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RESEARCH

Crown Rot Disease Complex Management and Maintaining Fruit Quality in Banana (*Musa spp.*) through Integrated Application of Sodium Carbonate, Hot Water and Carbendazim in Ethiopia

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ABSTRACT

Purpose: *The quality of banana fruit is adversely affected by biotic and abiotic constraints, among which crown rot disease plays a significant role. Thus, the objective of this study was to evaluate the effects of inorganic salt, hot water and fungicide as integrated management of banana crown rot disease.*

Research Method: *Inorganic salt (Na_2CO_3) at two levels (0 and 4 g/L), integrated with three levels of water temperature (24, 47 and 50°C) and Carbendazim at four levels (0, 0.2, 0.3 and 0.4 g/L) were tested. The experiment was set up using factorial arrangements and a completely randomized design. Disease incidence and severity of banana crown rot were recorded during the course of the experiment. In addition, banana fruit quality traits were recorded.*

Findings and Values: *The combination of 4 g/L Na_2CO_3 with hot water treatment at 50°C and 0.4 g/L Carbendazim significantly reduced disease severity compared to the other treatments and minimized crown rot complex by 74.6%. This combination reduced the incidence to 27.8% and had the maximum (88.9%) marketable fruits. The combined treatments also showed a highly significant effect on quality parameters of banana fruit such as pH, total soluble solids, titratable acidity, firmness and colour. In conclusion, the study revealed that integrated application of 4 g/L Na_2CO_3 combined with hot water treatment at 50°C and 0.4 g/L Carbendazim could suppress banana crown rot complex and improve marketability of banana fruits without pronounced effects on their edible qualities.*

Keywords: *Crown rot, Fruit quality, Hot water, Integrated disease management, Severity, Sodium carbonate.*

INTRODUCTION

Banana (*Musa* spp.), a widely grown fruit crop in tropical countries, has a high consumer demand globally (De Costa & Erabadupitiya 2005). In developing countries, it is one of the major staple crops. It is consumed as a source of energy and as a dessert. A highly significant product, bananas are the major fruit in international trade, ranking first in terms of volume exported and second in terms of value, after citrus (FAO 2006). In terms of production, bananas rank as a significant food commodity worldwide, behind rice, wheat, and maize.

It is grown in over 120 countries, with the primary producing regions being Asia, the Americas, and Africa (FAOSTAT 2021). Ethiopia is a tropical country with plenty of

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land suitable for banana cultivation. In Ethiopia, bananas are grown on both large commercial plantations and small homesteads. They are produced in the southern, eastern, southwestern, and western regions of the country under broader agro-ecological conditions. Large banana fruit farms are concentrated in the upper and middle Awash Basin and Arba Minch in the southern Rift Valley (Seifu 2003). In terms of both area covered (95,954 ha) and production (0.89 million tons), bananas are currently the most produced fruit crop in the country; the majority are grown using traditional agricultural methods (CSA 2021). However, several postharvest and pre-harvest constraints significantly impact Ethiopia's banana production.

The postharvest shelf life and quality of banana fruits are reduced by several diseases. Major diseases affecting bananas include the crown rot complex (*Fusarium* sp., *Colletotrichum musae*, *Cladosporium* sp., *Verticillium* sp.), anthracnose (*C. musae*), blossom end rot (*Colletotrichum* sp., *Fusarium* spp.), ripe rot (*Fusarium* spp.), Johnson spot (*Magnaporthe grisea*), stem-end rot (*Verticillium theobromae* and/or *Trachysphaera*), and black end (various fungi including *C. musae*, *Nigrospora sphaeroetca*) (John & Marchal 1995, Robinson 1996, Alvindia *et al.* 2000). Among these, crown rot is one of the most devastating postharvest diseases of banana under storage conditions. It is characteristically a disease complex caused by several pathogens (Snowdon 1990). In the Philippines, crown rot disease can cause up to 86% yield loss in banana fruits stored without postharvest chemical treatment (Alvindia *et al.* 2000).

Consistent crop residue sanitation in the field is the first step in managing crown rot. A number of postharvest treatments are also used with varying effectiveness. Hot water treatment is a useful approach for controlling postharvest infections in fruits when the temperature and exposure duration are optimal (Lurie 1998). Many fruits have shown the benefits of pre-storage hot water immersion in preventing the development of banana crown rot (Schirra *et al.* 2000). Frequently, combined hot water and fungicide treatments are used to reduce postharvest disease incidence in stored banana fruits. Inorganic salts are also recommended for preventing postharvest diseases of fruits and vegetables (Olivier *et al.* 1999, Smilanick *et al.* 1999). Alvindia *et al.* (2004) reported the first application of salts to combat the banana crown rot complex. The use of inorganic salts to control crown rot pathogens such as *Fusarium* spp., *Thielaviopsis paradoxa*, and *Colletotrichum musae* has been evaluated in many regions, with varying levels of effectiveness (Alvindia & Natsuaki 2007). Fungicides are also widely used to control fruit storage diseases. Fungicide dips or sprays are applied by growers and retailers to prevent crown rot and anthracnose development (Kawate 2006).

Several alternative methods—hot water treatments, salts, fungicides, and others—can help control banana crown rot. However, none of these approaches provide satisfactory disease management when used alone; better results are obtained when they are applied in combination (Janisiewicz & Korsten 2002). Integrated application of inorganic salts, hot water treatment, and fungicide can improve effectiveness of disease control, while reducing product damage and limiting the development of fungicide-resistant pathogen strains. Therefore, the present study was conducted to evaluate the integrated use of inorganic salt, hot water, and fungicide against postharvest banana crown rot complex.

MATERIALS AND METHODS

The experiment was conducted using three factors: sodium carbonate (Na_2CO_3), hot water treatment, and fungicide application. Factor one was Na_2CO_3 with two levels: no Na_2CO_3 and 4 g/L (Alvindia *et al.* 2004). Factor two consisted of three hot water temperature levels: ambient water (24 °C), 47 °C, and 50 °C. Hot water was prepared using a water bath and temperature was verified using a thermometer. Factor three had four levels of the Carbendazim fungicide: no fungicide, 0.2, 0.3 and 0.4 g/L Carbendazim.

Physiologically matured, unripe banana fruits of comparable size and color of Dwarf Cavendish were brought from Alage Agricultural Technical Vocational and Education Training (ATVET)

Table 1. The twenty-four treatment combinations used in the experiment.

No	Salt	Hot water	Carbendazim (g/L)	Treatment combination
1	4 g/L Na_2CO_3	50 °C	0.4	4 g/L Na_2CO_3 + 50 °C + 0.4 g/L
2		50 °C	0.3	4 g/L Na_2CO_3 + 50 °C + 0.3 g/L
3		50 °C	0.2	4 g/L Na_2CO_3 + 50 °C + 0.2 g/L
4		50 °C	0.0	4 g/L Na_2CO_3 + 50 °C + 0.0 g/L
5		47 °C	0.4	4 g/L Na_2CO_3 + 47 °C + 0.4 g/L
6		47 °C	0.3	4 g/L Na_2CO_3 + 47 °C + 0.3 g/L
7		47 °C	0.2	4 g/L Na_2CO_3 + 47 °C + 0.2 g/L
8		47 °C	0.0	4 g/L Na_2CO_3 + 47 °C + 0.0 g/L
9		24 °C	0.4	4 g/L Na_2CO_3 + 24 °C + 0.4 g/L
10		24 °C	0.3	4 g/L Na_2CO_3 + 24 °C + 0.3 g/L
11		24 °C	0.2	4 g/L Na_2CO_3 + 24 °C + 0.2 g/L
12		24 °C	0.0	4 g/L Na_2CO_3 + 24 °C + 0.0 g/L
13	No Na_2CO_3	50 °C	0.4	No Na_2CO_3 + 50 °C + 0.4 g/L
14		50 °C	0.3	No Na_2CO_3 + 50 °C + 0.3 g/L
15		50 °C	0.2	No Na_2CO_3 + 50 °C + 0.2 g/L
16		50 °C	0.0	No Na_2CO_3 + 50 °C + 0.0 g/L
17		47 °C	0.4	No Na_2CO_3 + 47 °C + 0.4 g/L
18		47 °C	0.3	No Na_2CO_3 + 47 °C + 0.3 g/L
19		47 °C	0.2	No Na_2CO_3 + 47 °C + 0.2 g/L
20		47 °C	0.0	No Na_2CO_3 + 47 °C + 0.0 g/L
21		24 °C	0.4	No Na_2CO_3 + 24 °C + 0.4 g/L
22		24 °C	0.3	No Na_2CO_3 + 24 °C + 0.3 g/L
23		24 °C	0.2	No Na_2CO_3 + 24 °C + 0.2 g/L
24		24 °C	0.0	No Na_2CO_3 + 24 °C + 0.0 g/L

College. Then the fruits were treated by dipping into the above combined treatments or the control (sterile distilled water) in 15 L plastic buckets for three minutes. Three levels of water temperature, 0 and 4 g/L of Na_2CO_3 , and four levels of fungicide were combined in a factorial fashion across three replications in a completely randomized design (CRD) experiment.

Disease assessment

At 48-hour intervals beginning from the disease onset, the incidence and severity of banana crown rot were scored for each treatment. Disease incidence was measured as the proportion of fruit showing symptoms of banana crown rot disease. A 0-7 disease rating scale was used to record the severity of the crown rot, where 0 = no mycelial development on fruit crown, 1= discoloration restricted to the surface of the banana crown, 2 denoting discoloration or mycelial growth less than 10% of the crown area, 3 denoting 11–40% discoloration or mycelial growth on the crown area, and 4 denoting 41–70% discoloration, 5 = 71–100% mycelial development on crown area, 6 = mycelial growth advanced to finger-stalks, and 7 = finger-stalk rot occurs and causing the fingers to drop-off (Alvindia *et al.* 2004). The percentage of crown rot reduction was then calculated using the following formula.

$$\text{Crown rot reduction (\%)} = \frac{\text{crown rot index (untreated fruit)} - \text{crown rot index (treated fruit)}}{\text{crown rot index (untreated fruit)}} \times 100$$

Assessment of fruit quality

Banana fruit quality parameters such as marketability, total soluble solid, pH, titratable acidity, firmness and peel color were recorded during data collection as described below:

Marketability of Banana Fruit: Data on the percentage of marketable and unvendible fruits were recorded at the time of disease measurement following the protocol of Mohammed *et al.* (1999) that was based on descriptive quality criteria such as the amount of visible lesion, shriveling, smoothness and shininess of the fruit. Portions of marketable fruit were calculated by using the following formula:

$$\text{Marketability of banana fruit (\%)} = \frac{\text{Number of marketable fruits}}{\text{Total number of fruits}} \times 100$$

Total Soluble Solids (TSS): Ten grams of pulp from the middle finger was blended with 40 mL of distilled water using a homogenizer for two minutes. Using a handheld refracto meter, the total soluble solids were measured from one to two drops of the filtrate (Brix 0-32%) (Hewage 1996, Anthony *et al.* 2003).

Titratable Acidity (TA): Ten ml of filtrates were diluted with 20 ml of purified water and titrated against 0.1 mL NaOH with phenolphthalein as the pH indicator. Titratable acidity (percentage of malic acid) was computed by multiplying the NaOH volume required with the dilution factor and the malic acid factor = 0.006706 g. The TA was expressed as the percentage of malic acid. The pH of filtrate was measured using pH meter.

Fruit firmness: Fruit firmness was measured by using a fruit firmness tester (CEVIZ, China). The probe (Probe diameter: 11mm/8mm, Accuracy: + 0.1, indenter depth: 10 mm) was pressed against a crosscut section of a finger until it indicated a constant value (Hewage 1996).

Peel color: Colors of banana fruits were visually determined using a Standard Color Index (SCI) developed at the Department of Botany, University of Kelaniya, where, 1 = Green, 2 = Color break, 3 = Greener than yellow, 4 = More yellow than green, 5 = Yellow with green tip, 6 = full yellow, and 7 = over ripe.

Statistical data analysis

All data collected were subjected to ANOVA using SAS Version 9.1 software, and Least Significant Difference (LSD) was used for mean comparison. Disease incidence and marketability data were arcsine-transformed and disease severity was square root transformed prior to statistical analysis.

RESULTS AND DISCUSSION

Disease incidence

Highly significant (P<0.0001) differences were found among all individual and combined treatments in their effects on crown rot incidence reduction as compared to the control (no salt, $24\,^{\circ}\mathrm{C}$ water temperature and no fungicide applications) (Table 2). In this study, disease incidence values assessed on fruits treated with different combined treatments of water temperature, inorganic salts and fungicide had a significant difference. The disease reached 100% incidence on the control treatment nine days after application, followed by 83.3% incidence recorded on integrated treatment of 0.2 g/L Carbendazim and at 47 °C water temperature. However, this level of incidence was reduced considerably by combined application of treatments. The lowest (27.8 %) incidence was observed in fruits dipped in a combined treatment of 4 g/L Na_2CO_3 and 0.4 g/L Carbendazim at 50°C water temperature, which was not significantly different from the incidence (33.3%) of fruits treated with combined treatments of 4 g/L Na_2CO_3, 47 °C hot water treatment and 0.4 g/L Carbendazim along with combined tratment application of 50 °C hot water and 0.4 g/L Carbendazim fungicide (Table 2).

In this experiment, applying different levels of Na_2CO_3 and carbendazim with different temperature levels of water had a greater impact on reducing the intensity of post-harvest banana crown rot in every situation. According to Lurie (1998), the fresh fruit produce treated with

the proper amounts of hot water and exposure times was noticeably important to control fruits postharvest diseases, as seen by the decrease in occurrence of banana crown rot. Inorganic salts also decreased the occurrence of crown rot complex (Alvindia *et al.* 2004).

Disease severity

Postharvest dipping of banana fruits in two levels of Na_2CO_3, three levels of hot water treatment and four levels of Carbendazim showed significant difference ($P<0.05$) among treatment interactions on the banana crown rot disease severity (Table 2). Banana crown rot complex was markedly reduced by integrated use of postharvest inorganic salt, hot water temperature and fungicide at all concentrations of these treatments. However, none of the combinations were able to completely inhibit crown rot development.

The lowest crown rot intensity was recorded when 4 g/L Na_2CO_3 was combined with 50°C hot water and 0.4 g/L Carbendazim, which was not statistically different from combined treatments of 4 g/L Na_2CO_3 and 0.3 g/L Carbendazim with 50°C hot water treatment; 4 g/L Na_2CO_3, 0.2 g/L Carbendazim in 50°C hot water; 4 g/L Na_2CO_3 and 0.4 g/L Carbendazim in 47°C hot water; 4 g/L Na_2CO_3 and 0.3 g/L Carbendazim in 47°C water temperature and 50°C hot water treatment with 0.4 g/L Carbendazim that resulted in (70.2%) crown rot reduction. However, the highest disease severity was recorded on the control treatment (Table 2). In this study, the combined effect of 4 g/L Na_2CO_3, hot water at 50°C and 0.4 g/L Carbendazim was the best treatment with the highest (74.6%) crown rot reduction after three weeks. Moreover, this combination was more effective for the suppression of pathogen development than other treatments and the control. This indicated that application of optimum concentration levels of salt, fungicide and hot water temperature combinations improved effectiveness in reduction of disease severity and increase quality of treated stored banana fruits. Similarly, Alvindia (2013) reported that the smallest crown-rot index was recorded on combined treatments of fungicide, hot water, sodium bicarbonate and sodium carbonate, and he also showed that this treatment integration resulted in a better look of banana fruits.

In the current study, all non-combined levels of fungicide, hot water, inorganic salt were found effective in reduction of banana crown rot intensity. This result agrees with previous work of Maria *et al.* (1998) that dipping banana fruit in hot water between 45 and 50°C alone for recommended time (2-5min) provided effective control of crown rot complex compared to control treatments. In addition, Fallik *et al.* (1996) suggested that hot water treatment of fresh produce has a direct effect on fungi, perhaps by killing spores and slowing germ tube development, thus slowing disease epidemic in the storage. In addition, according to Alvindia & Natsuaki (2007), sodium bicarbonate salt by itself offered modest protection against banana crown rot and other postharvest infectious disease causes. Carbonate solutions prevent fungus from growing without killing them (Smilanick *et al.* 1999). Carbendazim was also successful in reducing the severity of crown rot disease in banana fruits. This outcome is also supported by Alvindia & Natsuaki (2007), who found that fungicides provided superior protection against crown rot in stored banana fruits when compared to sodium bicarbonate salt.

Marketability of banana fruits

Dipping of banana hand in integrated treatments of hot water, Na_2CO_3 and Carbendazim had highly significant effect ($P<0.0001$) on marketability of banana fruits. In this study, application of the combined treatments played an important role in maintaining the marketability of banana, by tackling the disease problem and keeping up the shelf life of the fruits. Banana fruits treated with a combination of 4 g/L Na_2CO_3, 50°C hot water, and 0.4 g/L Carbendazim treatment yielded the maximum (88.9%) marketability percentage of the fruit, which was not significantly different from fruits treated with combined treatments of 4 g/L Na_2CO_3 with 47°C hot water and 0.4 g/L Carbendazim along with

Table 2. Effects of the combination treatments of Na_2CO_3, hot water treatment and Carbendazim on banana crown rot complex intensity.

Salt	Hot water	Carbendazim (g/L)	Incidence (%)[1]	Severity (0–7 Scale)[2]	Crown rot reduction %
4 g/L Na_2CO_3	50 °C	0.4	27.8 (31.5)^{g}	1.7 (1.5)^{g}	74.6
		0.3	38.9 (38.5)^{ef}	2.0 (1.6)^{fg}	70.2
		0.2	44.4 (41.8)^{def}	2.0 (1.6)^{fg}	70.2
		0.0	50.0 (45.0)^{cde}	2.3 (1.7)^{ef}	65.7
	47 °C	0.4	33.3 (35.3)^{fg}	2.0 (1.6)^{fg}	70.2
		0.3	44.4 (41.8)^{def}	2.0 (1.6)^{fg}	70.2
		0.2	50.0 (45.0)^{cde}	2.3 (1.7)^{ef}	65.7
		0.0	55.6 (48.3)^{cd}	2.7 (1.8)^{def}	59.7
	24 °C	0.4	38.9 (38.5)^{ef}	2.3 (1.7)^{ef}	65.7
		0.3	50.0 (45.0)^{cde}	2.3 (1.7)^{ef}	65.7
		0.2	55.6 (48.3)^{cd}	2.7 (1.8)^{def}	59.7
		0.0	61.1 (51.5)^{c}	3.3 (2.0)^{bcd}	50.8
No Na_2CO_3	50 °C	0.4	33.3 (35.3)^{fg}	2.0 (1.6)^{fg}	70.2
		0.3	38.9 (38.5)^{ef}	2.3 (1.7)^{ef}	65.7
		0.2	50.0 (45.0)^{cde}	2.3 (1.7)^{ef}	65.7
		0.0	50.0 (45.0)^{cde}	3.0 (1.9)^{cde}	55.2
	47 °C	0.4	50.0 (45.0)^{cde}	2.3 (1.7)^{ef}	65.7
		0.3	50.0 (45.0)^{cde}	2.7 (1.8)^{def}	59.7
		0.2	61.1 (51.5)^{c}	3.0 (1.9)^{cde}	55.2
		0.0	83.3 (65.9)^{b}	3.7 (2.0)^{bcd}	44.8
	24 °C	0.4	50.0 (45.0)^{cde}	2.7 (1.8)^{def}	59.7
		0.3	55.6 (48.3)^{cd}	3.0 (1.9)^{cde}	55.2
		0.2	83.3 (65.9)^{b}	4.0 (2.1)^{b}	40.3
		0.0	100.0 (88.9)^{a}	6.7 (2.7)^{a}	0.0
CV (%)			8.66	6.92	
LSD (0.05)			6.70	0.20	

[1]Mean percentage of disease incidence 9 days after treatment application; values in parenthesis are arcsine transformed.
[2]Disease severity measured on 0 to 7 scale 21 days after treatment application; values in parenthesis are square root transformed. Means followed by the same letter are not significantly different ($P < 0.05$).

the treatment combination of 50°C hot water and 0.4 g/L Carbendazim, which resulted in (83.3%) marketable fruit. Conversely, banana fruit in the untreated control reached the 100% unmarketable stage 14 days after treatment application (Table 3).

In the present study, all levels of Carbendazim, hot water, Na_2CO_3, and their combinations did not produce any peel damage or fruit injuries, such as browning of the peel and failure to soften. This result was agreed with the findings of Alvindia (2013), who reported that the combination of treatment applications of hot water, sodium carbonate, and fungicide resulted in banana fruits with the highest quality appearance. A temperature treatment at 45°C is effective without fruit damage (Maria *et al.* 1998). De Costa and Erabadupitiya (2005) showed that the optimal temperature for controlling the crown rot complex was 50°C, and higher temperatures lead to fruit peel damage.

Quality of banana fruits

Quality of fruits was measured 14 days after treatment application. There was a highly significant ($P < 0.0001$) effect on pH, TSS, TA, firmness, and color of banana fruits due to inorganic salt, hot water, and fungicide treatment alone and in combination with these treatments

Table 3. Effects of the combination of Na_2CO_3, hot water treatment and Carbendazim on marketability and quality parameters of stored banana fruits.

Salt	Hot water	Fungicide (g/L)	pH	TSS (°Br)	TA (%)	Firmness (N)	Color (SCI) (1–7 scale)[1]	Marketability (%)[2]
4g/L Na_2CO_3	50°C	0.4	4.9^{g}	24.3^{a}	0.89^{a}	11.4^{bc}	3.5^{g}	88.9 (73.6)^{a}
	50°C	0.3	5.0^{fg}	20.3^{bdf}	0.71^{b}	10.0^{cdef}	3.6^{g}	72.2 (58.5)^{bcd}
	50°C	0.2	5.5^{b}	20.3^{bdf}	0.52^{d}	8.0^{g}	4.1^{cdefg}	50.0 (45.0)^{fgh}
	50°C	0.0	5.2^{cdef}	19.7^{def}	0.39^{hij}	9.9^{cdef}	3.9^{defg}	55.6 (48.3)^{efg}
	47°C	0.4	4.6^{H}	21.6^{bc}	0.61^{c}	11.3^{bc}	3.6^{g}	83.3 (65.9)^{ab}
	47°C	0.3	5.5^{b}	22.4^{ab}	0.52^{d}	13.6^{a}	3.9^{defg}	66.7 (54.7)^{cde}
	47°C	0.2	5.5^{b}	16.7^{gh}	0.44^{fgh}	8.4^{fg}	4.8^{cb}	38.9 (38.5)^{h}
	47°C	0.0	5.2^{cdef}	20.3^{bdf}	0.39^{hij}	11.3^{bc}	4.3^{bcde}	50.0 (45.0)^{fgh}
	24°C	0.4	5.3^{bcd}	21.9^{bc}	0.38^{ijk}	10.5^{bcd}	4.1^{cdefg}	66.1 (51.5)^{def}
	24°C	0.3	5.3^{bcd}	19.0^{def}	0.38^{ijk}	10.1^{cdef}	3.7^{fg}	55.6 (48.3)^{efg}
	24°C	0.2	5.0^{fg}	19.6^{def}	0.33^{k}	10.9^{bc}	4.1^{cdefg}	50.0 (45.0)^{fgh}
	24°C	0.0	5.2^{cdef}	16.6^{gh}	0.39^{hij}	9.6^{cdef}	4.0^{defg}	44.4 (41.8)^{gh}
No Na_2CO_3	50°C	0.4	5.0^{fg}	21.6^{bc}	0.49^{edf}	10.2^{bcde}	3.6^{g}	83.3 (65.9)^{ab}
	50°C	0.3	5.3^{bcd}	20.9^{bcd}	0.41^{ghi}	10.0^{cdef}	3.7^{fg}	77.8 (62.2)^{bc}
	50°C	0.2	5.2^{cdef}	19.7^{def}	0.39^{hij}	10.1^{cdef}	4.3^{bcde}	55.6 (48.3)^{efg}
	50°C	0.0	5.1^{defg}	18.3^{fgh}	0.36^{ijk}	10.7^{bcd}	3.7^{fg}	50.0 (45.0)^{fgh}
	47°C	0.4	5.4^{bc}	20.7^{bde}	0.46^{efg}	11.3^{bc}	3.9^{defg}	66.7 (54.7)^{cde}
	47°C	0.3	5.2^{cdef}	20.3^{bdf}	0.39^{hij}	9.7^{cdefg}	3.8^{efg}	66.7 (54.7)^{cde}
	47°C	0.2	5.0^{fg}	16.3^{h}	0.34^{jk}	8.7^{efg}	4.1^{cdefg}	50.0 (45.0)^{fgh}
	47°C	0.0	5.2^{cdef}	16.0^{h}	0.32^{k}	9.0^{defg}	4.5^{bcd}	38.9 (38.5)^{h}
	24°C	0.4	5.4^{bc}	18.3^{fgh}	0.37^{ijk}	11.2^{bc}	3.8^{efg}	55.6 (48.3)^{efg}
	24°C	0.3	5.3^{bcd}	17.0^{gh}	0.34^{jk}	10.7^{bcd}	3.8^{efg}	44.4 (41.8)^{gh}
	24°C	0.2	5.3^{bcd}	15.9^{h}	0.32^{k}	9.0^{defg}	4.9^{b}	38.9 (38.5)^{h}
	24°C	0.0	6^{a}	11.2^{i}	0.20^{l}	3.4^{h}	6.8^{a}	0.0 (1.2)^{i}
CV (%)			2.90	7.72	8.38	10.27	9.92	9.90
LSD (0.05)			0.25	2.41	0.06	1.69	0.67	7.91

[1]Peel color determined using a Standard Color Index (SCI) where 1 = Green, 2 = Color break, 3 = More green than yellow, 4 = More yellow than green, 5 = Yellow with green tip, 6 = Full yellow, 7 = Over ripe.

[2]Mean percentage of marketable banana fruits 14 days after treatment application; values in parenthesis are arcsine transformed; means followed by the same letter are not significantly different at P<0.05.

(Table 3). The pH value of banana fruits ranged from 4.6 up to 6, and the highest (6) pH value was measured on the untreated control treatment. The combined treatment of 4 g/L Na_2CO_3, 47°C hot water, and 0.4 g/L Carbendazim had the lowest pH value (4.6). This might be due to the effects of the combined treatments applied and the early ripening of banana fruit on untreated fruits because of the crown rot epidemic. Dadzie (1998) reported that during ripening there was a decrease and rise in pH of Cavendish banana varieties.

The highest TSS value (24.3 °Brix) was recorded when 4 g/L Na_2CO_3 was combined with 50 °C hot water and 0.4 g/L Carbendazim, which was not significantly different from the TSS value of 22.4 °Brix recorded when 4 g/L Na_2CO_3 was applied in combination with 47 °C water temperature and 0.3 g/L Carbendazim. However, the lowest (11.2 °Brix) value of TSS was observed in the untreated control (Table 3).

This might be due to the high intensity of crown rot complex, which could accelerate ripening, increasing the TSS of the fruits, followed by a fall in the TSS levels earlier than the other treatments. Moreover, the microorganism may change the physiological activity of fruit; for example, the rise in respiration due to

disease may increase product temperature, thereby speeding up the progress of respiration and, consequently, increasing the rate at which the TSS falls in the control treatment. During storage and shelf-life simulation, it was demonstrated that the respiration rate and ethylene development of fruit treated with hot water were significantly lower than those of untreated fruit (Fallik *et al.* 1999, Fallik *et al.* 2000, Ilic *et al.* 2001). Salunkhe & Kadam (1995) further demonstrated that an increase in respiration during banana ripening is the cause of the overall decrease in carbohydrates.

The TA of banana fruits varied from 0.20% for the untreated control to 0.89% in the treatment combination of 4 g/L Na_2CO_3 combined with 50°C hot water and 0.4 g/L Carbendazim. In the control treatments of this study, the TA values were minimum, which might be attributed to their conversion into sugars and their further utilization in metabolic processes in the fruit as a result of high crown rot epidemics that might enhance ripening. According to Gowen (1995), as the fruit ripened, its pH dropped and its free acidity rose until it reached the fully ripe stage, at which point acidity gradually dropped and its pH value rose.

The banana fruit firmness varied significantly between treatments, with the control treatment having the least amount of firmness (3.4 N). The highest (13.6 N) firmness resulted when 4 g/L Na_2CO_3 was applied with 47°C hot water treatment and 0.3 g/L Carbendazim, followed by a treatment combination of 4 g/L Na_2CO_3, 50°C hot water, and 0.4 g/L Carbendazim (11.4 N) (Table 2). Shalom *et al.* (1996) revealed that one of the primary causes of heat treatment-induced firmness retention is the suppression of the pectin fractions solubilization. In the current study, the firmness of treated fruits was relatively higher than the control, which might be due partially to the inhibition effect of crown rot disease intensity, and thus reduced ripening and effects of softening-related enzymes. According to Dadzie (1998), pulp firmness declined rapidly after the onset of ripening, but the rate of decline depends on the type of banana cultivar, and showed that there was a reverse correlation between firmness and ripening.

There was significant variation in the peel color of banana fruit, ranging from 3.5 in the treatment combination of 4 g/L Na_2CO_3, 50°C hot water, and 0.4 g/L Carbendazim to 6.8 in the control treatment. The lower peel color was observed in treated fruit than in the control, which could be due to the reduction of disease and thus retarding fruit ripening. This result was in agreement with Krauss and Johanson (2000) that crown rot is the most serious banana postharvest disease, and it affects the quality as well as the ripening of banana fruits in all banana-growing countries.

Ripening may be enhanced by ethylene produced by mycelia of fungi, such as *Colletotrichum musae* (Daundasekera *et al.* 2003). Dadzie & Orchard (1997) reported that the market quality and consumer acceptance of banana fruit are substantially influenced by the color of the fruit.

CONCLUSION

In the current study, when postharvest banana fruits were dipped in inorganic salt, hot water, and fungicide treatments to control the crown rot complex, there were significant variations in the treatment interactions. Application of 4 g/L Na_2CO_3 with hot water treatment at 50°C and 0.4 g/L Carbendazim was more effective than other treatments and the control. This combination also reduced disease incidence and yielded maximum marketability of banana fruits after two weeks. Moreover, there was a highly significant difference among the treatments applied in pH, TSS, TA, firmness, and color of banana fruits. In conclusion, the present study has clearly indicated that the application of integrated postharvest treatments of inorganic salt, hot water and fungicide had the potential for the reduction of banana crown rot disease's complex severity and preserving significantly the quality of banana fruits. Therefore, this integrated postharvest crown rot disease management strategy can be used by farmers, wholesalers and retailers in Ethiopia. However, further research may be crucial in the laboratory and in the field evaluation of alternatives such as bioagents, botanicals, and resistant genotypes of banana alone or in combination on the control of the crown rot complex across locations. Furthermore,

the integrated disease management practice evaluated in the current study showed a potential for maintaining the quality of fruits, so they should be further tested under different storage conditions.

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