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PRELIMINARY STUDY ON POTENTIAL EDIBLE COATINGS DERIVED FROM CARBOXYL METHYLCELLULOSE AND FUNGI CULTURED METABOLITES ON THE SHELF-LIFE EXTENSION OF SWEET-ORANGE (*CITRUS SINENSIS*)

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ABSTRACT

This study focused on assessing the potential of formulated edible coatings derived from a metabolite of *Trichoderma viride* and *Penicillium chrysogenum*, combined with carboxyl methylcellulose (CMC) on the postharvest storage quality of orange fruits. The cultured metabolite of fungal bioagents combined with CMC, as well as glycerol (plasticizer), inadequate solution ratio based on wettability, was evaluated for microbiological quality and shelf-life extension of sweet orange. Thereafter, ascorbic acid, total soluble solids, pH, percentage weight loss, among other parameters were assessed for 7 weeks. The results of the study revealed that the pH of CMC + *Trichoderma viride* and CMC + *P. chrysogenum* coatings had 3.8 ± 0.02 and 3.17 ± 0.06 respectively, while it was reported 2.90 ± 0.04 for uncoated treatment. Also, the ascorbic acid and total soluble solids of the edible coated oranges were higher than the control. In addition, the percentage of weight loss was higher in the uncoated control compared to the potential edible coated oranges. Further, the microbial load count of the potential edible-coated oranges was less compared to the un-coated oranges. In conclusion, this formulated potential edible coating could be further improved upon and optimized for use in prolonging the storage of sweet oranges.

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1 Introduction

The foremost fruit crop produced globally is citrus. It is cultivated in most of the nations of the world with well over a hundred million tons (Mahawar et al., 2020). Citrus fruit is globally accepted for its impact on human well-being. It is widely available and possesses enhanced dietary, nutritional, and other value-added bioactive properties along with superior taste (El-Otmani et al., 2011; Ghoshal, 2019). According to Mishra & Patel (2020) consuming enough citrus fruits enhanced immunity and can reduce the disease incidence in human beings. Recently, the COVID-19 outbreak led to an increase in demand for fresh fruit worldwide.

However, yearly a significant percentage of harvested fruits are spoiled by pathogenic organisms (Onah et al., 2019). Post-harvest spoilage pathogens lead to the citrus fruit spoilage globally and make a loss in their economic and aesthetic value (Shi et al., 2018). Sweet oranges are prone to microbial infestations during the postharvest process of storing and transporting the fruit (Zhou et al., 2018). The optimum potential of commercial cultivation and consumption of citrus fruit in terms of value-added therapeutic advantages and economic impacts are being threatened due to the problem of postharvest microbial infestations, and lack of good post-harvest handling facilities, thereby leading to huge losses financially (Terao et al., 2017). It is estimated that food that is lost yearly throughout the world is in the range of over a billion tons (Ishangulyyev et al., 2019). Also, about 35% of fruits and vegetables are part of these losses in a lot of countries.

Despite this challenging scenario, the collection of research funds is mainly focused on productivity enhancement of the foods (up to 95 %), while only 5% of investment is directed at research on food losses (Kitinoja & Alhassan, 2012). The approach that is currently used in combating postharvest diseases of citrus fruits is by applying synthetic fungicides spray (Costa et al., 2019). However, there are various drawbacks associated with synthetic fungicides uses on edible orange fruits due to the cost implications, environmental pollution influence, and it also poses health hazards to mankind if some of these chemical residues remain on the orange fruit peels.

Hence, the trending scenario all over the world is an increase in public demand for a reduction in the use of fungicide, to produce healthy and eco-friendly safe “fruits”, without chemical inputs for combating postharvest infestation of fruits (Padmaperuma et al., 2020). Metabolic activities such as transpiration and respiration occur in fresh fruits after their harvesting; thereby inducing textural changes and loss of water (Jalali et al., 2020; Nourozi & Sayyari 2020). Thus, minimizing this bioactivity of fruits and vegetables postharvest is required through actions like the use of edible coatings thereby creating barrier/permeability to gaseous exchange (Md Nor & Ding, 2020).

Edible coatings are a sustainable alternative that could be used as a postharvest treatment method for the benefit of perishable vegetables and fruits by extending their shelf life (Abhirami et al., 2020; Jafarzadeh et al., 2021). Edible coatings (Carboxymethylcellulose and Fungi cultured metabolites) are good alternatives to combat the menace of post-harvest losses of fruits and vegetables, thereby extending their shelf life (Amiri et al., 2021; Iniguez-Moreno et al., 2021). They are natural and eco-friendly options for tackling this huge problem (Tosati et al., 2017). However, the optimum result is not always attainable with just a single source of coating materials. Research reports indicated that edible coating materials that are combined synergistically with other bioactive materials and compounds perform better (Tosati et al., 2018; Yang et al., 2019).

This study is, therefore, focused on assessing the potential of deploying carboxyl methylcellulose in combination with cultured metabolites from two well-known rhizosphere-competent filamentous fungi, as bioactive forming coatings to extend the shelf-life of sweet oranges.

2 Materials and Methods

2.1 Plant materials

Sweet oranges (*Citrus sinensis*), without any diseased or injury symptoms, were freshly collected from an orchard and were quickly transported to the laboratory for processing. The oranges were rinsed under tap water and followed by surface sterilization with 3% hypochlorite solution and 70 % ethanol, and finally rinsed with sterile distilled water.

2.2 Preparation of Carboxyl methylcellulose solution

Carboxyl methylcellulose (CMC) sodium salt powder 1g/L was hydrolyzed in sterile water at 70° C for 2 h, with constant stirring to obtain 1% (W/V) carboxyl methylcellulose solution.

2.3 Culturing of Fungi in submerged liquid fermentation and extraction of metabolites

Freshly prepared mycelia of *T. viride* and *P. chrysogenum* that was characterized in a previous study (Omomowo et al., 2020) were used to obtain the fermented cultured metabolites. The submerged liquid fermentation processing was done by using potato dextrose broth, under shaking incubation conditions at 150 rpm for 7 days at 28°C, to obtain the bioactive cultured metabolites used for bioactive coatings.

2.4 Postharvest treatment and storage conditions of oranges

The oranges were subjected to three treatments, using a combination of an equal volume of cultured metabolites of *T.*

viride and *P. chrysogenum* combined with a 1% (W/V) carboxyl methylcellulose solution. The third treatment was the control experiment that entails dipping the oranges in sterilized distilled water only. The oranges were processed with the bioactive coating solutions as per the Jiang et al. (2005) protocol. Treated oranges were stored at 25°C with a relative humidity between 70-80 % for the seven weeks.

2.5 Determination of the firmness of the orange fruits

The firmness of the treated fruits was determined using a penetrometer probe (Gong et al., 2020). This was calculated as the maximum force (N) attained for tissue breakage. The result obtained with this probe was delineated in Kg / cm².

2.6 Determination of Percentage loss in weight of orange

Loss in the weight of the treated and stored oranges was calculated by weighing orange fruit at the beginning of the experiment and reweighing it at the end of each week. It was calculated and expressed as a percentage, using the following equation.

$$\text{Weight loss (\%)} = (M_1 - M_2) / M_1 \times 100$$

Where M_1 = Weight of orange fruit before bioactive coatings and storage.

M_2 = Weight of orange fruit after bioactive coatings and storage in grams (Adetunji et al., 2018).

2.7 Determination of pH

After orange fruit firmness analysis, the oranges were cut into small pieces (approximately 10 g equivalent) and homogenized in a grinder, while the supernatant was diluted with 100 ml of distilled water and filtered. The solutions were titrated (phenolphthalein used as an indicator) to the endpoint of pH 8.2 and the acidity result was taken as citric acid percentage equivalence. The pH of the samples was assessed using a pH meter (MonjazebeMarvdashti et al., 2020).

2.8 Determination of the Total SSC, and Ascorbic acid content

The total soluble solid content of the oranges was evaluated using a hand refractometer with drops of orange fruit juice that had been previously extracted (Abd Allah et al. 2011).

Also, the ascorbic acid content was measured using the 2,6 - dichlorophenolindophenol dye method (Deepa et al., 2006). Titration of the juice with Trichloroacetic acid (TCA) led to the color changing to pink. The results were delineated as ascorbic acid equivalent (AOAC, 2006).

2.9 Microbiological analysis

The effects of the bioactive forming coatings on the oranges were determined by doing a total microbial plate count for bacteria, yeasts, and mold. For this, 1g of the treated and stored oranges were cut and dissolved in 9 ml of sterile distilled water. 10-fold sample dilutions were carried out and inoculated on PDA medium and glucose yeast extract agars incorporated with antibiotics, and then it was incubated at 28 °C and the colony-forming units (CFU) of the incubated plates were counted after 5 days. Also, the total mesophilic and psychophilic bacteria were determined following the same protocol on plate count agar, but incubation was for 48 hrs at 37 °C. The (CFU) was observed in triplicate and represented as CFU × g⁻¹ (Sogvar et al., 2016; Shah et al., 2017).

2.10 Data analysis

The data analysis was subjected to Duncan's test which provided the significance level for the differences of any pair of means.

3 Results

3.1 Fungal metabolites and carboxyl-methylcellulose as bioactive coatings

The potential of the bioactive edible coatings, obtained from the cultured filtrates of the fungal bioagents, when combined with carboxyl methylcellulose was screened for the ability to increase the shelf life of orange by maintaining its post-harvest qualities. The experiment was conducted for 7 weeks. The results obtained indicated that the potential bioactive edible coatings gave better physiological and microbiological results after 7 weeks of postharvest treatment storage compared with the control. For illustration, at the end of the 7 weeks, the ascorbic acid level in the orange fruits coated with CMC + *T. viride* solution was 5.8 ± 0.04 while it was reported 4.7 ± 0.04 for the CMC + *P. chrysogenum* bioactive solution (Table 1). These were better ascorbic acid content results, compared to the control having (4.0 ± 0.04). Also, the results obtained for the total soluble content of the orange fruits due to postharvest treatment with the potential bioactive edible coatings, indicated that after 7 weeks, the total soluble solid of fruits coated with CMC + *P. chrysogenum* bioactive solution had the highest value of 3.22 ± 0.01 , followed by the CMC + *T. viride* (3.1 ± 0.02) and control (2.90 ± 0.01). The result showed that potential bioactive edible-coated fruits performed significantly ($p < 0.05$) better than the control after seven weeks of observation (Table 2). In addition, the effects of the potential edible coatings derived from carboxyl methylcellulose with metabolites of *T. viride* and *P. chrysogenum* on the pH of the postharvest treated orange fruits are shown in Table 3. After the 7 weeks of experimentation, the pH of fruits coated with CMC + *T. viride* solution had the

highest pH value of 3.8 ± 0.02 , this was followed by CMC + *P. chrysogenum* bioactive solution (3.17 ± 0.06) and the lowest pH value was observed in the control (2.90 ± 0.04). The result showed that potential bioactive edible-coated fruits performed better compared to un-coated control fruits. Furthermore, the resultant effects of potential bioactive edible coatings with carboxyl methylcellulose solution, combined with the cultured metabolites of *T. viride* and *P. chrysogenum* on the percentage

weight loss of the orange fruits are illustrated in Table 4. After seven weeks of experimental storage, it was reported that potential bioactive edible-coated fruits performed significantly ($p < 0.05$) better than the uncoated orange fruits, and the highest value of weight loss was reported 53 ± 0.76 percentage for the orange fruits used as uncoated control while this value was reported 44.0 ± 0.4 and 37 ± 0.4 for the CMC + *P. chrysogenum* and CMC + *T. viride* bioactive edible-coated respectively.

Table 1 Effect of potential bioactive edible coatings derived from carboxyl methylcellulose and fungal metabolites on ascorbic acid content of orange fruits

Week(s)	<i>T. viride</i> filtrates + 1% (CMC) v/v (CFU/g)	<i>P. chrysogenum</i> filtrates + 1% (CMC) v/v (CFU/g)	Control (Sterile distilled water)
1	7.8 ± 0.05^a	7.8 ± 0.04^a	7.8 ± 0.01^a
2	7.5 ± 0.04^b	6.3 ± 0.03^b	6.0 ± 0.15^b
3	7.4 ± 0.04^b	6.0 ± 0.02^c	5.9 ± 0.04^b
4	7.0 ± 0.01^c	5.7 ± 0.04^d	5.0 ± 0.02^c
5	6.5 ± 0.04^d	5.3 ± 0.08^e	4.7 ± 0.08^d
6	6.3 ± 0.06^d	5.1 ± 0.04^e	4.3 ± 0.08^e
7	5.8 ± 0.04^e	4.7 ± 0.04^f	4.0 ± 0.04^f

Values are means $\pm$ standard error. Means with similar alphabetical superscripts within a column is non-significant at ($P < 0.05$)

Table 2 Effect of potential bioactive edible coatings derived from carboxyl methylcellulose and fungal metabolites on the total soluble solids content of orange fruits

Week (s)	<i>T. viride</i> filtrates + 1% (CMC) v/v (CFU/g)	<i>P. chrysogenum</i> filtrates + 1% (CMC) v/v (CFU/g)	Control (Sterile distilled water)
1	5.53 ± 0.01^a	5.53 ± 0.04^a	5.53 ± 0.01^a
2	5.42 ± 0.01^b	4.21 ± 0.01^b	4.21 ± 0.01^b
3	5.32 ± 0.01^c	4.01 ± 0.01^c	3.78 ± 0.01^c
4	4.92 ± 0.01^d	3.92 ± 0.01^d	3.51 ± 0.01^d
5	4.75 ± 0.01^e	3.71 ± 0.01^e	3.42 ± 0.01^d
6	4.62 ± 0.01^f	3.41 ± 0.01^f	3.11 ± 0.04^e
7	3.10 ± 0.02^g	3.22 ± 0.01^g	2.90 ± 0.01^f

Values are means $\pm$ standard error. Means with similar alphabetical superscripts within a column is non-significant at ($P < 0.05$).

Table 3 Effect of potential bioactive edible coatings derived from carboxyl methylcellulose and fungal metabolites on pH of orange fruits

Week(s)	<i>T. viride</i> filtrates + 1% (CMC) v/v (CFU/g)	<i>P. chrysogenum</i> filtrates + 1% (CMC) v/v (CFU/g)	Control (Sterile distilled water)
1	5.8 ± 0.20^a	5.8 ± 0.01^a	5.8 ± 0.01^a
2	5.2 ± 0.10^b	4.6 ± 0.10^b	4.3 ± 0.10^b
3	4.8 ± 0.02^c	4.4 ± 0.10^b	4.2 ± 0.04^{bc}
4	4.7 ± 0.02^{cd}	4.2 ± 0.10^b	4.0 ± 0.10^{bc}
5	4.5 ± 0.02^d	3.8 ± 0.04^c	3.8 ± 0.10^c
6	4.2 ± 0.02^e	3.5 ± 0.10^{cd}	3.0 ± 0.11^d
7	3.8 ± 0.02^f	3.17 ± 0.06^d	2.9 ± 0.04^d

Values are means $\pm$ standard error. Means with similar alphabetical superscripts within a column is non-significant at ($P < 0.05$).

Table 4 Effect of potential bioactive edible coatings derived from carboxyl methylcellulose and fungal metabolites on percentage weight loss of orange fruits

Week(s)	<i>T. viride</i> filtrates + 1% (CMC) v/v (CFU/g)	<i>P. chrysogenum</i> filtrates + 1% (CMC) v/v (CFU/g)	Control (Sterile distilled water)
1	25 ± 0.40 ^e	23 ± 1.13 ^e	25 ± 0.76 ^e
2	26 ± 0.40 ^e	28 ± 0.40 ^d	30 ± 0.40 ^d
3	28.67 ± 0.60 ^d	30 ± 0.40 ^d	38 ± 1.13 ^c
4	31 ± 0.40 ^{cd}	35 ± 0.76 ^c	40 ± 0.76 ^c
5	33 ± 0.40 ^{bc}	38 ± 0.40 ^b	46 ± 0.40 ^b
6	35 ± 0.40 ^{ab}	42 ± 0.40 ^a	48 ± 0.60 ^b
7	37 ± 0.40 ^a	44 ± 0.40 ^a	53 ± 0.76 ^a

Values are means ± standard error. Means with similar alphabetical superscripts within a column is non-significant at ($P < 0.05$)

Table 5 Effect of potential bioactive edible coatings derived from carboxyl methylcellulose and fungal metabolites on psychrophilic bacteria isolated from oranges

Week(s)	<i>T. viride</i> filtrates + 1% (CMC) v/v (CFU/g)	<i>P. chrysogenum</i> filtrates + 1% (CMC) v/v (CFU/g)	Control (Sterile distilled water)
1	2.3 ± 0.04 ^e	2.27 ± 0.06 ^f	2.3 ± 0.08 ^g
2	2.5 ± 0.08 ^e	2.7 ± 0.08 ^e	3.9 ± 0.04 ^f
3	2.8 ± 0.04 ^d	3.87 ± 0.06 ^d	5.7 ± 0.08 ^e
4	3.0 ± 0.05 ^d	4.87 ± 0.06 ^c	6.8 ± 0.10 ^d
5	3.4 ± 0.04 ^c	5.2 ± 0.08 ^c	7.8 ± 0.07 ^c
6	4.5 ± 0.30 ^b	5.67 ± 0.09 ^b	12.5 ± 0.20 ^b
7	4.8 ± 0.04 ^a	6.27 ± 0.06 ^a	18.3 ± 0.08 ^a

Values are means ± standard error. Means with similar alphabetical superscripts within a column is non-significant at ($P < 0.05$)

Table 6 Effect of potential bioactive edible coatings derived from carboxyl methylcellulose and fungal metabolites on mesophilic bacteria isolated from oranges

Week(s)	<i>T. viride</i> filtrates + 1% (CMC) v/v (CFU/g)	<i>P. chrysogenum</i> filtrates + 1% (CMC) v/v (CFU/g)	Control (Sterile distilled water)
1	1.6 ± 0.10 ^d	1.6 ± 0.07 ^f	1.6 ± 0.06 ^g
2	2.3 ± 0.04 ^c	2.33 ± 0.02 ^e	3.4 ± 0.01 ^f
3	2.5 ± 0.04 ^c	3.67 ± 0.06 ^d	4.6 ± 0.04 ^e
4	2.5 ± 0.04 ^c	4.3 ± 0.04 ^c	5.2 ± 0.10 ^d
5	3.6 ± 0.08 ^b	8.5 ± 0.04 ^b	5.8 ± 0.01 ^c
6	3.8 ± 0.04 ^{ab}	8.4 ± 0.04 ^b	16.8 ± 0.04 ^b
7	3.93 ± 0.06 ^a	8.9 ± 0.02 ^a	19.3 ± 0.08 ^a

Values are means ± standard error. Means with similar alphabetical superscripts within a column is non-significant at ($P < 0.05$)

3.2 Potentials of bioactive coatings on microbial qualities of orange fruits

The plate count results of the potential bioactive edible coatings revealed that the bioactive film-forming coating gave a decrease in microbial population during ambient storage conditions when compared to the uncoated fruits. The results presented in Table 5 indicated that the potential bioactive edible coatings led to the reduction of colony-forming units of psychrophilic bacteria. Further, the treatment containing CMC + *T. viride* bioactive solution produced the lowest colony forming unit per gram (4.8 ± 0.04 CFU/g) at the end of the 7 weeks storage with followed by

CMC + *P. chrysogenum* (6.27 ± 0.06 CFU/g), while the highest value (18.3 ± 0.08 CFU/g) was recorded for the uncoated control fruits.

Further, a similar trend of reduction in the number of mesophilic bacteria was observed due to the application of potential bioactive edible coatings on orange fruits (Table 6). Treatment with CMC + *T. viride* bioactive edible coatings produced the lowest colony-forming unit (3.9 ± 0.06 CFU/g) at the end of the 7th week while this was followed by CMC + *P. chrysogenum* bioactive edible coating solution (8.9 ± 0.02 CFU/g), while a higher value of (19.3 ± 0.08 CFU/g) was recorded for the uncoated control fruits.

Table 7 Effect of potential bioactive edible coatings derived from carboxyl methylcellulose and fungal metabolites on microbial load reduction of mold and yeast from oranges

Week(s)	<i>T. viride</i> filtrates + 1% (CMC) v/v (CFU/g)	<i>P. chrysogenum</i> filtrates + 1% (CMC) v/v (CFU/g)	Control (Sterile distilled water)
1	1.2 ± 0.01 ^d	1.2 ± 0.11 ^f	1.2 ± 0.08 ^f
2	1.4 ± 0.06 ^{cd}	1.6 ± 0.05 ^e	1.8 ± 0.08 ^e
3	1.4 ± 0.11 ^{cd}	1.9 ± 0.07 ^d	2.7 ± 0.04 ^d
4	1.7 ± 0.08 ^c	2.0 ± 0.01 ^d	3.0 ± 0.04 ^d
5	2.3 ± 0.08 ^b	2.5 ± 0.06 ^c	3.7 ± 0.06 ^c
6	2.4 ± 0.04 ^b	2.8 ± 0.04 ^b	4.3 ± 0.06 ^b
7	2.8 ± 0.01 ^a	3.9 ± 0.08 ^a	5.8 ± 0.12 ^a

Values are means ± standard error. Means with similar alphabetical superscripts within a column is non-significant at ($P < 0.05$)

More so, microbial load reduction of molds and yeasts was also attributed to the treatment of orange fruits using potential bioactive edible coatings as presented in (Table 7). Postharvest orange fruits treatments with CMC + *T. viride* solutions produced the lowest colony-forming unit (2.8 ± 0.01 CFU/g) at the end of the 7 weeks treatment storage with followed by CMC + *P. chrysogenum* bioactive solution (3.9 ± 0.08 CFU/g) and the highest value (5.8 ± 0.12 CFU/g) was recorded for the uncoated control oranges. Generally, these results revealed that there was variation in the effects of the potential bioactive edible coatings on microbial populations of orange fruits.

4 Discussion and conclusion

A preliminary investigative study on the potential of bioactive edible coatings that were derived from the culture filtrates of two fungal bioagents was subjected to submerged liquid fermentation to obtain the metabolites, these metabolites were tested in combination with carboxyl methylcellulose solution to assess the synergistic effects on the postharvest shelf-life extension of sweet oranges during a 7-week experimental setup. The results of the study suggested good prospects in this preliminary screening investigation of the potential bioactive edible coatings. The population of the microbial load was reduced significantly due to the effects of the potential bioactive edible coatings on orange fruits. The plate count analysis indicated a reduction in the microbial counts of mesophilic and psychophilic bacteria, as well as the molds and yeast count as reflected in their colony-forming units respectively. The CMC + *T. viride* bioactive solution led to a reduction in the population of psychophilic bacteria with a (4.8 ± 0.04 CFU/g), while (CMC + *P. chrysogenum*) bioactive solution gave microbial load value of (6.27 ± 0.06 CFU/g). The highest microbial load value of (18.3 ± 0.08 CFU/g) was recorded for the uncoated control fruits. Also, a similar trend was observed for the result of mesophilic bacteria population count, as well as the population of molds and yeast due to the potential bioactive edible coated orange fruits as compared with the uncoated control fruits. For example, the potential bioactive edible coated (CMC + *P.*

chrysogenum) orange fruits, had a mesophilic bacteria count of 8.9 ± 0.02 CFU/g, and the highest mesophilic bacteria count was 19.3 ± 0.08 CFU/g which was recorded for the uncoated control fruits. These results imply that the potential bioactive edible coatings have antimicrobial properties that led to a reduction in the microbial count of the coated oranges when compared to the uncoated control of orange fruits. Earlier studies that are in agreement with our findings reported the efficacy of using edible coatings in improving the microbiological and physiological status of fruits and vegetables, thereby extending their storage life (Nayak et al., 2019; Nair et al., 2020; Pirozzi et al., 2021). According to the previous studies (Arnon et al. 2015; Chen et al. 2016; Munhuweyi et al. 2020; Zhao et al. 2020; Atta et al. 2021), the postharvest storage quality of fruits using carboxyl methylcellulose indicated an enhancement in the storage quality of the fruit attributable to the following mechanisms; the creation of hydrogen bond inside the CMC coating and forming of an extra layer of cuticle on the outer surface of the fruit. Also, the CMC coatings inhibited the proliferation of microbial life on the fruits, it reduces moisture loss and the rate of transpiration. More so, in a study on Agege sweet orange, Adetunji et al. (2018) utilize the synergistic influence of chitosan and *P. aeruginosa* produced rhamnolipid to extend the shelf-life of sweet orange through improving the microbial quality and physiological attributes of the coated oranges. These findings are incongruent with the highlights of our study that led to an improvement in both microbiological and physiological qualities of *C. sinensis*.

Also, various previous studies stated that the quality and shelf-life extension of fruits were improved, due to the treatment with various edible coatings (Maftoonazad & Ramaswamy, 2019; Anjum et al., 2020; Jafarzadeh et al., 2021). The mechanisms of action or bioactivity of the edible coatings in improving the microbial and physiological quality of the treated fruits include production of antimicrobial, antioxidative enzymes, pathogenesis inducing protein, and other bioactive components to suppress microbial pathogens and also maintain the fruits physiological integrity (Nair et al., 2020; Tkaczewska, 2020).

Our study further highlighted that there was minimal weight loss due to the application of the potential bioactive edible coatings on the orange fruits as compared to the uncoated control fruits. This result agrees with earlier studies of Abd El-Razek et al. (2019) and Abd-Elkader et al. (2021) where they reported and attributed the prevention of dehydration, loss of water, and fruit shrinkage to edible coatings of fruits. In addition, the application of the potential bioactive edible coatings significantly ($P < 0.05$) improved the pH, ascorbic acid, and the total soluble solid content of the orange fruits. This was due to the modifications of the internal environmental conditions of the coated fruits, thereby minimizing the exchange of gases due to the edible coatings and subsequently delaying the ripening of the fruits. These results are in harmony with reports of previous studies (Sharma et al., 2019; Parven et al., 2020; Xing et al., 2020; Hajebi Seyed et al., 2021; Hasan et al. 2021).

Conclusion

In conclusion, this preliminary investigative study on potential bioactive edible coatings that was formulated from a combination of carboxyl methylcellulose and fungal cultured metabolites led to significant improvement in the microbiological and physiological qualities of postharvest treated sweet orange fruits. The potential bioactive edible coatings led to a reduction in the microbial load of the citrus fruits, as well as improving the physiological qualities of the orange fruits. This implies that the potential bioactive edible can be deployed in enhancing the quality and storage life of sweet oranges (*Citrus sinensis*). Therefore, this study is an addition to the growing knowledge of using readily available natural bioactive ingredients to improve the shelf-life of very important orange fruit, thereby minimizing wastes, and ensuring the safety and security of fruits in our society. However, more questions are needed to be answered in further studies to comprehend the safety and mechanisms of action of this potential bioactive edible coating.

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