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Yield and postharvest response of ‘Rosanna’ tomato to radiation-modified carrageenan and vermicompost tea

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Abstract. *Enano JD, Balderas MB. 2025. Yield and postharvest response of ‘Rosanna’ tomato to radiation-modified carrageenan and vermicompost tea. Asian J Agric 9: 339-348.* Tomatoes are one of the perishable crops, and inappropriate postharvest handling leads to a high amount of postharvest losses. The study investigated the effect of Radiation-Modified Carrageenan (RMC) and Aerated Vermicompost Tea (AVCT) on yield, fruit quality, and postharvest attributes in ‘Rosanna’ tomatoes. The study was laid out in a randomized complete block design consisting of seven treatments and three replicates and used the least significant difference test at a 5% level. Significant differences shown in fruit color at 20 Days from Initial Storage (DIS) (p = 0.0380); fruit firmness on 5 DIS (p = 0.0332), 15 DIS (p = 0.0099), and 25 DIS (p = 0.0291). Postharvest disease incidence at 14 DIS (p = 0.0115), 28 DIS (p = 0.0314); and postharvest disease severity index at 42 DIS (p = 0.0106), 56 DIS (p = 0.0416), and 72 DIS (p = 0.0297). No significant differences in other parameters; however, the 20,000 ppm RMC has the earliest day to harvest and the highest total yield. Fruits with the highest total soluble solids, titratable acids, and TSS/TA ratio at 40,000 ppm RMC + AVCT, 20,000 ppm RMC, and 20,000 ppm RMC + AVCT, respectively. The 1:1 (v:v) AVCT to water has the highest moisture and lowest dry matter. The highest fruit polar and equatorial diameter at 40,000 ppm RMC + AVCT. Fruits with the highest fruit color scale on 20,000 ppm RMC + AVCT at 5 DIS, and 20,000 ppm RMC at 10, 15, and 25 DIS. Firmer fruits in 1:1 (v:v) AVCT to water at 10 DIS, and 30,000 ppm RMC + AVCT at 20 DIS. The 10,000 ppm RMC + AVCT has the lowest percentage of disease incidence, the lowest severity index, and extended storage shelf life. The application of 10,000 ppm RMC + AVCT improved the fruit quality and extended the shelf life of the fruits.

Keywords: Carrageenan, fruit quality, shelf life, tomato, vermicompost tea, yield enhancement

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is the second most important fruit worldwide (FAO 2022). In 2022, the Philippines produced approximately 216.61 thousand metric tons, reflecting a decrease compared to the previous year's production volume (Balita 2023). The majority of tomato growers are small producers, and most of them grow the crop traditionally. Farmers use manual and traditional harvesting methods that occasionally result in high postharvest losses. Tomatoes contain a high percentage of water in their cell and exhibit high metabolic activity even after harvest (Hou et al. 2020). Postharvest losses result in both qualitative and quantitative deterioration due to factors such as growing conditions and improper postharvest handling. Tomato losses occur as early as the production, postharvest stages, and storage; these postharvest losses are generally due to fruit diseases, over-ripening, mechanical damage, and weight loss. Bayogan et al. (2023) reiterated that postharvest losses in the Philippines from Nueva Ecija to markets in Manila during transport were reported between 10-18% and 41% after 7 days in storage (Antolin et al. 2022); meanwhile, harvested tomatoes from Bukidnon to Manila resulted in postharvest losses of 41,125 tons. Abera et al. (2020) also reported that 39.3% of losses in the East Shewa Zone of Ethiopia, and annual economic losses in Nigeria reached $446, Maharashtra in India at $206 million, and in Rwanda at $48.2 million (Kitinoja et al. 2019).

The Department of Science and Technology - Philippine Nuclear Research Institute developed the Radiation-Modified Carrageenan (RMC), commonly known as the Carrageenan Plant Growth Promoter. The RMC was produced by exposing aqueous solutions of *Kappaphycus alvarezii* to gamma irradiation at doses ranging from 20kGy to 30kGy (Abad et al. 2016). Carrageenan is a group of high-molecular-weight sulfated galactans found in the cell walls of red algae (Tuvikene 2021), the polysaccharides that were degraded by radiation and yielded oligosaccharides. Thus, the RMC has a lower molecular weight, better water solubility, and higher absorption efficiency, which can induce a growth-promoting effect and stimulate various biological and physiological activities in plants. Currently, in the Bicol Region, the primary limitations of RMC are its availability in agricultural markets and the awareness of farmers. The effects of RMC are mostly tested on the growth and yield of agronomic crops. Still, studies on postharvest quality, postharvest disease incidence, and storage shelf life are limited in both agronomic and horticultural crops.

The Aerated Vermicompost Tea (AVCT) was produced by aerating the water with the presence of vermicompost while maintaining aerobic conditions. It extracts the nutrients, microorganisms, and other compounds that are abundantly present in the vermicompost. In the Philippines, the AVCT is commonly produced by organic practitioners and smallholder farmers, and this is being used as a foliar fertilizer. However, the raw materials for making AVCT are limited in other regions, but sometimes higher production costs occur than commercial fertilizer. The nutrient availability of the AVCT heavily relies on the quality of the vermicompost used. Storage and maintaining the quality of AVCT over a long period is difficult since it has microbes that require carbon as a food source and oxygen for respiration.

In the Philippines, most of the postharvest losses in tomatoes are caused by a lack of postharvest infrastructure and facilities, the way of handling, and the distribution system. Alternative management practices of farmers are desirable elements to maintain the overall quality and quantity of the produce. While the potential of the RMC and AVCT addresses multiple challenges in the production of some other crops, their synergistic effects on yield and postharvest responses in tomato remain largely unexplored. Thus, this study investigated the effects of radiation-modified carrageenan and aerated vermicompost tea on yield, fruit quality, and postharvest attributes in 'Rosanna' tomatoes. Specifically, the study aimed to: determine the effects of different application rates of RMC and a combination of AVCT on the yield of tomato; quantify changes in biochemical markers of fruit quality and fruit morphology; evaluate its effect on postharvest disease incidence, disease severity index, and storage shelf life of the fruits; and determine the effective application rate of RMC in enhancing tomatoes' fruit yield, quality, and storage shelf life.

MATERIALS AND METHODS

Soil sampling and analysis

Soil samples were randomly collected from ten sampling points in the experimental area. The collected samples were sent to the Department of Agriculture V - Regional Soils Laboratory. The report of the analysis showed that it is low in nitrogen content, about 1.3% of organic matter (OM), moderately low in phosphorus, about 12.17 ppm, deficient in potassium, and pH value at 6.48.

Test plant and experiment procedure

The study used the 'Rosanna' tomato as a test plant. The 'Rosanna' is a determinate open-pollinated table-type tomato variety. It yields 10-15 tons/ha during wet and 20-30 tons/ha during dry seasons. The study focused on the growing and postharvest period from August 2022 to January 2023 at the Central Bicol State University of Agriculture, San Jose, Pili, Camarines Sur. The experimental field was laid out in a Randomized Complete Block Design (RCBD) with seven treatments and three replications. A 4 × 4 m plot size was set, with 54 plants in each plot. Ten sample plants were randomly selected per plot to observe the yield parameters. Fruits from the net plot were randomly harvested to assess the fruit quality, morphology, postharvest disease assessment, and storage shelf life. The treatments used in the experiment were: T1 - Control; T2 - 20,000 ppm RMC; T3 - 1:1 (v:v) AVCT to water; T4 - 40,000 ppm RMC + AVCT; T5 - 30,000 ppm RMC + AVCT; T6 - 20,000 ppm RMC + AVCT; and T7 - 10,000 ppm RMC + AVCT.

Radiation-modified carrageenan nutrient content

A product of RMC was purchased from the Department of Science and Technology. The labels indicated that RMC has a total nitrogen of 1.8%, calcium of 24.8 ppm, potassium oxide of 933 ppm, copper of 4.6 ppm, magnesium oxide of 36.7 ppm, and Iron of 2.7 ppm (Source: Vital Gro).

Aerated vermicompost tea preparation

The AVCT was produced and prepared a day before the application. The 12.5 liters of non-chlorinated water were filled into the container, and the air stone of the aerator was placed at the bottom of the container and allowed to bubble and aerate the water for 30 minutes to increase the oxygen level; afterward, a half-liter of molasses and 25 mL of E.M.-1 were added and stirred well. The tea bag (customized mesh net bag) with 750 g of vermicompost was tied off on the end and suspended in water. The aeration continued for at least 24 hours before application. The E.M.-1 is a liquid probiotic that contains three groups of non-pathogenic microbes, and this includes photosynthetic bacteria, lactic acid bacteria, and yeast.

Cultural management practices

Land preparation

The area was prepared and cleared of weeds and other vegetation of no economic importance, and then it was plowed and harrowed twice.

Seedling preparation and transplanting

Tomato seeds were broadcasted evenly in seed boxes. After ten days, seedlings were pricked and transferred into seedling trays. The potting medium contains a mixture of carbonized rice hull and vermicompost in a 1:1 ratio. Twenty-five-day-old tomatoes were transplanted in the field, having a planting distance of 50 cm between hills and 75 cm between rows.

Fertilizer application

Different amounts of RMC (based on treatments) were applied on the 15th day after transplanting (DAT), 30 DAT, 45 DAT, and 60 DAT. The AVCT dilution rate in non-chlorinated water was a 1:1 ratio (by volume). AVCT application at 15 DAT and every once a week until 60 DAT. The RMC and AVCT were applied directly through foliar application in the early morning or later afternoon.

Water management

Drainage canals were installed in each plot before planting. Tomatoes were only watered until recovery from transplanting. No additional irrigation was applied during the rest of the growing period as the region received ample rainfall.

Pest management

A handheld hoe was used to remove the weeds between furrows, and manually uprooted near the base of the plants. No control measures were applied against insect pests and diseases.

Trellising and training

A hip-high I trellis made from bamboo poles and vegetable twine was used to support the plants and trained to grow vertically by tying at the main stems.

Harvesting

Tomatoes were manually harvested.

Data gathering procedures

Yield parameters

Days to the first harvest were determined by counting from the transplanting date to the first priming day. The number of fruits was counted from successive harvests per sample plant. Fruit yield was recorded per plant and plot.

Fruit quality parameters

The total soluble solids of tomatoes were obtained after each harvest and analyzed using a handheld fruit refractometer. A representation of fruits (about 500 g) in each treatment was sent to the laboratory for titratable acid analysis. Moisture and dry matter content were obtained by weighing 10 g of tomato pulp as initial weight and drying in an oven at a temperature of 70°C for eight hours; the final weight was obtained using an analytical balance.

Fruit morphology parameters

Every harvest, fruit polar and equatorial diameters were measured by using a digital vernier caliper. Fruit color was determined using a numerical scale, where 1: green stage; 2: breaker stage, 3: turning, 4: pink, 5: light red, 6: red, and 7: ripe red. Twenty sample fruits were used to measure the fruit color. Fruit firmness was determined using a fruit penetrometer with a model of GY-2, capacity of 4 $kg/cm^{2,}$ and punctured three times. Twenty-five sample fruits per replicate were used to measure the fruit firmness.

Postharvest disease assessment

There were no sample fruits collected from the control (T1) to assess the postharvest diseases and storage shelf life of the fruits due to the limited number of fruits yielded, insect damage, and typhoons. Twenty sample fruits per replicate were collected from T2 to T7 for disease assessment and storage shelf life. The appearance of disease symptoms in the fruits during storage was described and identified, and these were verified under an electric compound microscope. The percent disease incidence was calculated (Zhang et al. 2014) as follows:

$$Disease\ Incidence\ (\%) = \frac{number\ of\ infected\ fruit}{total\ number\ of\ fruits\ a\ every\ date}\ X\ 100$$

The disease severity scores (Table 1) were used to assess the tomato fruits infected with fungus and were calculated as follows:

$$DS\% = \frac{\Sigma\ (severity\ rating\ x\ number\ of\ fruits\ cluster\ in\ the\ rating}{total\ number\ of\ fruit\ clusters\ assessed\ x\ highest\ DS\ score}\ X\ 100\%$$

Storage shelf life parameter

Sample fruits per replicate were placed in their respective fruit crates and were stored at ambient room temperature. The investigation starts from harvesting and extends up to the start of fruit rotting.

Meteorological data

Agroclimatic conditions were obtained during the entire cropping season from the Philippine Atmospheric Geophysical and Astronomical Services, Central Bicol State University of Agriculture, AGROMET Station at San Jose, Pili, Camarines Sur.

Statistical analysis

The data was analyzed using the analysis of variance to determine the significant differences between treatments. The Least Significant Difference (LSD) test at 5% level was utilized to determine the difference of the treatment means using Statistical Tool for Agricultural Research (STAR, 2.0.1 version).

RESULTS AND DISCUSSION

Field environmental condition

The highest wind speed was recorded in October 2022 at 36 mps, and the lowest in November 2022 at 09 mps. The highest temperature was recorded in September 2022 at 28.6°C and the lowest during November 2022 at 27.6°C. Meanwhile, heavy rainfall occurred in October 2022 at an average of 21.1 mm and was minimal in the month of November 2022 at 2.8 mm. The month of September 2022 has the highest evaporation at 4.8 mm and the lowest during August 2022 at 4.0 mm. Months with high relative humidity occurred in August and October 2022 at 90%, and the lowest was recorded in November 2022 at 88%. Such weather conditions contributed to stresses, which resulted in some plants yielding limited fruits, while other plants did not bear fruits. To emphasize, the majority of the plants from the control group (T1) did not bear fruits, which leads to the unavailability of sample fruits to assess the postharvest disease incidence, postharvest disease severity index, and storage shelf life.

Table 1. Disease severity scores were used to assess disease resistance in tomato fruits (Safari et al. 2021)

Score	Description	Inference
0	No visible symptoms on the fruit	No infection
1	1-25% of the area is covered by slight necrotic and fungal mycelia	Mild infection
2	26-50% of the area is covered by necrotic and fungal mycelia	Moderate infection
3	51-75% of the fruit is necrotic with the presence of spore mass	Severe infection
4	>76% necrotic tissue with fungal mass, and the fruits appear soft and decayed	Very severe/devastating

Effects of RMC and AVCT on the yield of tomatoes

Table 2 shows the mean value, and no significant differences in days to first harvest (p = 0.7127), number of fruits per plant (p = 0.5855), fruit yield per plant (p = 0.6547), and total yield (p = 0.4999) of tomatoes. However, the study showed an earlier day to harvest and yield increase in tomatoes applied with RMC and AVCT over the control plants. Those tomatoes applied with 20,000 ppm RMC were observed to have the earliest day to harvest at 69.33 Days After Transplanting (DAT) and had the highest total yield at 1.02 tons per hectare, which surpasses the other treatments. Notably, the 30,000 ppm RMC + AVCT emerged as more fruits were produced at 1.93 per plant, and the 20,000 ppm RMC + AVCT had the highest yield per plant at 62.40 g.

Biochemical markers in fruit quality and morphology of tomatoes

Table 3 shows no significant differences in the Total Soluble Solids (TSS) of tomatoes (p = 0.1334); and the mean value of Titratable Acids (TA), and TSS/TA ratio. Results showed that tomatoes with the highest TSS mean value in 40,000 ppm RMC + AVCT at 4.92 °Brix, TA in 20,000 ppm RMC at 4.53%, and TSS/TA ratio in 20,000 ppm RMC + AVCT at 1.53. An increase in the TSS and TSS/TA ratios of tomatoes applied with AVCT and RMC over the control fruits. Only tomatoes applied with 20,000 ppm RMC increase in TA as compared to the control fruits.

Table 4 shows the mean value, and no significant differences in tomatoes' moisture content (p = 0.1449) and dry matter content (p = 0.1449) between the treatments. However, the 1:1 (v:v) AVCT to water exhibits the highest moisture content at 94.81%, and the lowest dry matter content at 5.19%. Meanwhile, fruits from control plants obtained the lowest moisture content at 91.76% and the highest dry matter content at 8.24%. A slight difference in the mean value among the treatments.

Table 5 displays the mean value and shows no significant differences in fruit polar (p = 0.3864), fruit equatorial diameter (p = 0.7427), and fruit shape index (p = 0.5383) of tomatoes among the treatments. However, the effects of RMC and AVCT in tomatoes showed an increased value in fruit polar and equatorial diameter over the control fruits. Tomatoes applied with 40,000 ppm RMC + AVCT had the highest mean value, having 41.28 and 36.25 mm in polar and equatorial diameter, respectively. The 20,000 ppm RMC + AVCT exhibits the highest fruit shape index value as compared with other treatments. A similar fruit shape index in control, 20,000 ppm RMC, and 1:1 (v:v) AVCT to water, and these treatments are higher than the 10,000 ppm RMC + AVCT, which exhibits the lowest mean value.

Table 6 shows significant differences in fruit color among the treatments at 20 Days from Initial Storage (DIS) (p = 0.0380), where the highest scale is 20,000 ppm RMC, which significantly differs from the control, 40,000 ppm RMC + AVCT, 20,000 ppm RMC + AVCT, and 10,000 ppm RMC + AVCT. No significant differences at the 5 DIS, 10 DIS, 15 DIS, and 25 DIS. At 5 DIS, the 20,000 ppm RMC + AVCT has the highest mean value at 3.50 (between turning and pink). Meanwhile, at 10 DIS, 15 DIS, and 25 DIS, the 20,000 ppm RMC has consistently the highest mean value at 5.21 (light red), 5.37 (light red), and 5.93 (turning to red), respectively.

Table 2. Mean of days to first harvest, number of fruits per plant, fruit yield per plant, and total yield of tomato

Treatments	Days to first harvest (DAT)	Number of fruits per plant	Fruit yield per plant (grams)	Total yield (t ha^{-1})
T1 - Control	76.33	0.37	22.11	0.29
T2 - 20,000 ppm RMC	69.33	1.33	54.95	1.02
T3 - 1:1 (v:v) AVCT to water	70.33	1.40	50.00	0.91
T4 - 40,000 ppm RMC + AVCT	73.67	1.67	58.54	0.85
T5 - 30,000 ppm RMC + AVCT	75.33	1.93	58.55	1.00
T6 - 20,000 ppm RMC + AVCT	71.67	1.07	62.40	0.75
T7 - 10,000 ppm RMC + AVCT	73.67	1.20	33.84	0.91
p-value	0.7127	0.5855	0.6547	0.4999

Note: DAT: Days After Transplanting

Table 3. Mean of total soluble solids, titratable acid, and TSS/TA ratio of tomato fruits

Treatments	Total soluble solids (°Brix)	Titratable acid (%)	TSS/TA ratio
T1 - Control	2.67	3.94	0.67
T2 - 20,000 ppm RMC	4.67	4.53	1.03
T3 - 1:1 (v:v) AVCT to water	4.75	3.13	1.51
T4 - 40,000 ppm RMC + AVCT	4.92	3.46	1.42
T5 - 30,000 ppm RMC + AVCT	4.17	3.30	1.26
T6 - 20,000 ppm RMC + AVCT	4.67	3.05	1.53
T7 - 10,000 ppm RMC + AVCT	4.58	3.07	1.49
p-value	0.1334		

Table 4. Mean of moisture and dry matter content of tomato fruit

Treatments	Moisture content (%)	Dry matter content (%)
T1 - Control	91.76	8.24
T2 - 20,000 ppm RMC	92.70	7.30
T3 - 1:1 (v:v) AVCT to water	94.81	5.19
T4 - 40,000 ppm RMC + AVCT	92.55	7.45
T5 - 30,000 ppm RMC + AVCT	92.78	7.22
T6 - 20,000 ppm RMC + AVCT	93.33	6.67
T7 - 10,000 ppm RMC + AVCT	92.73	7.27
p-value	0.1449	0.1449

Table 5. Mean of fruit polar and equatorial diameter and fruit shape index

Treatments	Fruit polar diameter (mm)	Fruit equatorial diameter (mm)	Fruit shape index
T1 - Control	37.98	32.87	0.86
T2 - 20,000 ppm RMC	40.57	35.07	0.86
T3 - 1:1 (v:v) AVCT to water	41.05	35.56	0.86
T4 - 40,000 ppm RMC + AVCT	41.28	36.25	0.87
T5 - 30,000 ppm RMC + AVCT	41.03	34.86	0.84
T6 - 20,000 ppm RMC + AVCT	38.69	34.70	0.90
T7 - 10,000 ppm RMC + AVCT	40.22	34.63	0.85
p-value	0.3864	0.7427	0.5383

Table 6. Mean of tomato fruit color

Treatments	Fruit color				
	5 DIS	10 DIS	15 DIS	20 DIS	25 DIS
T1 - Control	1.13	3.62	5.13	5.38[bcd]	5.50
T2 - 20,000 ppm RMC	3.47	5.21	5.37	5.83[a]	5.93
T3 - 1:1 (v:v) AVCT to water	2.20	3.73	5.33	5.63[abc]	5.81
T4 - 40,000 ppm RMC + AVCT	2.50	4.15	5.00	5.17[d]	5.75
T5 - 30,000 ppm RMC + AVCT	2.40	4.30	5.31	5.66[ab]	5.87
T6 - 20,000 ppm RMC + AVCT	3.50	4.80	5.20	5.38[bcd]	5.67
T7 - 10,000 ppm RMC + AVCT	2.97	3.53	4.73	5.22[cd]	5.63
p-value	0.1777	0.3762	0.3334	0.0380	0.6943

Note: There is no significant difference between the means of the similar letters. DIS: Days from Initial Storage

Table 7. Mean of fruit firmness

Treatments	Fruit firmness (kg/cm^2)				
	5 DIS	10 DIS	15 DIS	20 DIS	25 DIS
T1 - Control	2.90[bc]	2.98	2.00[b]	2.33	2.62[ab]
T2 - 20,000 ppm RMC	3.35[ab]	2.53	2.97[a]	2.65	2.44[bc]
T3 - 1:1 (v:v) AVCT to water	3.62[a]	3.47	3.02[a]	2.78	2.37[bc]
T4 - 40,000 ppm RMC + AVCT	2.50[c]	3.45	2.91[a]	2.67	2.46[bc]
T5 - 30,000 ppm RMC + AVCT	3.31[ab]	3.17	3.08[a]	3.03	2.80[a]
T6 - 20,000 ppm RMC + AVCT	2.85[bc]	3.07	2.81[a]	2.86	2.34[c]
T7 - 10,000 ppm RMC + AVCT	3.00[abc]	2.72	2.01[b]	2.40	2.49[bc]
p-value	0.0332	0.1307	0.0099	0.1963	0.0291

Note: There is no significant difference between the means of the similar letters. DIS: Days from Initial Storage

Table 7 shows a significant difference in tomato fruit firmness at 5 DIS (p = 0.0332), 15 DIS (p = 0.0099), and 25 DIS (p = 0.0291). At 5 DIS, firmer fruits in 1:1 (v:v) AVCT to water, which significantly differed from the control, 40,000 ppm RMC + AVCT and 20,000 ppm RMC + AVCT. At 15 DIS, the 20,000 ppm RMC, 1:1 (v:v) AVCT to water, 40,000 ppm RMC + AVCT, 30,000 ppm RMC + AVCT, and 20,000 ppm RMC + AVCT showed significant similarity, and these treatments differed from the control and 10,000 ppm RMC + AVCT. At 25 DIS, the 30,000 ppm RMC + AVCT produced firmer fruits, which significantly differed from 20,000 ppm RMC, 1:1 (v:v) AVCT to water, 40,000 ppm RMC + AVCT, 20,000 ppm RMC + AVCT, and 10,000 ppm RMC + AVCT. The 1:1 (v:v) AVCT to water showed the highest mean value at 3.47 kg/cm^2 on 10 DIS, and the 30,000 ppm RMC + AVCT at 3.03 kg/cm^2 on 20 DIS.

Effects of RMC and AVCT on postharvest disease incidence and storage shelf life of tomato

Table 8 showed significant differences between treatments at 14 DIS (p = 0.0115) and 28 DIS (p = 0.0314). At 14 DIS and 28 DIS, the 10,000 ppm RMC + AVCT exhibited the lowest postharvest disease incidence, which significantly differed from 20,000 ppm RMC and 20,000 ppm RMC + AVCT. The 10,000 ppm RMC+AVCT also significantly differed from 1:1 (v:v) AVCT to water at 14 DIS. From 42 DIS, 56 DIS, and 72 DIS, the 10,000 ppm RMC + AVCT consistently obtained the lowest percentage of postharvest disease incidence at 23.33, 26.67, and 26.67%, respectively. Notably, the 20,000 ppm RMC obtained the highest disease incidence on 42, 56, and 72 DIS at 78.57, 86.67, and 86.67%, respectively.

Table 9 displays significant differences in the postharvest disease severity index at 42 DIS (p = 0.0106), 56 DIS (p = 0.0416), and 72 DIS (p = 0.0297), where the 10,000 ppm RMC + AVCT with the lowest disease severity index significantly differed from all the treatments. Similar observation at 14 DIS and 28 DIS, where the 10,000 ppm RMC + AVCT obtained the lowest postharvest disease severity index at 16.67 and 33.33%, respectively. This indicates a mild to moderate infection on fruit surfaces (Table 1). Notably, the 20,000 ppm RMC and 20,000 ppm RMC + AVCT exhibited the highest postharvest disease severity index at 14 DIS, and the 20,000 ppm RMC at 28 DIS. Meanwhile, a very severe infection with a 100% fungal mass, fruits appear soft and deteriorate in 1:1 (v:v) AVCT to water, and 40,000 ppm RMC + AVCT at 56 DIS to 72 DIS. Similar results in 20,000 ppm RMC, 30,000 ppm RMC + AVCT, and 20,000 ppm RMC + AVCT at 72 DIS.

Table 10 showed that among the treatments, the 10,000 ppm RMC + AVCT exhibited the most extended shelf life at 76.10 DIS. Early deteriorated fruits in 20,000 ppm RMC at 39.57 DIS showed a shorter shelf life than fruits from 1:1 (v:v) AVCT to water. The early deteriorated fruits were caused by severe fungal infection and deterioration (Table 9).

The effective dosage of RMC and AVCT

The 20,000 ppm RMC revealed the most effective for yield improvement (Table 2). Meanwhile, the 10,000 ppm RMC + AVCT exhibited the lowest postharvest disease incidence (Table 8) and postharvest disease severity index (Table 9) that resulting in the longest shelf life (Table 10). Both the application of RMC and AVCT in tomato plants improved the fruit quality (Tables 3 and 4) and fruit morphology (Tables 5, 6, and 7).

Discussion

The field experiment was conducted during the wet cropping season, and the experimental site was characterized by a waterlogged environment, but drainage canals were installed on both sides of each plot. The tomato plants experienced a favorable temperature during the vegetative stage. However, with continuous rainfall and high relative humidity in October 2022, tomatoes experienced a prolonged exposure to water, which triggered water stress to the plants and later resulted in less fruit setting and fruit cracking. It has been observed in the field a high incidence of plant diseases and insect damage to the fruits. Additionally, the region experienced a severe tropical storm on October 29, 2022, as a typhoon hit the province.

Table 8. Mean of postharvest disease incidence at fruit storage

Treatments	Postharvest disease incidence (percentage)				
	14 DIS	28 DIS	42 DIS	56 DIS	72 DIS
T2 - 20,000 ppm RMC	34.29[a]	47.14[ab]	78.57	86.67	86.67
T3 - 1:1 (v:v) AVCT to water	20.00[b]	33.33[abc]	60.00	66.67	66.67
T4 - 40,000 ppm RMC + AVCT	13.33[bc]	33.33[abc]	66.67	80.00	80.00
T5 - 30,000 ppm RMC + AVCT	13.33[bc]	23.33[bc]	63.33	70.00	70.00
T6 - 20,000 ppm RMC + AVCT	20.00[b]	60.00[a]	60.00	70.00	70.00
T7 - 10,000 ppm RMC + AVCT	3.33[c]	10.00[c]	23.33	26.67	26.67
p-value	0.0115	0.0314	0.3825	0.3290	0.3290

Note: There is no significant difference between the means of the similar letters. DIS: Days from Initial Storage

Table 9. Mean of postharvest disease severity index

Treatments	Postharvest disease severity index (percentage)				
	14 DIS	28 DIS	42 DIS	56 DIS	72 DIS
T2 - 20,000 ppm RMC	75.00	88.33	97.22[a]	96.15[a]	100.00[a]
T3 - 1:1 (v:v) AVCT to water	54.17	66.67	68.75[a]	100.00[a]	100.00[a]
T4 - 40,000 ppm RMC + AVCT	33.33	52.78	87.50[a]	100.00[a]	100.00[a]
T5 - 30,000 ppm RMC + AVCT	58.33	66.67	95.83[a]	95.00[a]	100.00[a]
T6 - 20,000 ppm RMC + AVCT	75.00	79.11	100.00[a]	93.50[a]	100.00[a]
T7 - 10,000 ppm RMC + AVCT	16.67	33.33	22.62[b]	33.33[b]	33.33[b]
p-value	0.2559	0.4887	0.0106	0.0416	0.0297

Note: There is no significant difference between the means of the similar letters. DIS: Days from Initial Storage

Table 10. Mean of storage shelf life of tomato fruit

Treatments	**Storage shelf life (DIS)**
T2 - 20,000 ppm RMC	39.57
T3 - 1:1 (v:v) AVCT to water	64.47
T4 - 40,000 ppm RMC + AVCT	42.77
T5 - 30,000 ppm RMC + AVCT	55.50
T6 - 20,000 ppm RMC + AVCT	52.99
T7 - 10,000 ppm RMC + AVCT	76.10
p-value	0.4567

Note: DIS: Days from Initial Storage

The study shows no significant differences among yield parameters in various treatments. However, despite the lack of statistical significance, the study consistently showed an earlier day to harvest and yield increase in tomatoes applied with RMC and AVCT over the control plants. This showed a positive numerical effect across the treated groups and corroborates earlier findings of increased productivity in rice by 60% (DOST-PNRI 2015), mungbean at 104.7%, peanut at 68.90% (DOST - PCAARRD 2018), and pepper (Guzman and Valdez 2024). Previous studies have found that seaweed extract application promotes early flowering, enhances fruit weight (Hernández-Herrera et al. 2022), and improves yield in tomatoes (Villa e Vila et al. 2023). Improved reproductive growth of tomato plants suggests that polysaccharide-enriched extracts derived from seaweeds contain functional compounds. This activates the signaling mechanism of tomato plants to increase the uptake and use efficiency of available nutrients for productive functions (Mzibra et al. 2021).

For AVCT, yield improvement was likely linked to its rich composition of nutrients, plant growth regulators, and microorganisms (Yatoo et al. 2021). However, composition, quality, and presence of microorganisms in AVCT vary in the quality of vermicompost and raw materials used. Souffront et al. (2022) reported that tomatoes applied with vermicompost tea influenced the secondary metabolites. Based on the metagenomic analysis of bacterial specimens in vermicompost tea revealed the abundant genera as *Novosphingobium* Takeuchi, Hamana & Hiraishi, 2001, *Sphingobium* Takeuchi, Hamana & Hiraishi, 2001, *Luteimonas* Finkmann et al., 2000, *Pseudomonas* Migula, 1894, *Planctomyces* Gimesi, 1924, *Rhodoplanes* Hiraishi & Ueda, 1994, *Mycoplana* Gray & Thornton, 1928, *Bacillus* Cohn, 1872, *Achromobacter* Yabuuchi & Yano, 1981, and *Devosia* Nakagawa et al., 1996 (Javanmardi et al. 2024). Previous studies also reported an enhanced yield in onion (Hatungimana et al. 2024), tomato (Yatoo et al. 2024), faba bean (Hussein 2023), chinese kale (Luu et al. 2023), and broccoli (Alkobaisy et al. 2021). The study suggests that RMC and AVCT offer a tangible benefit for farmers who are facing near-total crop failure, as observed in the control. Any numerical yield increase represents a substantial economic gain during extreme weather disturbances.

The total soluble solids and titratable acids are essential factors for flavor quality in tomatoes, and they are indicators of the sweetness and sourness of the fruits. The TSS/TA ratio represents the balance between sweetness and acidity. The present study revealed no significant differences and only observed the numerical differences in TSS, TA, and TSS/TA ratio of tomatoes among the treatments, which similar finding to Yao et al. (2020). This is also consistent with previous findings where polysaccharide-enriched extracts improved the total soluble solids and sugar-acid ratio (Mzibra et al. 2021) and effective in retaining the titratable acidity in strawberries (Gomaa et al. 2024). Likewise, Saeed and Abbas (2024) reported that vermicompost tea improved TSS and sugar contents while reducing acidity and total soluble tannins percentage in date palm fruits. Interestingly, the present study showed that there was an increase in TSS in tomatoes applied with RMC and AVCT over the control fruits. A notable distinction was that only tomatoes applied with 20,000 RMC had an increase in the TA as compared to the control fruits. This suggests the 20,000 ppm RMC alone has a distinct metabolic pathway or regulatory effects on fruit acidity. Furthermore, the TSS/TA ratio of tomatoes revealed that AVCT and RMC improved the balance of sweetness and acidity in tomato fruits. These findings indicate that the application of RMC and AVCT enhanced the quality of the fruit, which potentially increases the market value.

A high dry matter content of the fruit generally implies a more concentrated non-water component, while higher moisture indicates greater juiciness. A high dry matter content in the control fruits, despite their limited numbers, might be interpreted as a compensatory mechanism under extreme stresses. The plant might prioritize concentrating available resources into the fruits to produce a much denser composition. Conversely, the 1:1 (v:v) AVCT to water appears to enhance the tomato's ability to manage water uptake while the fruits are developing, which results in juicier fruits.

The effects of RMC and AVCT in tomatoes showed an increased value in fruit polar and equatorial diameter over the control fruits. Larger diameters directly translate to larger fruits. The increase in fruit dimension suggests that RMC and AVCT enhanced the nutrient and water uptake, improving the efficiency of photoassimilate partitioning to the developing fruit or modulating hormonal balances. This effect is particularly important because environmental stresses typically limit fruit growth and size, and the treatments appear to mitigate this limitation. According to Nour et al. (2010), foliar spray with seaweed extracts did not reflect any significant effect on fruit length, diameter, and shape index of tomato fruits. However, Mannino et al. (2020) reported that plants treated with biostimulants significantly produced larger fruits than untreated plants. It was also reiterated that applying seaweed-based biostimulants could improve fruit yield and large-sized fruits with superior quality (Khan et al. 2009; Rouphael et al. 2017). Saeed and Abbas (2024) also stated that spraying with bacterial strains and vermicompost tea gave the highest weight of 100 fruits, fruit weight, flesh percentage, and dimension of date palm fruits compared to the control. Larger tomato fruit size is a highly desirable trait in the market, as it often correlates with higher market value, increased consumer appeal, and improved sorting efficiency.

Fruit color development is a primary visible indicator of ripening progression in tomato fruits. Fruit color is linked to lycopene biosynthesis, which mainly depends on the genetic characteristics and environmental factors during the growing conditions of tomatoes. A higher numerical scale signifies a more advanced red color and indicative of optimal ripeness. The study showed that a significant and consistent increase in the numerical fruit color scale from tomatoes applied with 20,000 ppm RMC. This result was similar to Ali et al. (2016), who reported that the application of seaweed extract made from *Ascophyllum nodosum* (L.) Le Jol. showed significant increases in fruit color. Meanwhile, high concentrations of vermicompost tea altered the production and accumulation of terpenoids, phenolic compounds, fatty acids, and alkanes in tomatoes (Souffront et al. 2022). These changes in secondary metabolites influenced the production of pigments in the fruits. Fruit firmness decreases as the fruits ripen during storage. The present study is consistent with the findings that seaweed extract has significantly increased the rate of fruit firmness in tomatoes (Jalali et al. 2022) and strawberries (El-Miniawy et al. 2014). Likewise, Ali et al. (2016) reported that *A. nodosum* extract showed a significant increase in firmness of the fruits. Guo et al. (2023) found that soaking treatment of carrageenan oligosaccharides significantly improved the physical and chemical factors in strawberries as compared with the control group.

Oxygenation during the brewing of aerated tea effectively promotes the growth and propagation of beneficial microorganisms (Ingham 2005). The vermicompost tea application can safeguard crops from pathogens and can cover leaf surfaces, thereby reducing potential sites for pathogen infection, and it can increase the microbial populations, which can further reduce plant diseases (Yatoo et al. 2021). This also happens when tomato fruits have direct contact with the AVCT during spraying, and the antagonistic microbes might be brought to the storage. In this way, the AVCT serves as the biocontrol agent for the tomato plants and on the fruits in storage. Yatoo et al. (2021) also reiterated that mycelial growth of *Botrytis cinerea* Pers., *Sclerotinia sclerotiorum* (Lib.) de Bary, *Rhizoctonia solani* J.G.Kühn, *Corticium rolfsii* Curzi, and *Fusarium oxysporum* Schltdl. was inhibited significantly by liquid extracts from vermicompost.

Tasende and Manriquez-Hernandez (2016) reiterated that seaweeds such as carrageenan have antibacterial, antiviral, and antifungal properties. Such properties may even inhibit the growth of beneficial microorganisms present in the AVCT. Ramani and Murugan (2020) reported that seaweed extracts had better inhibition against *Aspergillus flavus* Link, *Aspergillus niger* Tiegh., *Aspergillus fumigatus* Fresen., *Candida albicans* (C.P.Robin) Berkhout, and *Candida tropicalis* (Castell.) Berkhout. The same finding was observed by Bahammou et al. (2017) in that tomato fruits inoculated with the fungal species, with the aqueous extract of the brown algae, ensured their protection against the phytopathogenicity of the fungus. It is also used as a protective coating or edible film on fresh-cut packaged fruits, and improves food preservation. Carrageenan is used for various applications in the food industry (Necas and Bartosikova 2013). As a gelling agent, carrageenan can withstand high temperatures, and it can produce a gel that remains stable at room temperature (Anggraini and Lo 2023).

Accordingly, Guo et al. (2023) found that carrageenan oligosaccharides significantly prolonged the shelf life of strawberries and suggested that they could potentially maintain the quality attributes and reduce decay incidence during storage. Ramani and Murugan (2020) reported that the coating of seaweed gel provided fruit with better quality characteristics and shelf life of tomatoes, and can be used as a bio-preservative in fruit and vegetables. The physical characteristics of the tomato fruits, such as the thickness of the exocarp and availability of moisture content, influenced postharvest disease infection. Tomato fruits were susceptible to deterioration during the first two weeks because of high moisture content. Fungal colonization of the fruits took about 3-4 days before the tomato fruits were fully rotten. The first pathogen that infected the fruits was *Colletotrichum gloeosporiodes* (Penz.) Penz. & Sacc. at the light red ripe stage of the fruits, a few days after, followed by the *Rhizopus stolonifer* (Ehrenb.) Vuill. and *Goetrichum candidum* Link. *Colletotrichum gloeosporiodes* and *R. stolonifer* were observed to have their spores on fruit surfaces. Meanwhile, *G. candidum* was expressed in a watery fruit that softened the entire fruit. Most of the infections began on the underside of the peduncle, a locular cavity where the pathogen appeared to grow down in vascular tissue in the stem scar into the endocarp. Because of the perishable nature of tomatoes, fruits can be susceptible to physical and mechanical damage and biological factors. The quality of the fruits also contributed to these damages and losses, such as the firmness and moisture of the fruits. Moisture content influences the physical and mechanical properties of fruits and the growth of postharvest pathogens, which is important in prolonging the storage life of tomato fruits. It has been observed from the data that fruits from 10,000 ppm RMC + AVCT treated plants have the lowest postharvest disease incidence and severity index and extended shelf life. Fruits without the presence of peduncles were observed to have a longer shelf life and a minimal incidence of phytopathogens. On the contrary, despite the fruit's lowest moisture and high dry matter content, it does not extend its shelf life, which might be due to the high incidence and severity of diseases.

Physiological maturity of the fruits during harvesting is important as this influences the quality. Harvest the fruits at the mature green or breaker stage. Care must also be taken to avoid fruit injuries, and the cleanliness of tools and materials is also necessary. Separate disease-infected and injured fruits from the marketable fruits to avoid contamination and extend their shelf life. Harvesting should be done at early or late hours of the day. Proper fruit stocking to minimize injury is also encouraged, or avoid excessive fruits in a single fruit crate. Ethylene production increases upon the ripening of tomatoes, and changes occur in its physicochemical properties. These changes can lower the quality of the fruits and the consumers' acceptability. It is required that the storage room be well-ventilated to avoid ethylene accumulation and adequately cleaned to avoid contamination. Proper postharvest handling of perishable crops is sometimes neglected by farmers or handlers, and failure to adhere to such practices will result in a high amount of losses. It is also important to train and capacitate them on appropriate postharvest handling practices.

This technology is cost-effective and efficient in regions having lack of postharvest facilities and infrastructure. It has been advantageous to use this technology during off-season cropping. Generally, crop production during off-season cropping resulted in yield reduction; however, high selling prices in the market occurred. Both the RMC and AVCT have no harmful effects on farmers' health, beneficial insects, and other arthropods. The findings of this study could offer a climate-friendly alternative to chemical inputs, increase the bio-functional activities in the ecosystem, and reduce the postharvest losses in tomatoes.

In conclusion, tomato plants were exposed to various environmental stressors, and this profoundly affected the fruit setting and yield, particularly for the untreated plants. Despite the stresses, the 20,000 ppm RMC promotes early harvesting and increases the total yield of tomato plants. Both the RMC and AVCT improved the fruit quality attributes and produced larger fruit dimensions as compared to the control. The 10,000 ppm RMC + AVCT had the lowest postharvest disease incidence, the lowest disease severity index, and extended the storage shelf life of tomato fruits. The study suggests that applications of RMC and AVCT for tomato production in regions prone to similar adverse weather conditions and environmental stresses might maximize the farmers' income and provide a year-round market supply. It is recommended to conduct further studies on large-scale, multi-seasonal, and multi-locational field trials.

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