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Gumghatti-based composite coating improves postharvest quality and nutritional value of black plums

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ABSTRACT

Functional materials, along with plasticizers, surfactants, and other additives, dissolved in the right proportions in various solvents form edible coatings play a significant role in the extension of fresh produce's shelf-life. The aim of the study was to improve the quality of black plum during storage (*Prunus salicina* Lindl.) using gumghatti and lipid-based composite edible coatings. Different concentrations of gumghatti in combination with oils (coconut oil, jojoba oil, and chamomile oil) were coated onto plum fruits and stored at a temperature of 24 ± 5°C for 16 days. The physicochemical and biochemical changes occurring during the ripening of treated and untreated black plums were analyzed. Untreated plum fruits exhibited higher activity of cell wall softening enzymes compared with those treated with gumghatti alone and other formulations. Fruits treated with gumghatti and chamomile oil retained firmness better (6 lb) throughout the storage period. Treatment of plums with gumghatti in combination with chamomile oil and jojoba oil showed a significant impact on the retention of bioactive compounds like antioxidants, ascorbic acid, phenols, and anthocyanins. The findings offer suggestions for an economical and convenient alternative to maintain the keeping quality of black plum fruits stored at room temperature.

1. INTRODUCTION

Plums (*Prunus salicina* Lindl.), popularly known as stone fruits, belong to the Rosaceae family, which are nutritious in terms of minerals, vitamins, phytochemicals (i.e., phenolic acids, anthocyanins, and carotenoids), and also low in calories [1]. However, plums have a very low shelf life of 3–4 days, further resulting in the postharvest losses due to fruit softening, chilling injuries, and browning issues [2]. To increase their shelf life after harvest and maintain their quality, it is recommended to store plums at 0°C [3].

It is essential to be cautious with cold storage as it can lead to softening and chilling injuries in most tested plum cultivars, as observed by Vangdal *et al*. [4]. To address this, researchers have explored various postharvest technologies like the application of methyl cyclopropane (1-MCP) [5], modified atmosphere packaging [6], and edible coatings [7,8] to preserve the quality and extend the storage life of plums.

Application of the edible coatings has become a promising approach to enhance the shelf life of various fresh produces. This can be achieved by reducing food-borne pathogens, maintaining firmness, and preventing weight loss during storage for up to a month [9]. Edible coatings can be made from proteins, polysaccharides, lipids, resins, or combinations of these materials. In addition to these, functional ingredients like essential oils, antioxidants, and flavors can also be incorporated aiming toward the better quality, stability, safety, and functionality of food during processing, handling, and storage [10]. Selection of coating material depends on factors such as water solubility, hydrophilicity, hydrophobicity, ease of formation, and sensory properties.

One such coating material is gumghatti, also known as Indian gum, which is a complex nonstarch polysaccharide widely utilized in the food and pharmaceutical industries due to its excellent emulsification and thickening properties [11]. Combining gumghatti with various edible/essential oils having antibacterial and antifungal properties has shown promising results. For example, an edible coating formulated using gumghatti and clove oil emulsion enhanced the shelf life of papaya, along with preserving its quality throughout the storage

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period. This approach not only conserves energy but also minimizes the risk of cold storage disorders during fruit preservation [11]. Therefore, the objective of the present research is to investigate the shelf life enhancement of plums during the postharvest storage by retaining their physicochemical characteristics using an affordable and eco-friendly method of applying edible coatings (i.e., gumghatti combination with coconut oil, jojoba oil, and chamomile oil) at room temperature.

2. MATERIALS AND METHODS

2.1. Sample Selection and Postharvest Treatment

The initial step involved in the study was the selection of black plum fruits that were of uniform maturity, shape, and size, with no physical damage. Prior to the coating process, fruits were washed carefully with water, followed by disinfection using a 2% sodium hypochlorite solution. Finally, the fruits were kept to air-dry at ambient temperature.

The plum fruits were graded into five sets, each set consisting of 15 fruits. The sets T1, T2, T3, and T4 were subjected to distinct formulations of edible coating emulsions, while the fifth set served as the control (C). After the application of coatings on the fruits, they were kept for surface drying at room temperature. Subsequently, the treated and control fruits were stored at a temperature of 24 ± 5°C and relative humidity ranging from 44% to 62%. Throughout the 16-day storage period, the stored fruits were assessed for their physicochemical, biochemical, and microbial properties at intervals of 0, 4, 8, 12, and 16 days.

2.2. Viscosity Measurement of the Coatings

The rheological analysis aimed to investigate the viscosity of various concentrations of gumghatti (0.3%, 0.6%, and 0.9%) both individually and in conjunction with coconut oil, jojoba oil, and chamomile oil (0.2 and 0.3%). After analyzing the initial findings [Table 1], the study focused on intermediate viscous concentrations of the different coatings. Optimized concentrations of gumghatti were employed alongside three oils: coconut oil, jojoba oil, and chamomile oil. According to rheological analysis, gumghatti alone (0.6%) or in conjunction with oils, like gumghatti (0.6%) + coconut oil (0.3%) and gumghatti (0.6%) + chamomile oil (0.3%), exhibited moderate viscosity, making them the chosen applicants for the study. Table 2 presents the concentrations and viscosities of the coatings.

Table 1: Viscosities of different formulations of gumghatti and combination of oils like coconut oil, jojoba oil, and chamomile oil.

Treatments	Sample	Viscosity (mPa)
TA1	0.3% gum-ghatti	11.782
TA2	0.6% gum-ghatti	6.461
TA3	0.9% gum-ghatti	5.672
TA4	0.6% gum-ghatti + 0.2% coconut oil	2.707
TA5	0.6% gum-ghatti + 0.3% coconut oil	2.930
TA6	0.9% gum-ghatti + 0.3 % coconut oil	3.744
TA7	0.6% gum-ghatti + 0.2% jojoba oil	3.667
TA8	0.6% gum-ghatti + 0.3% jojoba oil	25.06
TA9	0.9% gum-ghatti + 0.3% jojoba oil	16.24
TA10	0.6% gum-ghatti + 0.2% chamomile oil	2.679
TA11	0.6% gum-ghatti + 0.3% chamomile oil	3.14
TA12	0.9% gum-ghatti + 0.3% chamomile oil	6.1543

2.3. Preparation of Coating Formulations

T1: 0.6% gumghatti

T2: 0.6% gumghatti + 0.3% coconut

T3: 0.9% gumghatti + 0.3% jojoba oil

T4: 0.6% gumghatti + 0.3% chamomile oil

The abovementioned mixture was filtered to get better purity, and distilled water was added to obtain a final volume of 100 ml. To reduce surface tension, Tween-80 was incorporated into all the coatings. A magnetic stirrer was used to make a uniform solution. After the addition of 0.75% glycerol, the plasticizer component solution was again stirred for 10 min. The resulting formulations were then applied to four sets of fruits, with the fifth set serving as a control to compare the ripening process between coated and uncoated fruits.

2.4. Physicochemical and Biochemical Analyses

The efficacy of the edible coatings was assessed by evaluating various physicochemical parameters:

The percentage of decay was calculated using the formula

Decay % = ((Initial no. of fruits - Final no. of fruits) / Final no. of fruits) x 100

The percentage of weight reduction was assessed using the formula

Weight loss % = ((Initial weight of fruits - Final weight of fruits) / Initial weight of fruits) x 100

The shelf life of the coated fruits was evaluated following the below methods described by Mondal [12]. The pH and total soluble solids (%) (TSS) were measured using the AOAC method [13]. The total sugar content was analyzed using Sadasivam and Manickam's method [14]. The browning index was calculated as described by Eissa [15]. Anthocyanins and flavanols were measured using Lees and Francis's method [16] to assess the presence of antioxidants. The total phenolic content and total antioxidant activity of the samples were evaluated by the methods described by Larrauri *et al.* [17] and McDonald *et al*. [18], respectively. Ascorbic acid, carotene, and lycopene content were analyzed by the methods described by Roe and Keather [19] and Wang *et al*. [20].

Table 2: Treatments considered for the coating application on black plum fruits.

Treatment	Viscosity (mPa)
T1	6.461 (TA2)
T2	2.930 (TA5)
T3	16.24 (TA5)
T4	3.14 (TA11)

T1: Gum-ghatti 0.6%; T2: Gum-ghatti (0.6%) + coconut oil (0.3%); T3: Gum-ghatti (0.9%)+ jojoba oil (0.3%) and T4: Gum-ghatti (0.6%) + chamomile oil (0.3%).

To observe the efficacy of the edible coatings, the degrading activity of cell wall enzymes, like pectate lyase (PL) and polygalacturonase (PG), was determined using the methods of Ouattara *et al*. [21], Pathak and Sanwal [22], and Eissa [15], respectively. The activity of polyphenol oxidase enzyme responsible for browning was also evaluated using Xing *et al*. [23] method.

2.5. Statistical Analysis

All the analyses were performed in triplicates ($n = 3$) and represented as mean ± SEM. Following the methodology described by Bliss [24], the data from the present study were put through Duncan's multiple range test to assess the significant difference between the obtained parameters ($p < 0.05$). To detect the significant differences among all the treatments and control set, the overall least significant difference ($p \leq 0.05$) was also calculated.

3. RESULTS AND DISCUSSION

3.1. Weight Loss and Decay

A significant ($p \leq 0.05$) increase in weight loss percentage was observed, which can be attributed to the increased respiration activity following harvest. However, the treated fruits exhibited lower weight loss compared with the control group. Among the treated fruits, those treated with jojoba oil showed significant changes in weight loss percentage ($p \leq 0.05$). For instance, after 8 days of storage, the weight loss in gumghatti + jojoba oil (T3) was 9.30%, while the control group recorded a weight loss of 24.41%. Additionally, the decay percentage was found to be lower in the treated fruits, with only 20% decay observed in the T4 treatment, as opposed to the 40% decay in the control group after 8 days of storage. The reduction in weight loss and decay has been reported earlier in papaya fruit with gumghatti 3% and clove oil 0.1% [11].

Moreover, Rojas-Argudo elucidated that the incorporation of lipids, along with the polysaccharide coatings, can enhance the water barrier nature of the coatings [25]. In line with the above study, edible coatings in the current research also reported better effectiveness due to the addition of a lipid component, chamomile oil with gumghatti, indicating the maintenance of the hydrophilic–hydrophobic balance, which results in the reduction in water loss from the fruit. The above findings were also in accordance with Kittur *et al*., who reported the reduction in weight loss when polysaccharide-based composite coatings were applied on banana fruits compared with uncoated ones [26]. In another study, it was also noticed that the coatings incorporated with composite oil were able to retard the ethylene emission in pineapple and reduce the weight loss during storage [27].

3.2. Firmness

An increase in the storage duration lead to a decrease in the firmness of the fruits significantly ($p \leq 0.05$). Nevertheless, fruits treated with a combination of gumghatti and chamomile oil (T4) maintained their firmness during the entire storage period compared with the control and other formulations [Table 3]. Retention of firmness in the coated fruits could be attributed to the reduction in PG and pectinesterase activities that are responsible for breaking of bonds in the pectin present in the cell wall, thus leading to the disintegration of insoluble protopectins to more soluble pectic acid and pectins [28]. Higher percentage of carbon dioxide and lower concentrations of oxygen also reduce the activities of these enzymes, allowing the coated fruits to retain the firmness better [29].

Therefore, the results of this study show a lot of resemblance to the findings by Mahfoudhi and Hamdi [30], who noticed that the maximum firmness in cherry fruit was maintained by coatings with gum arabic and almond gum and also with the reports of Pandey *et al*., confirming the role of composite edible coatings in retarding ethylene emission and enhancing texture, thereby preserving the quality of fruits [31].

3.3. pH and TSS

During storage, initially pH was found to be 4.043 ± 0.015 and a slight decrease was observed in all fruits during the storage. T3 (3.306 ± 0.005-16th day) and T4 (3.273 ± 0.005-16th day) exhibited a slower decrease in pH compared with other groups (T1-3.223 ± 0.005-12th day, T2-3.910 ± 0.020-16th day, C-3.456 ± 0.005-8th day); however, there were no notable variations in pH between the treated and control fruits. On the contrary, both control and treated fruits exhibited an increase in TSS until the eighth day, after which it gradually declined in coated fruits [Table 3]. A large amount of polysaccharides (e.g., pectin and cellulose) present in the cell wall will be digested by the degrading enzymes, leading to an increase in the soluble solid content during the process of ripening; however, they are utilized for the respiration process in the later stages [32]. The changes in TSS were significantly slower in coated fruits than in control ($p \leq 0.05$), proving the efficacy of edible coatings as selective barriers to CO_2 and O_2, thus modifying

Table 3: Changes in firmness and total soluble solids of black plum fruits during storage at 25 ± 1°C.

	Day 0	Day 4	Day 8	Day 12	Day 16
Treatments			**Firmness (lb)**		
T1	16.0	7.0	6.0	6.0	-
T2	16.0	10.0	9.0	5.0	-
T3	16.0	8.5	6.0	4.0	-
T4	16.0	14.0	10.0	5.0	6.0
C	16.0	8.0	3.0	-	-
Treatments			**Total soluble solids (%)**		
T1	0.5 ± 0^{a}	1.43 ± 0.06^{c}	1.37 ± 0.12^{d}	1.20 ± 0.00^{b}	-
T2	0.5 ± 0^{a}	1.03 ± 0.06^{a}	1.13 ± 0.06^{b}	1.20 ± 0.00^{b}	1.20 ± 0.00^{b}
T3	0.5 ± 0^{a}	1.47 ± 0.06^{d}	1.10 ± 0.00^{a}	1.10 ± 0.00^{a}	0.83 ± 0.06^{a}
T4	0.5 ± 0^{a}	1.37 ± 0.06^{b}	1.30 ± 0.00^{c}	1.17 ± 0.06^{c}	1.33 ± 0.06^{c}
C	0.5 ± 0^{a}	1.50 ± 0.00^{e}	1.37 ± 0.06^{e}	-	-

Values are mean ± standard deviation, $n = 3$. Values within treatments with different letters (a–d) in a column differ significantly ($p \leq 0.05$) with values from higher to lower. T1: Gum-ghatti 0.6%; T2: Gum-ghatti (0.6% coconut oil (0.3%); T3: Gum-ghatti (0.9%) + jojoba oil (0.3%) and T4: Gum-ghatti (0.6%) + chamomile oil (0.3%) and C: control.

Table 4: Changes in anthocyanins, flavanols, and lycopene content of black plum fruits during storage at 25 ± 1°C.

	Day 0	Day 4	Day 8	Day 12	Day 16
Treatments			**Anthocynins (µg g⁻¹ FW)**		
T1	1.711 ± 0.079[a]	2.810 ± 0.003[d]	2.799 ± 0.016[c]	3.679 ± 0.039[d]	-
T2	1.711 ± 0.079[a]	2.551 ± 0.013[b]	2.665 ± 0.008[b]	2.939 ± 0.024[c]	1.218 ± 0.063[c]
T3	1.711 ± 0.079[a]	2.745 ± 0.026[c]	1.363 ± 0.009[a]	1.499 ± 0.005[a]	1.198 ± 0.023[b]
T4	1.711 ± 0.079[a]	2.515 ± 0.015[a]	3.236 ± 0.003[d]	2.847 ± 0.000[b]	1.118 ± 0.005[a]
C	1.711 ± 0.079[a]	3.295 ± 0.008[e]	3.662 ± 0.006[e]	-	-
Treatments			**Flavanols (µg g⁻¹ FW)**		
T1	3.089 ± 0.019[e]	2.578 ± 0.012[d]	3.250 ± 0.016[b]	6.185 ± 0.035[d]	-
T2	3.089 ± 0.019[e]	2.065 ± 0.013[a]	4.202 ± 0.015[c]	5.181 ± 0.016[c]	2.134 ± 0.031[c]
T3	3.089 ± 0.019[e]	2.099 ± 0.018[b]	1.686 ± 0.003[a]	0.996 ± 0.003[a]	2.122 ± 0.077[b]
T4	3.089 ± 0.019[e]	2.211 ± 0.009[c]	4.386 ± 0.005[d]	3.315 ± 0.003[b]	1.372 ± 0.003[a]
C	3.089 ± 0.019[e]	3.709 ± 0.005[e]	5.155 ± 0.003[e]	-	-
Treatments			**Lycopene (µg g⁻¹ FW)**		
T1	0.289 ± 0.001[a]	0.526 ± 0.001[e]	0.846 ± 0.001[b]	1.407 ± 0.010[d]	-
T2	0.289 ± 0.001[a]	0.520 ± 0.002[d]	2.484 ± 0.056[e]	0.834 ± 0.013[a]	0.814 ± 0.011[b]
T3	0.289 ± 0.001[a]	0.464 ± 0.001[c]	0.859 ± 0.064[c]	0.879 ± 0.019[c]	0.404 ± 0.007[a]
T4	0.289 ± 0.001[a]	0.308 ± 0.001[a]	0.836 ± 0.030[a]	0.862 ± 0.023[b]	0.940 ± 0.007[c]
C	0.289 ± 0.001[a]	0.313 ± 0.001[b]	0.934 ± 0.020[d]	-	-

Values are mean ± standard deviation, n = 3. Values within treatments with different letters (a–d) in a column differ significantly (p ≤ 0.05) with values from higher to lower. T1: Gum-ghatti 0.6%; T2: Gum-ghatti (0.6%)+ coconut oil (0.3%); T3: Gum-ghatti (0.9%) + jojoba oil (0.3%) and T4: Gum-ghatti (0.6%) + chamomile oil (0.3%) and C: control.

Table 5: Changes in total phenols, ascorbic acid, and total antioxidant activity of black plum fruits during storage at 25 ± 1°C.

	Day 0	Day 4	Day 8	Day 12	Day 16
Treatments			**Total phenols (mg g⁻¹ FW)**		
T1	2.162 ± 0.007[e]	2.238 ± 0.005[d]	1.286 ± 0.009[e]	0.832 ± 0.004[d]	-
T2	2.162 ± 0.007[e]	2.529 ± 0.006[e]	0.465 ± 0.002[a]	0.952 ± 0.004[b]	0.558 ± 0.002[a]
T3	2.162 ± 0.007[e]	1.329 ± 0.002[b]	0.516 ± 0.008[b]	0.251 ± 0.001[a]	0.805 ± 0.001[b]
T4	2.162 ± 0.007[e]	2.214 ± 0.005[c]	0.736 ± 0.013[d]	0.939 ± 0.004[c]	0.952 ± 0.004[c]
C	2.162 ± 0.007[e]	1.270 ± 0.013[a]	0.595 ± 0.002[c]	-	-
Treatments			**Ascorbic acid (mg 100 g⁻¹ FW)**		
T1	37.50 ± 0.00[e]	30.42 ± 0.01[e]	17.71 ± 0.01[a]	51.88 ± 0.00[d]	-
T2	37.50 ± 0.00[e]	15.42 ± 0.00[a]	50.21 ± 0.03[e]	32.50 ± 0.01[b]	23.75 ± 0.01[c]
T3	37.50 ± 0.00[e]	18.75 ± 0.00[c]	22.29 ± 0.01[b]	13.75 ± 0.01[a]	18.54 ± 0.01[a]
T4	37.50 ± 0.00[e]	16.67 ± 0.00[b]	35.00 ± 0.01[d]	43.13 ± 0.02[c]	20.21 ± 0.01[b]
C	37.50 ± 0.00[e]	27.29 ± 0.00[d]	28.96 ± 0.00[c]	-	-
Treatments			**Total antioxidant activity (%/FW)**		
T1	94.554 ± 0.000[a]	93.812 ± 0.000[b]	90.890 ± 0.001[e]	94.015 ± 0.002[c]	-
T2	94.554 ± 0.000[a]	94.389 ± 0.001[c]	93.240 ± 0.001[b]	93.629 ± 0.005[b]	87.387 ± 0.017[a]
T3	94.554 ± 0.000[a]	94.554 ± 0.001[c]	95.890 ± 0.001[c]	73.488 ± 0.014[a]	90.927 ± 0.006[b]
T4	94.554 ± 0.000[a]	95.132 ± 0.001[d]	99.947 ± 0.001[d]	94.723 ± 0.001[c]	93.308 ± 0.001[c]
C	94.554 ± 0.000[a]	80.000 ± 0.000[a]	73.230 ± 0.001[a]	-	-

Values are mean ±standard deviation, *n* = 3. Values within treatments with different letters (a–e) in a column differ significantly (*P* ≤ 0.05) with values from higher to lower. T1: Gum-ghatti 0.6%; T2: Gum-ghatti (0.6% coconut oil (0.3%); T3: Gum-ghatti (0.9%) + jojoba oil (0.3%) and T4: Gum-ghatti (0.6%) + chamomile oil (0.3%) and C: control.

the internal atmosphere of the fruit followed by slowing down the rate of respiration [33].

3.4. Anthocyanin and Flavanols

Throughout the study period, the anthocyanin content of control fruit exhibited a gradual increase. However, in the case of treated black plum fruits, the increase in anthocyanin content was slower and sustained as the ripening was delayed compared with the control group [Table 4] that led to the greater anthocyanin content in treated fruits by the end of storage. These findings align similarly with the results obtained from investigation on cherries coated with olive leaves' extract enriched with combinations of alginate and chitosan were carried out by Zam [34]. Moreover, in black plum fruit, the flavanols initially increased, followed by a declining trend, corroborating the findings from previous research on black plums [35]. Therefore, the stability of anthocyanins during storage duration acting as a scavenger-preventing oxidation of fruit enhances its shelf life.

3.5. Lycopene

Fruits coated with (T4) 0.6% gumghatti + 0.3% chamomile oil exhibited less loss of lycopene throughout the storage period ($p \leq 0.05$). In comparison, all the treated fruits exhibited lower lycopene

Table 6: Changes in polygalactouranase, pectate lyase, and amylase activity of black plum fruits during storage at 25 ± 1°C.

	Day 0	Day 4	Day 8	Day 12	Day 16
Treatments	**Polygalacturonase (U/min/mg protein)**				
T1	0.0217 ± 0.0033^{a}	0.0330 ± 0.0040^{b}	0.0408 ± 0.0010^{c}	0.0263 ± 0.0034^{b}	-
T2	0.0217 ± 0.0033^{a}	0.0280 ± 0.0017^{a}	0.0402 ± 0.0047^{c}	0.0632 ± 0.0157^{d}	0.0254 ± 0.0016^{b}
T3	0.0217 ± 0.0033^{a}	0.0384 ± 0.0007^{e}	0.0566 ± 0.0044^{b}	0.0190 ± 0.0077^{a}	0.0158 ± 0.0016^{a}
T4	0.0217 ± 0.0033^{a}	0.0340 ± 0.0012^{c}	0.0465 ± 0.0037^{d}	0.0563 ± 0.0102^{c}	0.0257 ± 0.0007^{c}
C	0.0217 ± 0.0033^{a}	0.0440 ± 0.0024^{d}	0.0504 ± 0.0004^{a}	-	-
Treatments	**Pectate lyase (U/min/mg protein)**				
T1	0.0210 ± 0.0038^{a}	0.0277 ± 0.0003^{b}	0.0299 ± 0.0009^{b}	0.0398 ± 0.0030^{b}	-
T2	0.0210 ± 0.0038^{a}	0.0291 ± 0.0004^{c}	0.0316 ± 0.0018^{d}	0.0423 ± 0.0022^{c}	0.0492 ± 0.0008^{c}
T3	0.0210 ± 0.0038^{a}	0.0259 ± 0.0013^{a}	0.0327 ± 0.0021^{e}	0.0391 ± 0.0004^{a}	0.0438 ± 0.0026^{b}
T4	0.0210 ± 0.0038^{a}	0.0306 ± 0.0013^{d}	0.0275 ± 0.0020^{a}	0.0425 ± 0.0021^{d}	0.0424 ± 0.0007^{a}
C	0.0210 ± 0.0038^{a}	0.0313 ± 0.0016^{e}	0.0300 ± 0.0007^{c}	-	-
Treatments	**Amylase (U/min/mg protein)**				
T1	86.39 ± 0.319^{a}	24.11 ± 0.18^{c}	38.23 ± 0.034^{j}	45.05 ± 0.04^{l}	-
T2	86.39 ± 0.319^{a}	51.44 ± 0.27^{m}	29.13 ± 0.07^{d}	33.77 ± 0.05^{g}	30.64 ± 0.02^{e}
T3	86.39 ± 0.319^{a}	81.43 ± 0.65^{p}	31.78 ± 0.04^{f}	23.13 ± 0.03^{b}	21.38 ± 0.01^{a}
T4	86.39 ± 0.319^{a}	70.92 ± 0.55^{o}	34.38 ± 0.02^{h}	36.64 ± 0.08^{i}	40.72 ± 0.08^{k}
C	86.39 ± 0.319^{a}	68.24 ± 0.07^{n}	34.67 ± 0.01^{h}	-	-

Values are mean ±standard deviation, $n = 3$. Values within treatments with different letters (a–o) in a column differ significantly ($P \leq 0.05$) with values from higher to lower. T1: Gum-ghatti 0.6%; T2: Gum-ghatti (0.6% coconut oil (0.3%); T3: Gum-ghatti (0.9%) + jojoba oil (0.3%) and T4: Gum-ghatti (0.6%) + chamomile oil (0.3%) and C: control.

Table 7: Changes in browning index and polyphenol oxidase activity of black plum fruits during storage at 25 ± 1°C.

	Day 0	Day 4	Day 8	Day 12	Day 16
Treatments	**Browning index**				
T1	0.134 ± 0.001^{a}	0.212 ± 0.003^{d}	0.224 ± 0.002^{d}	0.280 ± 0.002^{d}	-
T2	0.134 ± 0.001^{a}	0.165 ± 0.002^{c}	0.251 ± 0.002^{e}	0.150 ± 0.001^{c}	0.149 ± 0.001^{b}
T3	0.134 ± 0.001^{a}	0.221 ± 0.005^{a}	0.127 ± 0.000^{b}	0.096 ± 0.001^{a}	0.145 ± 0.002^{a}
T4	0.134 ± 0.001^{a}	0.162 ± 0.006^{b}	0.183 ± 0.003^{c}	0.124 ± 0.003^{b}	0.162 ± 0.001^{c}
C	0.134 ± 0.001^{a}	0.145 ± 0.001^{e}	0.217 ± 0.001^{a}	-	-
Treatments	**Polyphenol oxidase (U min^{-1} mg protein^{-1})**				
T1	0.0217 ± 0.0033^{a}	0.0330 ± 0.0040^{a}	0.0408 ± 0.0010^{d}	0.0263 ± 0.0034^{a}	-
T2	0.0217 ± 0.0033^{a}	0.0280 ± 0.0017^{c}	0.0402 ± 0.0047^{b}	0.0632 ± 0.0157^{d}	0.0254 ± 0.0016^{c}
T3	0.0217 ± 0.0033^{a}	0.0384 ± 0.0007^{d}	0.0566 ± 0.0044^{e}	0.0190 ± 0.0077^{c}	0.0158 ± 0.0016^{a}
T4	0.0217 ± 0.0033^{a}	0.0340 ± 0.0012^{b}	0.0465 ± 0.0037^{c}	0.0563 ± 0.0102^{b}	0.0257 ± 0.0007^{b}
C	0.0217 ± 0.0033^{a}	0.0440 ± 0.0024^{e}	0.0504 ± 0.0004^{a}	-	-

Values are mean ± standard deviation, $n = 3$. Values within treatments with different letters (a–d) in a column differ significantly ($P \leq 0.05$) with values from higher to lower. T1: Gum-ghatti 0.6%; T2: Gum-ghatti (0.6% coconut oil (0.3%); T3: Gum-ghatti (0.9%) + jojoba oil (0.3%) and T4: Gum-ghatti (0.6%) + chamomile oil (0.3%) and C: control.

loss than the control group, proving the effectiveness of coating [Table 4]. These results exhibited that the coatings on fruits developed a protective barrier on plum fruit skin that retarded the gaseous exchange and ripening process [36,37]. On the eighth day from the start of the shelf life study, fruits treated with gumghatti + coconut oil displayed a significant rise in lycopene content followed by a gradual decrease. The above trend in the lycopene values aligns with research findings from earlier studies conducted on the coating of tomatoes with the chitosan/zeolite [36], and the combinations of aloe vera and chitosan [37].

3.6. Total Phenols and Ascorbic Acid

According to [Table 5], as the storage duration increased, the total phenol content in the fruits decreased. Nonetheless, fruits treated with gumghatti and chamomile oil (T4) exhibited the least decrease in phenolic content. The decrease in total phenolic content by the end of the storage period was due to the degradation of cell structure as an indication of senescence phenomena during storage [38]. Regarding the ascorbic acid content, it initially increased and then a gradual decrease was noted, with the treated fruits showing higher content compared with untreated fruits ($p \leq 0.05$). Fruit sugar's availability, which is a precursor to ascorbic acid production, may have caused an early enhancement in ascorbic acid. However, oxidative ascorbic acid degradation by oxidase may have contributed to a subsequent decline in ascorbic acid [39]. These findings align with earlier studies conducted on tomatoes [38] and sweet cherry fruit [30].

3.7. Total Antioxidant Activity

Antioxidants act as free radical scavengers by donating a pair of electrons and neutralizing free radicals, which are oxidizing in nature and harm-causing agents [40]. In the present study, better antioxidant activity was observed in the treated black plums while a rapid loss in antioxidant activity was noted in the control groups. Anthocyanins were also found to increase, leading to an increase in the total antioxidant activity as a whole. Throughout the storage period, the fruit's total antioxidant activity remained relatively stable, except a slight increase on the eighth day in T3 and T4, followed by a subsequent decrease until the final day of storage [Table 5]. This observation aligns with findings from previous studies in which the papaya fruits were coated with gumghatti and clove oil [11]. However, in the present study, T4 exhibited better antioxidant activity than any other treatments and control on the 16th day of storage.

3.8. Polygalactourinase Activity and Pectate Lyase Activity

An increase in PG activity, reaching a peak, followed by a subsequent decline [Table 6], was observed during the storage period. Nonetheless, treated fruits exhibited a slower rise in enzyme activity compared with untreated fruits. Moreover, PL activity also resulted in a significant increase in the duration of storage ($p \leq 0.05$). A similar trend of delayed increase in PG activity was reported by Gol *et al.* [41] in strawberry fruit where chitosan was used as edible coating. These coatings provide less accessibility for the above enzymes to act on pectin, leading to reduced pectin solubilization and softening. According to Zhou *et al*. [42], hydrolysis of (1-4) galacturonan linkages of demethylated pectins is catalyzed by PG, followed by the release of shorter chains causing the dissolution of pectins. They also noticed a lower activity of PG in the pears coated with shellac compared with control, thus retaining the firmness of the fruit better.

3.9. Amylase Activity

During storage, the amylase activity, responsible for starch break down, showed a significant decrease from the initial to the final day in all groups, while it is slower in treated group compared with control ($p \leq 0.05$). Among the treated groups, fruits coated with gumghatti and jojoba oil (T3) exhibited the lowest activity of amylase on the 16th day of storage [Table 6]. In a study performed on edible coating of berry cactus fruit, it was found that sodium caseinate coatings inhibited the amylase activity better than control. This inhibitory activity aids in slower break down of starch, thus resulting in lower glucose levels in blood after consumption [43]. Rahman et al. also found a similar trend in amylase activity pertaining to mangoes stored at three varied temperatures (−5, 4, and 25°C); however, it increased with an increase in temperature [44].

3.10. Browning Index and PPO Activity

Browning is mainly caused by oxidation of phenolic compounds by an enzyme; the PPO present in fruits. PPO is a key enzyme that activates during senescence, ripening, or stress conditions like membrane damage, resulting in browning of fruit tissues [45]. In the present study, browning phenomena were increased in treated as well as untreated fruits, but this process was found to be comparatively slower in coated black plum fruits than in the control set of fruits [Table 7]. As mentioned above, less intensity of browning was observed in treated fruits due to the coatings that acted as barriers and led to a reduction in the oxygen supply for enzymatic oxidation of contained phenolics [46]. On the fourth day of storage, the control group exhibited higher polyphenol oxidase activity, which is associated with the browning process, compared with the coated fruits [Table 7]. Among the coated fruits, those treated with gumghatti displayed the lowest enzyme activity, while the combination of gumghatti and chamomile oil also contributed to a significant reduction in the enzyme activity comparatively ($p \leq 0.05$). The utilization of gumghatti and chamomile oil (T4) resulted in the least browning, comparable to the findings observed in sweet cherry fruits [47].

3.11. Shelf Life of Fruits

The control fruits had a shelf life of 7–8 days, whereas the fruits treated with combinations of gumghatti and various oil (T2, T3, and T4) had shelf lives of 15, 15, and 16 days, respectively. It is noteworthy that the combination of gumghatti and chamomile oil significantly doubled the fruits' shelf life ($p \leq 0.05$). Furthermore, all treatments not only enhanced the fruits' visual appearance and commercial acceptability but also extended their shelf life by more than 8 days. Thus, the current study reports are in accordance with the results of Vyas *et al*. [48], who reported that polysaccharide-based coatings have a significant role in improving the quality of papaya, thereby extending its shelf life.

4. CONCLUSION

Edible coatings are found to be versatile alternatives for enhancing the quality of fresh produce. However, knowledge of the physicochemical and functional characteristics of biopolymers is critical in selecting the appropriate biomaterial specific to the fresh produce. The inherent carrying capacity of the coating materials opens a wide range of opportunities through structural modifications and incorporation of additives like bioactive compounds that might result in better efficiency of the coatings. In the present study, attempt has been made by the application of gumghatti coating, alone and in combination with oils, to enhance the shelf life and postharvest quality characteristics of black plum fruits. The coatings effectively minimized weight and moisture loss, while also enhancing firmness and delaying decay and browning. Furthermore, the treated fruits exhibited elevated levels of essential antioxidants, including lycopene, anthocyanin, and ascorbic acid, leading to delayed ripening compared with the control group. Moreover, the coatings had a notable impact on enzyme activities linked to fruit softening and browning. Among the various coatings, the combination of gumghatti and chamomile oil (T4) demonstrated the highest effectiveness in extending the shelf life of black plum fruits. This combination of chamomile oil and gumghatti can be taken as a promising composite edible coating material for future aspects. This study presents a practical, cost-effective, and user-friendly edible coating that effectively prolongs fruit shelf life even at room temperature.

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6. AUTHORS' CONTRIBUTIONS

Study conception and design: TVRR and PKD; data collection: PKD, JBP and NP; analysis and interpretation of results: TVRR, PRP, and AP; draft manuscript preparation: PKD, TVRR, PRP, AP and NP. The results and final version of the manuscript is approved by all the authors.

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8. CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this work.

9. ETHICAL APPROVAL

This study does not involve experiments on animals or human subjects.

10. DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the present study.

11. USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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