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Effect of harvest maturity stage and ripening remediation agents on the shelf life and biochemical quality attributes of tomato (*Solanum lycopersicum* L.) fruits

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Abstract: Tomato fruit is highly perishable because of the characteristic high rate of ethylene production and respiration during ripening. Delayed ripening could be achieved through the use of ripening remediation agents (RRA) that either absorb or block ethylene binding to the fruit receptor. The effects of ripening remediation agents on shelf life and biochemical quality attributes were evaluated on tomato fruits harvested at three maturity stages (breaker, turning and full-ripe). In 2018 and 2019, harvested fruits were stored under seven ripening remediation treatments: 0.1 µL/L 1-MCP, 0.3 µL/L 1-MCP, 0.5 µL/L 1-MCP, 5% $KMnO_4$, 10% $KMnO_4$, 10 g of Zeolite and 20 g of Zeolite and an open shelf condition as the control. At the end of the storage period, fruits were assessed for shelf life as well as total soluble solids (TSS), titratable acids (TA), ascorbic acid, and lycopene contents. There was significant ($p \leq 0.05/0.01$) influence of ripening remediation treatments on fruits for all the measured parameters. Fruits stored with RRAs consistently out-performed those stored in the open shelf. RRAs 0.3 µL/L1-MCP, 0.5 µL/L1-MCP and 5% $KMnO_4$ solution media had longer shelf life and higher values of total soluble solids, titratable acidity, lycopene and ascorbic acid contents. The use of 1-MCP and 5% $KMnO_4$ is recommended as effective scavenger of ethylene for extending the shelf life and maintaining some quality attributes of stored tomato fruits.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important fruit vegetables crops in the world. It plays an important role in human diet, being mostly used as a vegetable in the preparation of soup, salad, pickles, ketchup, puree, sauces and in many other ways. It is also a rich source of phytochemicals and vitamins that provide protection against chronic diseases, different types of cancers, cardiac vascular diseases and age-related ailments because of its anti-oxidant, anti-carcinogenic and antimutagenic properties (Chaudhary *et al*., 2018).

Regardless of the health and nutritional relevance of tomato, its production and value chain potentials realization is constrained by post-harvest losses of quantity and quality of produce available to consumers. One of the impacts of post-harvest losses results in reduction of food that is accessible for human consumption, which is worsened by increasing demand for food (Kikulwe *et al.,* 2018). The tomato fruit is highly perishable, and a climacteric rise in respiration takes place during ripening, which is considered a turning point in the life of the fruits as regards quality. Being a climacteric fruit, a marked increase of respiration rate and ethylene production during ripening process occurs that reduces the shelf life of the fruit, which may constitute a major challenge in the value chain (Arah *et al.,* 2015). The presence of this gas accelerates fruit ripening and quality deterioration by shortening the shelf life of the fruit. Ripening is a natural phenomenon that involves a series of biochemical changes that are responsible for the textural changes, starch breakdown, change of color, pigment formation, volatile and aroma development and finally abscission of fruits (Maduwanthi and Marapana, 2019). In tomato, ripening involves different dramatic biochemical and physiological changes of the fruit which are characterized by lycopene accumulation, chlorophyll loss, softening, and changes in aroma and other compositional properties. The regulation of these changes, thus, has been a major corcern for research aimed towards improving fruit quality and shelf life (Yasuhiro, 2016).

Increasing the postharvest life of tomato is an important aspect in view of its huge postharvest losses. The onset of ripening in tomato is governed by an increase in ethylene production and it is highly dependent on continuous presence of ethylene and ethylene-mediated actions (Zhao *et al*., 2021), therefore, the need to prevent the build-up of the gas around the produce. This has been found effective in delaying ripening in bananas (Zewter *et al*., 2012) and was achieved through the use of substances that either absorb or block ethylene binding to its receptor and these substances could be termed Ripening Remediation Agents (RRA).

Because of the important role of ethylene and ethylene-mediated actions in the onset and progression of ripening in tomato (Paul *et al*., 2002), preventing the buildup of the gas around the produce had been used to delay ripening in bananas. This has been achieved through the use of Ripening Remediation Agents (RRAs) which either absorb or block ethylene binding to its receptor. Concerning the latter, some RRAs inhibits ethylene's role in ripening by their presence at the ethylene-binding sites so that ethylene would not be able to bind and cause subsequent signal translation and transduction in the ripening process (Zewter *et al*., 2012). Others act by removing unwanted ethylene gas through the oxidation process, converting it to carbon dioxide and water, thereby halting the ripening process and ensuring the quality of freshness of the product in the packaged environment (Sen *et al*., 2012). Also some act as ethylene adsorbers as they have great potential in the agro-industry to remove ethylene due to their cation exchange capacity, high porosity and surface area of uptakes (Yin *et al*., 2020).

Tomato, being a perishable crop due to its high moisture content, has a short shelf life under tropical conditions (Arah *et al*., 2015). This makes it important to develop strategies for the development of handling technologies that reduce or remove the ethylene production of the storage environment, while at the same time sustaining the quality. In view of these, the present study was carried out to compare the effects of different ripening remediation agents on shelf life and some biochemical quality attributes of stored tomato fruits.

2. Materials and Methods

Plant materials

The tomato fruits (var. Beske) used for the experiment were obtained from the experimental field at the Teaching and Research Farm, Directorate of University Farms, Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria in 2018 and 2019 where they were grown under field conditions. Harvesting was done at three harvest maturity indices following the USDA Tomato Colour Chart. Harvested fruits were taken to the Laboratory of the Department of Horticulture and Landscape Management, College of Plant Science and Crop Production, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria for storage. The fruit samples were sorted and graded according to uniformity of size. Thereafter, fruits were carefully visually observed and only those that were wholesome were finally used in the experiment while those with defects or signs of diseases were discarded.

*Treatments a*nd *experimental design*

Tomato fruits were harvested at three maturity stages identified by the USDA tomato colour chart, viz breaker, turning, full ripe (USDA, 2005), and were washed in distilled water to reduce microbial population and remove adhering dirt and dust. Thereafter, 500 g of fruits in the different maturity stages were exposed to seven (7) RRAs and an open shelf (that is, without any RRA, serving as the 'control'). Seven RRAs were employed which were in three categories: ethylene absorber [Potassium permanganate ($KMnO_4$)], ethylene absorber (Zeolites) and ethylene inhibitor [1-Methylcyclopropene (1-MCP)]. The amounts of RRAs used were: 0.1 µl/L, 0.3 µl/L and 0.5 µl/L for 1-MCP; 5% and 10% for $KMnO_4$ solution; 10 g and 20 g of Zeolite. Thus, 24 treatments were composed by combining three harvest maturity indices and and eight exposures (RRAs and control). Gaseous 1-MCP was prepared from SmartFreshTM (AgroFresh Inc.) commercial powder (0.14% of active ingredient). The application was done in air-tight plastic containers (capacity of 1 m^3) applying 0.1, 0.3 and 0.5 µl/L of 1-MCP for 24 h, at a temperature of 25°C and 85-90% RH. Potassium permanganate ($KMnO_4$) solutions of 5% and 10% concentrations were prepared by dissolving 5 g and 10 g $KMnO_4$ powder in 100 ml of distilled water and put into small containers to be placed beside fruit samples. Also, 10 g and 20 g of Zeolite, in granular form, were also put into small containers to be placed beside fruit samples. Fruits with the treatments applied were stored at room temperature. Control treatment fruits were also stored at room temperature, but without any RRA.

Each treatment had 500 g of whole and healthy tomato fruits stored in perforated plastic containers. Untreated fruits (control) were kept in similar containers and placed in an open shelf. The experiment was laid out in Completely Randomized Design with three replications. After the storage, five fruits were sampled randomly per treatment in each replication and were evaluated for shelf life and some quality parameters, viz total soluble solids, ascorbic acid, titratable acidity and lycopene.

Assessment of shelf life and some fruit quality attributes

Tomato fruits were stored at an average temperature between 30-32°C and a relative humidity of 78-80% in both years. The shelf life (days) of the tomato fruits was determined by visually observing the incidence and extent of spoilage with respect to storage days. This was determined from the time they were stored to the time they became unsuitable for consumption. For the analysis of total soluble solids content (TSS) and titratable acidity (TA) of each sample, tissue sap was squeezed out from fresh fruit materials with a press. In this juice, TSS were determined with an Atago Handheld Refractometer in Brixº. Titratable acid (TA) content was determined by titrating method and calculating the result as grams of malic acid per 100 g fresh weight (%). Ascorbic acid content of the samples was determined according to the recommended method of AOAC (2000) using 2, 6-dichlorophenol indophenol and expressed as mg kg^{-1}. Lycopene content was estimated using a Spectrometer by extraction with hexane and absorbance measurement at 503 nm and expressed in mg kg^{-1}. Fruit firmness was determined using hand-pi model GY-series penetrometer. Fruit firmness in a sample was measured by pushing the central probe against the equatorial plane of the fruit until the central probe flattened. The flattening of the probe caused the needle in the instrument to deflect and the number where the needle stopped was recorded as the value for the fruit firmness (Kitinoja and Hussein, 2005).

Statistical analysis

Data were subjected to 2-way analysis of variance (ANOVA) and significantly different means were separated at 5% probability level. Correlation between all pair-wise traits were estimated for measured traits. All analyses were performed using the Statistical Analysis System, SAS, version 9.3 (SAS Institute, 2012).

3. Results

Harvest maturity index significantly ($p \leq 0.05$) affected the shelf life of stored tomato fruits, and followed the same trend in both years of the study. In 2018 and 2019 respectively, fruits harvested at breaker stage had the longest shelf life of 37 and 40 days, followed by those harvested at turning stage with 36 and 35 days shelf life while fruits harvested at full ripe stage had the shortest shelf life of 35 and 32 days (Table 1).

The shelf life of stored tomato fruits was significantly ($p \leq 0.05$) affected by the Ripening remediation treatments and this has comparable trends in both years of the study (Table 2). In 2018, fruits exposed to 0.3 µL/L had the longest shelf life of 45 days, immediately followed by fruits stored with 0.5

Table 1 - Effect of harvest maturity index on shelf life of tomato fruits in years 2018 and 2019

Harvest index	Shelf life (Days)	
	2018	2019
Breaker	37.99 a	40.70 a
Turning	35.73 b	34.70 b
Full ripe	31.08 c	32.18 c

Means followed by the same letters in the same column are not significantly different at 5% probability level of DMRT.

Table 2 - Effect of ripening remediation agent on shelf life of tomato fruits in years 2018 and 2019

Ripening remediation agent	Shelf lfe (Days)	
	2018	2019
0.1 µL/L 1-MCP	36.63 b	36.75 ab
0.3 µL/L 1-MCP	43.25 a	42.75 ab
0.5 µL/L 1-MCP	41.88 a	37.88 ab
5% KMnO4	44.63 a	45.74 a
10% KMnO4	36.38 b	32.10 b
10 g of Zeolite	27.75 c	30.25 cb
20 g ofZeolite	35.50 b	32.40 b
Open shelf (control)	18.25 d	17.88 c

Means followed by the same letters in the same column are not significantly different at 5% probability level of DMRT.

µ L/L 1-MCP and 5% $KMnO_4$ solution media with 43 and 42 days shelf life respectively. Furthermore, fruits stored with 0.1 µL/L 1-MCP had a shelf life of 37 days while those stored in 10% $KMnO_4$ solution and 20 g of Zeolite media had the same shelf life of 36 days. Untreated fruits however, had the shortest shelf life of 18 days.

In the second year of the experiment, a similar trend was observed in the effect of RRAs on the shelf life of the stored fruits. Fruits exposed to 0.3 µL/L and 0.5 µL/L 1-MCP and those stored in 5% $KMnO_4$ solution medium had shelf life of 46, 43 and 39 days respectively, followed by fruits under 0.1 µL/L 1-MCP with a shelf life of 37 days. Fruits stored in 10% $KMnO_4$ solution and 20 g of Zeolite medium had comparable shelf life of 32 days while fruits left in the open shelf had the shortest shelf life of 18 days. It was noted that 0.3 µL/L1-MCP, 0.5µL/L1-MCP and 5% $KMnO_4$ solution were the most effective in extending the shelf life of tomato.

As displayed in Table 3, total titratable acidity (TTA) was significantly ($p \leq 0.05$) affected by the ripening remediation treatments in both 2018 and 2019. In years 2018 and 2019, the highest TTA of 0.43 and 0.42 g/l respectively were recorded for fruits treated with 0.3 µl/L and 0.5 µl/L 1- MCP and those in 5% $KMnO_4$ solution medium while fruits left on the open shelf had the lowest average TTA concentration of 0.37 g/l.

The lycopene content of the fruits was significantly affected by the ripening remediation treatments (Table 3). In both years of the experiment, fruits kept in open shelf condition recorded the highest lycopene contents of 401.40 µg/100 g (in 2018) and 392.53 µg/100 g (in 2019) which were comparable with the values obtained for fruits treated with 10% $KMnO_4$ solution (405.55 µg/100 g in 2018), 10 g Zeolite medium having lycopene content of 403.20 and 392.45 µg/100 g in 2018 and 2019 respectively. The lowest lycopene contents of 389 µg/100 g in 2018 and 365.19 µg/100 g in 2019 were observed for 5% $KMnO_4$ and 0.5 µl/L 1-MCP respectively. Further-more, ascorbic acid content of the fruits was significantly ($p \leq 0.05$) influenced by the ripening

Table 3 - Effect of ripening remediation substances on some nutritive traits of tomato fruits in 2018 and 2019

Ethylene remediation treatments	TTA (g/l)		Lycopene (µg/100 g)		Ascorbic acid (mg/100 g)		TSS (%)	
	2018	2019	2018	2019	2018	2019	2018	2019
0.1 µL/L 1-MCP	0.42 a	0.40 ab	390.79 ab	381.41 ab	18.26 a	18.55 a	5.73 ab	5.78 ab
0.3 µL/L 1-MCP	0.43 a	0.42 a	392.21 ab	372.06 b	17.71 ab	19.15 a	5.89 a	5.85 a
0.5 µL/L 1-MCP	0.43 a	0.42 a	392.99 bc	365.19 b	17.79 ab	18.80 a	5.80 a	5.89 a
5% KMnO4	0.43 a	0.42 a	389.00 b	375.36 b	17.78 ab	18.07 a	5.80 a	5.85 a
10% KMnO4	0.39 b	0.40 ab	405.55 a	384.29 ab	17.34 ab	18.09 a	5.50 b	5.61 b
10 g Zeolite	0.38 b	0.40 ab	403.20 a	392.45 a	16.69 b	16.74 b	5.50 b	5.49 b
20 g Zeolite	0.41 ab	0.38 b	398.29 ab	387.28 ab	17.01 ab	17.29 ab	5.50 b	5.52 b
Open shelf (control)	0.37 b	0.37 b	407.40 a	392.53 a	16.31 b	17.51 ab	5.25 bc	5.22 bc

Means followed by the same letters in the same column are not significantly different at 5% probability level of DMRT.

remediation treatments in both years (Table 3). In 2018, the ascorbic acid content ranged from 16.31 mg/100 g for fruits stored in the open shelf to 18.26 mg/100 g for fruits stored with 0.1 µl/L 1-MCP. Substantial amounts of ascorbic acid were also observed in fruits with 0.5 µl/L 1-MCP, 5% $KMnO_4$, 0.3 µl/L 1-MCP, 10% $KMnO_4$, and 20 g Zeolite in decreasing order. In 2019, ascorbic acid content of stored fruits ranged from 16.74 mg/100 g for 10 g Zeolite to 19.15 mg/100 g for 0.3 µl/L 1-MCP. Substantial Ascorbic acid contents were also observed for 0.1 µl/L 1-MCP, 0.5 µl/L 1-MCP, 10% $KMnO_4$, 5% $KMnO_4$, open shelf and 20 g Zeolite, in decreasing order. The total soluble solids (TSS) of stored fruits was also significantly ($p \leq 0.05$) affected by the ripening remediation treatments (Table 3). Fruits kept in the open shelf condition, however, recorded the highest TSS in both years of the study. In 2018, the TSS content recorded in fruits exposed to 0.1 µl/L and 0.5 µl/L 1-MCP and 5% $KMnO_4$ solution medium was lower compared to those stored in Zeolite medium and those kept in the open shelf. In 2019, fruits stored in 10 g and 20 g of Zeolite medium had higher TSS compared to those exposed to 1-MCP concentrations and those stored in 5% and 10% $KMnO_4$ solution (Table 3).

As reported before, tomato fruits harvested at the breaker and turning stages recorded significantly longer shelf life than fruits harvested at the full ripe stage except for fruits harvested at the turning stage and stored with Zeolite (Table 1). Comparing fruits from the same stage of maturity in both 2018 and 2019, fruits stored with 0.3 µl/L 1-MCP had the longest shelf life for fruits harvested at the breaker stage, while 5% $KMnO_4$ effected the longest shelf life for fruits picked at the turning stage while full ripe fruits had the longest shelf life when stored with 0.3 µL/L 1-MCP and 5% $KMnO_4$ (Table 4).

There was a general decrease in TTA for all the treatments. However, fruits harvested at breaker and turning stages recorded higher TTA contents with exposure to 0.1 µl/L, 0.3 µl/L and 0.5 µl/L 1- MCP and those stored in 5% $KMnO_4$ solution medium when compared to other treatments (Table 5). Lycopene content was higher for fruits harvested at full ripe kept in the open shelf while there was low lycopene content for those harvested at breaker stage with stored with 1-MCP and 5% $KMnO_4$ solution medium.

In the same vein, fruits harvested at breaker and turning stages had higher ascorbic acid contents when exposed to 1-MCP and 5% $KMnO_4$ solution medium while those kept in the open shelf had lower ascorbic acid content comparable with those stored with 10% $KMnO_4$ solution and Zeolite. On the other hand, fruits harvested at the breaker stage and exposed to 1-MCP or $KMnO_4$ solution media recorded significantly lower TSS than the full-ripe fruits kept in the open shelf as shown in Table 5.

Significant ($p \leq 0.05/0.01$) levels of association, comparable for both 2018 and 2019 experiments, were observed in the relationship among shelf life and measured biochemical parameters of tomato

Table 4 - Harvest maturity index and ripening remediation agents on shelf life of tomato fruit in years 2018 and 2019

	Shelf life (days)							
	0.1 µL/L 1-MCP	0.3 µL/L 1-MCP	0.5 µL/L 1-MCP	5% KMnO4	10% KMnO4	10 g Zeolite	20 g Zeolite	Open shelf (control)
Breaker								
2018	37 ab	46 a	37 ab	42 a	40 a	27 b	40 a	19 c
2019	31 ab	42 a	36 ab	45 a	36 ab	36 ab	36 ab	18 c
mean	34	44	36.5	43.5	38	31.5	38	18.5
Turning								
2018	36 ab	37 ab	33 ab	41 a	40 a	25 b	36 ab	19 c
2019	33 ab	40 a	37 ab	42 a	33 ab	28 b	36 ab	19 c
mean	34.5	38.5	35	41.5	36.5	26.5	36	19
Full-ripe								
2018	34 ab	40 a	31 ab	40 a	37 ab	31 ab	39 a	16 c
2019	37 ab	39 ab	34 ab	39 ab	28 b	33 ab	37 ab	13 c
mean	35.5	39.5	32.5	39.5	32.5	32	38	14.5

Means followed by the same letters in the same column are not significantly different at 5% probability level of DMRT.

Table 5 - Interaction of harvest maturity index and ripening remediation agents on biochemical quality attributes of tomato fruits in years 2018 and 2019

Harvest maturity index	Ripening remediation treatments	TTA (g/l)		Lycopene (µg/100g)		Vitamin C (mg/100g)		TSS (%)	
		2018	2019	2018	2019	2018	2019	2018	2019
Breaker	0.1 µL/L 1-MCP	0.41 a	0.42 a	382.26 ab	381.38 ab	16.67 a	16.87 a	5.59 b	5.57 b
	0.3 µL/L 1-MCP	0.41 a	0.42 a	384.93 ab	371.42 b	16.43 a	16.39 a	5.56 b	5.52 b
	0.5 µL/L 1-MCP	0.41 a	0.42 a	382.18 ab	378.93 b	16.78 a	16.36 a	5.54 b	5.52 b
	5% $KMnO_4$	0.42 a	0.42 a	388.67 ab	384.94 ab	16.21 a	16.11 a	5.53 b	5.54 b
	10% $KMnO_4$	0.36 b	0.40 a	399.10 ab	396.71 ab	15.21 ab	15.22 ab	5.67 b	5.62 b
	10 g Zeolite	0.37 b	0.38 b	397.89 ab	411.30 a	15.83 ab	15.93 ab	5.75 ab	5.75 ab
	20 g Zeolite	0.38 ab	0.38 b	396.71 ab	411.23 a	15.38 ab	15.01 ab	5.75 ab	5.75 ab
	open shelf (control)	0.35 b	0.35 b	412.73 a	407.36 a	15.91 ab	15.96 ab	5.95 a	5.93 a
Turning	0.1 µL/L 1-MCP	0.39 ab	0.39 ab	394.77 ab	391.22 ab	16.91 a	16.91 a	5.64 b	5.69 b
	0.3 µL/L 1-MCP	0.39 ab	0.40 a	386.42 ab	389.41 ab	16.71 a	16.86 a	5.69 b	5.66 b
	0.5 µL/L 1-MCP	0.39 ab	0.40 a	386.99 ab	388.50 ab	16.82 a	16.50 a	5.66 b	5.64 b
	5% $KMnO_4$	0.40 a	0.40 a	389.63 ab	389.71 ab	16.38 a	16.31 a	5.66 b	5.63 b
	10% $KMnO_4$	0.37 ab	0.38 ab	400.51 a	402.38 a	15.98 ab	15.92 ab	5.72 ab	5.77 ab
	10 g Zeolite	0.37 ab	0.38 ab	396.18 ab	403.78 ab	15.78 ab	15.61 ab	5.75 ab	5.79 ab
	2 0g Zeolite	0.37 ab	0.39 ab	389.28 ab	391.18 a	15.86 ab	15.89 ab	5.71 ab	5.71 ab
	open shelf (control)	0.34 b	0.34 b	410.91 a	413.67 a	14.71 b	14.62 b	5.99 a	5.98 a
Full-ripe	0.1 µL/L 1-MCP	0.38 ab	0.38 ab	392.51 ab	392.73 ab	15.43 ab	15.93 ab	5.77 ab	5.78 ab
	0.3 µL/L 1-MCP	0.39 ab	0.39 ab	389.42 ab	392.11 ab	15.56 ab	15.45 b	5.72 ab	5.78 ab
	0.5 µL/L 1-MCP	0.39 ab	0.39 ab	384.66 ab	389.81 ab	15.77 ab	15.86 ab	5.72 ab	5.78 ab
	5% $KMnO_4$	0.39 ab	0.39 ab	387.48 ab	389.82 ab	15.39 ab	15.93 b	5.74 ab	5.74 ab
	10% $KMnO_4$	0.40 a	0.37 ab	402.38 a	404.86 a	14.73 b	14.78 b	5.82 a	5.89 a
	10 g Zeolite	0.37 b	0.37 ab	403.56 a	405.36 a	14.48 b	14.14 b	5.94 a	5.92 a
	20 g Zeolite	0.37 b	0.37 ab	399.83 ab	396.74 ab	14.97 b	14.76 b	5.95 a	5.95 a
	open shelf (control)	0.34 b	0.37 ab	413.56 a	411.86 a	13.92 b	13.82 b	5.99 a	5.99 a

Means followed by the same letters in the same column are not significantly different at 5% probability level of DMRT.

fruits in this study (Table 6). In 2018 and 2019, titratable acidity had positive and significant correlation with ascorbic acid (r = 0.64 and 0.63 respectively) and shelf life (r= 0.70 and 0.74 respectively) but shared negative and significant correlation with lycopene (r = -0.86 and -0.83 respectively) and total soluble sugars (r= -0.94 and -0.82 respectively). In 2018 and 2019, lycopene content had positive and significant association with total soluble sugars (r = 0.80 and 0.85 respectively) and shared negative and significant association with ascorbic acid (r= -0.70 and -0.71 respectively) and shelf life (r= -0.65 and -0.68 respectively). Furthermore, there was negative and significant correlation between ascorbic acid and total soluble sugars with r= -0.76 and -0.80 while sharing positive and significant association with shelf life with r= 0.51 and r 0.42 for 2018 and 2019 respectively. Total soluble sugars also had negative and significant correlation with shelf life (r= -0.70 and r= -

Table 6 - Pearson correlation coefficients of the relationship among shelf life and measured biochemical quality components of tomato fruits stored with ripening remediation agents in 2018 (lower diagonal) and 2019 (upper diagonal)

Parameter measured	Titratable acidity	Lycopene	Ascorbic acid	Total soluble sugars	Shelf life
Titratable acidity	1	-0.86 **	0.64 **	-0.94 **	0.70 **
Lycopene	-0.83 **	1	-0.70 **	0.80 **	-0.65 **
Ascorbic acid	0.63 **	-0.71 **	1	-0.76 **	0.51 *
Total soluble sugars	-0.82 **	0.85 **	-0.80 **	1	-0.70 **
Shelf life	0.74 **	-0.68 **	0.42 *	-0.69 **	1

*, ** significant at 5 and 1% probabilities, respectively.

0.69 in 2018 and 2019 respectively).

4. Discussion and Conclusions

The ripening remediation treatments considerably affected the shelf life of stored tomato in both years of the study and the extended shelf life could have been as a result of the efficacy of these treatments to delay the conversion of starch to sugars thus reducing the ethylene production and peroxidase activity of the fruits. Similar results of delay in conversion of starch to sugars for extended shelf life of tomato were observed with the use of gibberellic acid as reported by Srividya *et al*. (2014). The identified RRAs could also have been able to extend the shelf life of the fruits due to their ability to control respiratory metabolism, thus maintaining the produce for a longer period as suggested by Nath *et al*. (2015).

During storage, acidity decreased with ripening as the organic (malic and citric) acids in the fruits got metabolized. The loss of TTA during storage period could be related to higher respiration rate as ripening advances, where organic acids are used as substrate in the respiration process. Exposure of the tomato fruits to the RRAs in this study delayed the consumption of the TTA, with 1-MCP and 5% $KMnO_4$ being the most reliable in achieving this. Regassa *et al*. (2012) reported the sequential disappearance of malic and citric acids in ripening tomato fruits leading to reduction in the amount of TTA.

Lycopene content of tomato fruits were differently affected by RRA but exposure to 1-MCP concentrations and 5% $KMnO_4$ solution treatments delayed the accumulation of lycopene in the fruits for both years. This might be due to decrease in respiratory rate, inhibiting ethylene activity, consequently reducing metabolism of the fruit (Nath *et al*., 2015). The delay in lycopene development in this study could have been as a result of the efficacy of the ripening remediation treatments in suppressing the production of ethylene in fruits thus delaying lycopene accumulation. The restrictive effect of 1-MCP on lycopene accumulation in this study supports the previous reports of Taye *et al*. (2019).

The treatment with 1-MCP concentrations and $KMnO_4$ had comparable patterns of effect on ascorbic acid content. Generally, fruits treated with 1-MCP and 5% $KMnO_4$ had higher ascorbic acid contents compared to other treatments. The efficacy of 1-MCP concentrations in this study corroborates the observations of Sabir *et al*. (2012) that 1-MCP had significant effect on ascorbic acid content by decreasing ethylene content of tomato fruit thereby increasing ascorbic acid content. Generally, this study indicated that there was a decrease in ascorbic acid content of tomato fruits which showed significant decrease during storage as reported by Ahmed *et al*. (2018).

Generally, as reported by Tilahun *et al*. (2019), tomato fruits harvested at the matured green and breaker stages had lower TSS level, while fruits harvested at light-red stage of full-ripe had the highest TSS. However, in this study, the efficacy of the ripening remediation agents was evident in slowing down the breakdown of carbohydrates into soluble sugars (fructose and glucose) or excessive moisture loss that aids the hydrolysis of cell wall polysaccharides. The fact that fruits kept in the open shelf recorded the highest TSS in both years can be attributed to faster advancement in ripening than those treated with RRAs as previously specified by Ahmed *et al*. (2018). The increase as influenced by the ripening remediation treatments may have occurred as a result of breakdown of carbohydrates into soluble sugars, or excessive moisture loss that aids the hydrolysis of cell wall polysaccharides. However, Beckles (2012) earlier noted that 1-MCP may increase, reduce or leave unchanged, the development of TSS depending on fruit species.

1-MCP at 0.3 µl/L concentration and 5% $KMnO_4$ were the most effective in extending the shelf life of fruits harvested however, those left in the open shelf consistently had the shortest shelf life implying that RRA application was effective in extending the marketable life of the fruits. The longer shelf life recorded by the fruits at the breaker and turning stages may be attributed to the ability of the ripening remediation agents to control respiratory metabolism, thus maintaining the produce for a longer period as suggested by Nath *et al*. (2015). Harvesting fruits at the proper maturity stage has a great influence on the nutrient content as well as shelf life of any fruit. However, in this study, the ripening remediation agents had great influence in slowing down the action of the ripening hormone that could accelerate the decline in the ascorbic acid content of the tomato fruit.

It is cumbersome to consider multiple traits in a selection scheme. Information on the relationship among various traits with shelf life would thus be beneficial to designing an efficient storage system. The significant correlation of shelf life with all the measured nutritional quality attributes coupled with the interrelationship among the attributes presents the possibility of extending the shelf life of tomato fruits through designing an effective storage system that focuses on manipulating the production and/or accumulation of titratable acids, total soluble solids, lycopene and ascorbic acid. Comparable findings in the relationship among nutritional quality traits of tomato, including titratable acids, total soluble solids, and lycopene have earlier been reported by Singh *et al.* (2018) and Shobo *et al.* (2020).

The use of RRAs was effective in increasing the shelf life and maintaining the nutritional properties of tomato fruits in storage. However, the RRAs differed in their effectiveness in both capacities. RRAs 0.3 µL/L1-MCP, 0.5µL/L1-MCP and 5% $KMnO_4$ solution media had longer shelf life and higher values of total soluble solids, titratable acidity, lycopene and ascorbic acid contents. The use of 1-MCP and 5% $KMnO_4$ is recommended as effective scavenger of ethylene for extending the shelf life and maintaining some quality attributes of stored tomato fruits.

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References

AHMED M.E.M., ATTIA M.M., AL-ARABY A.A., ABD EL-KHALEK A.F., EL-NAGGAR M.A.F., 2018 - *Effect of 1-MCP treatment on keeping quality of tomato fruits at ambient temperature.* - Hortscience Journal of Suez Canal University, 7(2): 63-72.

AOAC, 2000 - *Official methods of analysis of the association of official's analytical chemists, (17th ed).* - AOAC, The Association of Official Analytical Chemists, Gaithersburg, MD, USA.

ARAH I.K., AMAGLO H., KUMAH E.K., OFORI H., 2015 - *Preharvest and postharvest factors affecting the quality and shelf life of harvested tomatoes: A mini review*. - Int. J. Agron., Vol. 2015, pp. 1-7.

BECKLES D.M., 2012 - *Factors affecting the postharvest soluble solids and sugar content of tomato (*Solanum lycopersicum *L.) fruit.* - Postharvest Biol. Techn., 63(1): 129-140.

CHAUDHARY P.G., SHARMA A., SINGH B., NAGPAL A.K., 2018 - *Bioactivities of phytochemicals present in tomato*. - J. Food Sci. Techn., 55: 2833-2849.

KIKULWE E.M., OKURUT S., AJAMBO S., NOWAKUNDA K., STOIAN D., NAZIRI D., 2018 - *Postharvest losses and their determinants: A challenge to creating a sustainable cooking banana value chain in Uganda.* - Sustainability, 10(7): 1-19.

KITINOJA L., HUSSEIN A., 2005 - *Postharvest tools and supplies kit utilization, calibration and maintenance manual*. - University of California, Davis.

MADUWANTHI S.D.T., MARAPANA R.A.U.J., 2019 - *Induced ripening agents and their effect on fruit quality of banana*. - Int. J. Food Sci., Vol. 2019, pp. 1-8.

NATH A., BAGCHI B., VERMA V.K., RYMBAI H., JHA A.K., DEKA B.C., 2015 - *Extension of shelf life of Tomato using $KMnO_4$ as ethylene absorbents*. - Indian J. Hill Farming, 28: 77-80.

REGASSA M.D., MOHAMMED A., BANTEE K., 2012 - *Evaluation of tomato (*Solanum lycopersicum *L.) genotype for fruit quality and shelf life.* - The African J. Plant Sci. Biotech., 6: 50-56.

SABIR F.K., KUSVURAN S., DASGAN H.Y., AGAR I.T., 2012 - *Effects of 1-methylcyclopropene treatment on postharvest life and quality in four tomatoes cultivars*. - J. Animal Plant Sci., 22(4): 1086-1091.

SAS, 2012 - *SAS/STAT users guide*. - Version 64th ed. SAS Institute, Inc., Cary, NC, USA.

SEN C., MISHRA H.N., SRIVASTAV P.P., 2012 - *Modified atmosphere packaging and active packaging of banana (*Musa *spp.): A review on control of ripening and extension of shelf life*. - J. Stored Products Postharvest Res., 3: 122-132.

SHOBO B.A., ODUNTAN O.A., ADEDIRAN O.I., BODUNDE G., OGUNLEYE M.T., 2020 - *Correlation and path coefficient analysis for total soluble solids in tomato (*Solanum lycopersicum *Mill) fruit.* - Nigerian J. Hortic. Sci., 25(1): 18-22.

SINGH A.K., SOLANKEY S.S., AKHTAR S., KUMARI P., CHAURASIYA J., 2018 - *Correlation and path coefficient analysis in tomato (*Solanum lycopersicum *L.)*. - Inter. J. Curr. Microb. Appl. Sci., 7: 4278-4285.

SRIVIDYA S., SYAMSUNDAR REDDY P., SUDHAVANI V., RAMANJANEYA REDDY A., 2014 - *Effect of post-harvest chemicals on fruit physiology and shelf life of tomato under ambient conditions*. - Inter. J. Agric. Food Sci. Techn., 5: 99-104.

TAYE A.M., TILAHUN S., SEO M.H., PARK D.S., JEONG C.S., 2019 - *Effects of 1-MCP on quality and storability of cherry tomato (*Solanum lycopersicum). - Horticulturae, 5(29): 1-13.

TILAHUN S., PARK D.S., SOLOMON T., CHOI H.R., JEONG C.S., 2019 - *Maturity stages affect nutritional quality and storability of tomato cultivars. CyTA* - J. Food*,* 17(1): 87-95.

USDA, 2005 - *Composition of foods. - Raw, processed, prepared*. - USDA National Nutrient Database for standard reference, Release 18. pp. 1-18.

YASUHIRO I.T.O., 2016 - *Review-regulation of tomato fruit ripening by MADS-Box transcription factors*. - National Food Research Institute, National Agriculture and Food Research Organization, Japan.

YIN C.Y, AKHIR M.A.M, UDA M.N.A., NURADIBAH M.A., 2020 - *Effect of potassium permanganate and ZeoliteZeolite on shelf life and quality of* Musa acuminata. - IOP Conference Series: Materials Science and Engineering, 864. 2nd Joint Conference on Green Engineering Technology & Applied Computing 2020. Bangkok, Thailand.

ZEWTER A., WOLDESTADIK K., WORKNEH T.S., 2012 - *Effect of 1-Methylcyclopropene, potassium permanganate and packaging on quality of banana*. - African J. Agric. Res., 16: 2425-2437.

ZHAO T., NAKANO A., IWASAKI Y., 2021 - *Differences between ethylene emission characteristics of tomato cultivars in tomato production at plant factory*. - J. Agric. Food Res., 5: 1-6.