subjected to Analysis of variance (ANOVA) using SAS statistical software to examine the effect of the treatments and interactions. Whenever the ANOVA result showed a significant ( $P \leq 0.05$ ) difference, mean separation was performed using LSD at a 5% probability level.




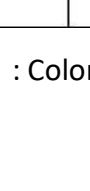


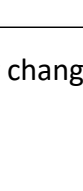

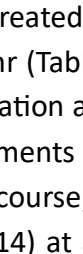
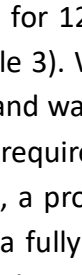
Based on the standard stage, bananas fruits subjected to 12hrs kerosene smoke attained a fully ripened stage slowly compared to bananas fruits subjected to 24hrs kerosene smoke. The result showed that banana fruits treated with kerosene smoke for 12 hours attained stage 2 within a day during both cool and hot season conditions. Stages 3 to 5 were continuously developed day after day and attained the last banana color change stage (Stage 6) within 5 and 4 days for banana fruits tested under cool and hot season conditions, respectively without any perishability signs (Tables 1 and 2). Bananas treated with kerosene burns for 18 hr. reached stage 6 banana color changes within 4.5 and 3 days under cool and hot season conditions, respectively. However, the majority of the fingers were detached from the hands of banana bunch. Regarding fruits treated with 24-hour kerosene smoke treatment, very rapid ripening and senescence was observed compared to the other treatments due to the accumulation of more ethylene in the room. Banana fruit peel color change variation was showed starts within a day and advanced quickly in kerosene smoke treatments. On the other hand, banana fruits treated with the polyethylene sheet and banana leaf-wrapped treatments did not develop acceptable color change within 7 days and became brownish as time progressed due to enzymatic activity. Moreover, stage 6 of banana color change or fully yellow peel color was attended in the hot season condition quickly compared to the cool condition. Fortunately, the fruit color change observed under cool season conditions was

desired and uniform (Table 1 and Figure 3). According to Mebratie et al. (2016), the fully ripened stage was recorded within 6 days for banana fruits treated with 24 hr. smoking duration while it took 13 days for banana fruits packed with polyethylene plastic with dull yellow color development, followed by 14 days banana fruits packed with banana leaf at Haramaya University condition (2000 m.a.s.l.). Our result the fully ripened stage was recorded within 4 days for a cool season (November) and 3 days for a hot season (May) for banana fruits treated with 24 hr due to high temperature at Metema ripening days decreased. Similar result also line with my finding in Addis Ababa for 100 quintals banana bunch 3-4 kerosene burners were placed for about 1½ days. However, only two burners were used for the same quantity of banana for 24 hours in Hawasa, which has a warmer climate as compared to Addis Ababa (Berhe et al., 2008).

Banana fruit color change as influenced by ripening techniques at Metema condition

	Day 1		Day 2		Day 3		Day 4		Day 5		Day7	
	Cool season	Hot season	Cool season	Hot season	Cool season	Hot season	Cool season	Hot season	Cool season	Hot season	Cool season	Hot season
12 hr	Stage 2	Stage 2	Stage 3	Stage 3	Stage 4	Stage 5	Stage 3	stage4	Stage 6	Stage 7	-	-
18hr	Stage 2	stage3	Stage 3	Stage 4	Stage 4	Stage 6	Stage 5	Stage 7	-	-	-	-
24hr	Stage3	Stage3	Stage 4	Stage 5	Stage 5	Stage 6	Stage 6	Stage 7	-	-	-	-
PE	Stage1	Stage1	Stage 2	Stage 2	Stage 2	Stage 2	Stage 2	stage2	stage2	Stage 2	Stage 2	Stage 2
BL	Stage1	Stage1	Sage2	Stage 2	Stage 2	Stage 2	Stage 2	Stage 2	Stage 2	Stage 2	Stage 2	Stage 2

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Treatments	Color change of banana fruits in days			
	Day 2	Day 3	Day 4	Day 5
6 hr				
12hr				
18 hr				
24 hr				
PE				
BL				

: Color change of banana fruits in days after treatment, \* =

At the full ripening stage TSS, weight loss, and pulp-to-peel ratio were significantly influenced ( $P \leq 0.001$ ) by banana ripening techniques. The highest weight loss 21.49 and 23.86 % was observed when banana fruits were treated for 12 hr under cool and hot season conditions, respectively followed by 18 hr. and 24 hr (Table 3). Weight loss of banana fruits from harvesting to ripening may be attributed to respiration and water loss through transpiration (Molla et al., 2007). Short time kerosene smoke treatments required longer days to reach the fully ripe stage (low ripening process) and through this course, a process, of high weight loss was exhibited. Our finding is similar with Vala et al. (2014) at a fully ripe stage, the weight loss of fruits increased with the advancement of the storage period in smoke treated fruit. In all the treatments, the percentage of weight loss increased as storage time and ripening progressed. At full ripening stage (stage 6), treatments showed a significant difference in terms of pulp-to-peel ratios. Banana fruits treated with 12 hr kerosene treatments scored the pulp-to-peel ratio of 2.33 and 3.19 in cool and hot season conditions, respectively (Table 3). This means that a 12 hr kerosene smoke treatment supplies a sufficient amount of ethylene to trigger fruits to achieve a proper stage of ripening. Regarding TSS, the highest values of 18.27 and 17.3% were obtained with 12hr kerosene burn treatment in the hot and cool seasons, respectively. Water loss during ripening may cause a rise in the concentration of organic solutes, which in turn causes an increase in TSS (Kader et al.,

2001). The titrable acidity of fruits was not significantly influenced by ripening techniques in the present study. Its values were found in the range of 0.36–0.39% in all the treatments (Table 3).

: Mean physiological weight loss (PWL), pulp-to-peel ratio (PPR), TSS, and Titratable acidity (TA) of different hours of Kerosene Burn during banana ripening at Metema (2019 and 2020).

	2019				2020			
	PWL (%)	PPR	TSS (%)	TA (%)	PWL (%)	PPR	TSS (%)	TA (%)
12 hr.	21.49 <sup>A</sup>	2.33 <sup>A</sup>	17.3	0.38	23.98 <sup>A</sup>	3.19 <sup>A</sup>	18.27	0.39
18 hr.	17.58 <sup>B</sup>	1.86 <sup>B</sup>	16.65	0.36	14.94 <sup>B</sup>	2.55 <sup>B</sup>	16.65	0.37
24 hr.	7.86 <sup>C</sup>	1.98 <sup>B</sup>	15.88	0.36	12.88 <sup>C</sup>	1.69 <sup>C</sup>	15.75	0.38
CV (%)	8.57	7.87	7.75	8.33	8.98	8.69	7.15	4.67
Sig (5%)	***	***	NS	NS	***	***	***	NS

\*

pulp-to-peel ratio,

Appropriate and easily accessible banana ripening techniques are necessary to attain the desirable color of banana fruit in the market. However, majority of the attempts such as wrapped with some covering materials to ripen banana fruits after harvest have limitation to attain the desirable color change. The current study confirmed that fruit ripening technique using kerosene smoke found promising in situations where commercial ethylene sources are unavailable. Kerosene smoking as trigger agent to induce the fruit and release endogenous ethylene to speed up the ripening process considerably as compared to other fruit wrapping materials tested in the current study. Generally, banana fruits are subjected to 24 hours of kerosene smoke within short days, while banana fruits subjected to 12 hours require extra days to attain a fully ripe color stage. Although, there was a substantial weight loss, fruits subjected to 12 hours of kerosene smoke showed the best quality attributes such as TSS, and pulp-to-peel color among all the treatments at Metema conditions under the cool and hot season conditions. On the other hand, in case of fruits subjected to 18 and 24 hr. kerosene smoke treatments, fingers detachment from hands was very substantial which leads fruit inferior quality at the market place. Hence, it is concluded that 12 hours of kerosene smoke was found promising to maintain desirable ripening of banana fruits under the Metema condition.

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