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EXTENDING THE SHELF LIFE OF APRICOT (*PRUNUS ARMENIACA*) WITH *ARTEMISIA ABSINTHIUM* ESSENTIAL OIL-BASED EDIBLE COATING: A STUDY ON QUALITY AND ANTIMICROBIAL PROPERTIES

SYED ARIF HUSSAIN RIZVI[1*], REHANA BATOOL[2*], KASHIF HUSSAIN[3], MOHAMED A. WADAAN[4] AND FAHD A. AL-MEKHLAFI[4]

[1]Department of Entomology, College of Plant Protection, South China Agricultural University, Guangzhou 510642, China
[2]Institution of Food and Nutritional Science, PMAS Arid Agriculture University, Rawalpindi, Pakistan
[3]Department of Food Science, The University of Agriculture, Peshawar 25000, Pakistan
[4]Department of Zoology, College of Science, King Saud University, P.O. Box 2455 Riyadh, 11451 Riyadh, Saudi Arabia

*Corresponding author's email: rehanabs16@gmail.com, arifrizvi@scau.edu.cn

Abstract

Natural plant-based additives and preservatives are gaining popularity due to their perceived safety benefits and potential to reduce disease risks associated with synthetic chemicals. This study investigates the potential of *Artemisia absinthium* essential oil (AAEO) collected from the highlands of Skardu, Baltistan, Pakistan, as a natural preservative to extend the shelf life of organically grown apricots. The essential oil (EO), analyzed via GC-MS, revealed a terpenoid- rich composition, primarily comprising guaiol (19. 33%), α-bisabolol (8. 83%), carveol (6. 16%), chamazulene (5. 94%), geranyl-α-terpinene (5. 63%), and limonene- 6-ol, pivalate (5. 37%) as the major dominant constituents, with an EO yield of 0. 46% (w/w). Our current study demonstrated a concentration-dependent response, where apricots coated with AAEO concentrations of 7.5 and 10 µL/mL significantly enhanced stability in various quality parameters, including pH, weight loss, total soluble solids, titratable acidity, ascorbic acid, and total sugar content. Furthermore, the edible coating effectively delayed ripening and senescence, preserving ascorbic acid and titratable acidity levels, and ultimately extended shelf life by 9 days ($p<0.001$) compared to uncoated apricots, while maintaining overall quality. Notably, the AAEO exhibited potent antioxidant properties, with a lethal concentration (LC50) value of 0.291 mg/mL and an antioxidant index value of 2.74, indicating significant free radical scavenging activity. The AAEO exhibited antimicrobial activity against *Escherichia coli*, *Staphylococcus aureus*, and *Proteus mirabilis*, with zone of inhibition values of 22 mm ± 0.09, 20 mm ± 0.65, and 18 mm ± 0.19, respectively, at a concentration of 15 µL. Additionally, AAEO demonstrated antifungal activity, inhibiting the mycelial growth of *Penicillium italicum* (98.23 ± 0.83%) and *Candida albicans* (85.76 ± 0.98%) at a concentration of 10 µL/mL, showcasing its potential as an antimicrobial agent. Our current investigation reveals that AAEO's significant antimicrobial and antioxidant properties, combined with its ability to enhance stability in various quality parameters, effectively preserved apricot quality and extended shelf life by 9 days. This finding highlights AAEO's potential as a promising natural edible coating for different food products, offering benefits in quality preservation, shelf-life extension, and enhanced food safety.

Key words: Natural preservatives; Edible coatings; Antimicrobial; Antioxidant; Shelf life

Introduction

Edible coatings, particularly those derived from plant sources, have emerged as a promising approach for enhancing food quality, safety, and extending shelf life (Khaliq *et al*., 2023). Recently, there has been a growing interest in developing edible coatings using natural and sustainable ingredients, such as essential oils (Hamid *et al*., 2024). The essential oils extracted from various plant species exhibit antimicrobial, antioxidant, and anti-inflammatory properties, offering potential as natural food additives and preservatives, and serving as a viable alternative to synthetic options (Boulares *et al*., 2025). Sodium alginate, a polysaccharide derived from algae, exhibits gelling, stabilizing, and water-retention properties. It's used in the medicinal, textile, and food industries to create edible coatings and extend shelf life (Song *et al*., 2024).

Tween 80, also known as Polysorbate 80, is a nonionic surfactant, emulsifier, and stabilizer used in edible coatings for fruits, as well as in the food and pharmaceutical industries. It is non-toxic, rapidly biodegradable, and safer for human and environmental health (Khandelwal *et al*., 2024). *Artemisia absinthium* L. (wormwood) is considered a perennial small herb plant. This plant and its essential oil have been extensively studied for their antimicrobial, antifungal, antiprotozoal, insecticidal, and acaricidal properties (Zouari *et al*., 2024). The AAEO collected from temperate regions has demonstrated significant antibacterial activity against *Micrococcus luteus*, *Staphylococcus aureus*, *Salmonella typhi*, and *Escherichia coli* (Ricardo-Rodrigues *et al*., 2024), as well as antifungal activity against *Aspergillus niger*, *Enterococcus faecalis,* and *Staphylococcus aureus* (Hrytsyk *et al*., 2021). Similarly, the addition of 2-4% *A. absinthium* powder to functional yogurt extends shelf life up to 28 days under storage conditions by reducing acidity and lipolysis (Boulares *et al*., 2025).

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Apricots are rich in health-promoting components, including carbs, proteins, lipids, minerals, and vitamins (Xu *et al*., 2025). It also contains antioxidants, bioactive phenolics, and carotenoids (Joia *et al*., 2025; Ullah *et al*., 2017). Apricots have a short shelf life (around 5 days) and are prone to microbial deterioration and damage. Globally, 4 million tons are produced annually, with Pakistan contributing 0.5 million tons (Joia *et al*., 2025; Ullah *et al*., 2017). According to a report compiled in the northern districts of Pakistan, the annual apricot losses are alarmingly high, with around 46% of fresh apricots wasted each year (Joia *et al*., 2025; Zaman *et al*., 2024). Despite existing preservation methods, sustainable and healthy alternatives are needed to minimize post-harvest losses. The study focuses on developing an edible coating with AAEO as a natural preservative to extend the shelf life and maintain the quality of apricots (*Prunus armeniaca*), while assessing its antioxidant and antimicrobial effects.

Material and Methods

Plant material and essential oil extraction: The aerial parts of *Artemisia absinthium* were collected from Halqa 2, Skardu, Baltistan, Pakistan, in August 2024, before the onset of flowering. The plant material was identified through comparing the voucher specimens ART004 and SK 108 previously submitted to Quaid-e-Azam University, Islamabad, and the University of Peshawar, Pakistan Herbarium (Bano *et al*., 2014; Hayat *et al*., 2009). The plant materials were dried in the shade for two weeks and ground into a fine powder. Fresh apricots of the local variety Halman were obtained from a nearby orchard. A Clevenger-type apparatus was used to extract EO (CNW Technologies, Inc., Shanghai) through hydro-distillation for four hours. The extracted EO was dried over anhydrous sodium sulfate to remove the remaining water content. The EO was kept at 4°C for future experiments. The study used the widely grown 'Halmond' variety of apricots, sourced from local farmer orchards where they were organically grown without the application of synthetic chemicals throughout the seasons. The graphical illustration of the experiment is presented in (Fig. 1).

Preparation of edible coating formulation: After the preliminary experiment following concentrations of the coating emulsion was prepared by dissolving varying amounts of AAEO in distilled water at concentrations of T_2-T_6 (1µL/mL, 2.5 µL/mL, 5.0 µL/mL, 7.5 µL/mL, and 10 µL /mL) along with 2g sodium alginate (NaAlg), 0.5mL Tween 80, and 1.5mL glycerol until wholly dissolved and a homogenous emulsion. T_1 apricots were treated with 2 g sodium alginate (NaAlg), 0.5 mL Tween 80, and 1.5 mL glycerol, whereas T^0 served as a control without emulsion coating, as described by (Hajji *et al*., 2018). The apricot samples were carefully washed with distilled water and dried with muslin towels and hot air before applying the prepared edible coating (emulsion). The apricots were divided into seven groups and coated with emulsion by dipping each fruit for 5 seconds. A set of five apricots constituted a single treatment, with each treatment replicated five times. After coating, the samples were stored under ambient conditions (26 ± 2°C and 40-60% relative humidity) and covered with muslin cloths.

Physicochemical analysis: After applying different treatments of AAEO emulsion to freshly harvested apricots, the physicochemical analysis of the various treatments was conducted at intervals of 0, 3, 6, and 9 days.

Weight loss and total soluble solids: During storage, the weight of the apricots was measured using a standard balance, and the results for total weight loss and total soluble solids were recorded. Weight loss was used as an indicator of quality deterioration. and total soluble solids (TSS) were determined using a digital refractometer according to the AOAC specifications (1990).

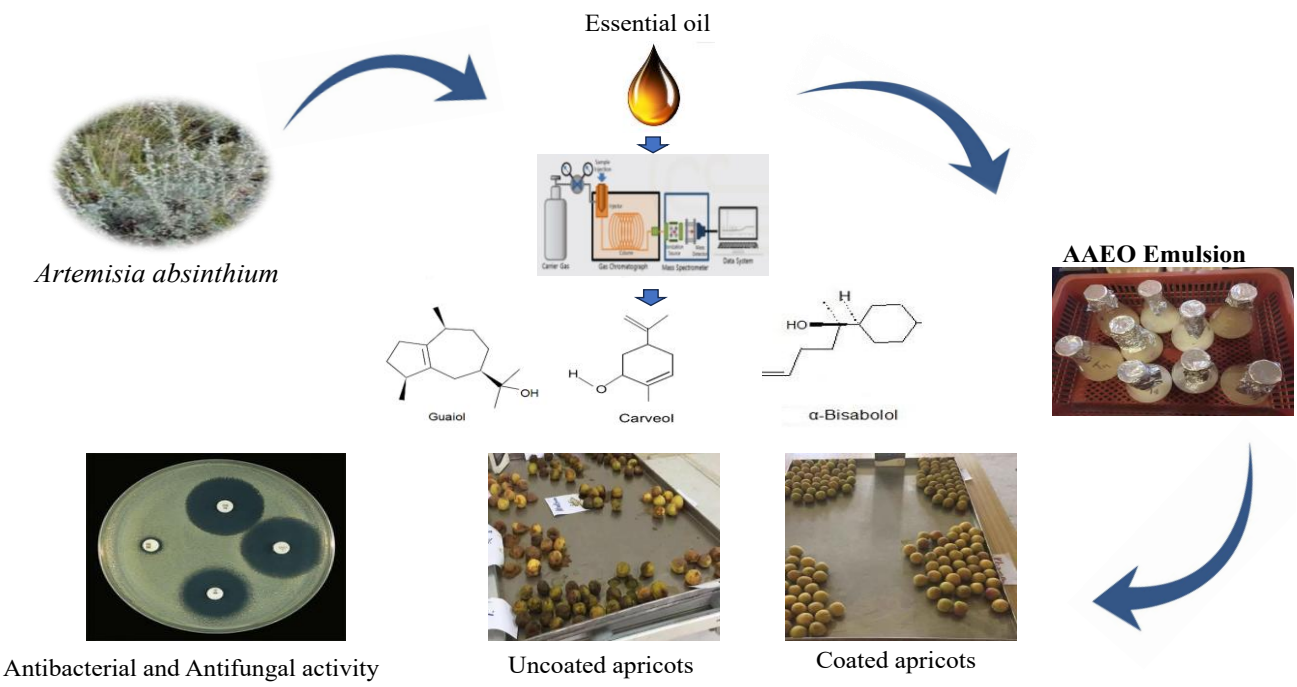

Fig. 1. The graphical illustration of the experiment.

PH, ascorbic acid, titratable acidity, and Total sugar: The pH was measured using a pH meter, and ascorbic acid content in apricots was determined via titrimetric analysis with 2,6-dichlorophenol indophenol dye, following the standard AOAC method (1990). The titratable acidity and total sugar content of both coated and uncoated apricots were determined using Fehling solutions and the phenolphthalein indicator method, with titration performed with 0.1 N NaOH.

DPPH assay: The antioxidant activity of AAEO was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay (Sharma and Bhat, 2009). Briefly, 0.1 mM DPPH solution in methanol and mix it with the following concentrations of AAEO: 0.1, 0.5, and mg/mL. After 30 minutes of incubation at ambient temperature, the optical density (OD) was measured at 517 nm using a spectrophotometer (BioTek H1 synergy). DPPH radical inhibition was calculated as

$$\text{Percent Inhibition} = [(A0 - A1)/A0] \times 100 \quad (1)$$

whereas, A0 is the absorbance of the DPPH solution without the sample, and A1 is the absorbance with the sample.

The LC50 values were determined via Probit analysis, with Quercetin as a positive control.

Test microorganisms: The bacterial strains *E. coli* (ATCC 8738), *S. aureus* (ATCC 6538), and *P. mirabilis* (ATCC 12453) were obtained from PCSIR Laboratories, Peshawar. These strains were maintained on nutrient agar. The fungal pathogens *P. italicum* and *C. albicans* were isolated from rotten fruits and cultured on potato dextrose agar at 26 ± 2°C.

Antifungal activity: The fungal pathogens *P. italicum* and *C. albicans* spore concentrations were fixed up to 5×10^5 CFU mL^{-1} using a hemocytometer. The antifungal activity of AAEO was assessed using the protocol described by Sharma & Tripathi (2008). Following the preparation of EO concentrations (0.00, 1.00, 2.50, 5.00, 7.50, and 10 L), 40% ethanol with the addition of Tween 80 (0.05% v/v) was included in the growth media to ensure that the essential oil was distributed safely and uniformly. However, in the control Petri dishes, an equivalent volume of distilled water was added instead of EO. The plates were maintained at 25 ± 2°C for two days, and the inhibition of mycelial growth was assessed using a ruler. The mycelial growth inhibition percentage was used to determine the zone of fungal inhibition in Petri dishes (Yahyazadeh *et al*., 2008).

$$\text{GI} = [(dc - dt)/dc] \times 100 \quad (2)$$

whereas, dc stands for colony diameter of control, and dt stands for colony diameter for treatment.

Antibacterial activity: The inhibitory effects of AAEO on bacterial strains were investigated using the agar well diffusion technique (Kirmani *et al*., 2024). A total of 75 ml of Mueller-Hinton (MH) agar was poured into Petri plates, and the media was kept to solidify. A sterile glass spreader was used to distribute the pre-cultured bacterial inoculum evenly throughout the Petri plates. A sterile cork borer (6 mm diameter) was used to create wells, and 5, 10, and 15 µL/mL of AAEO were added, corresponding to 0.5%, 1%, and 1.5% concentrations, respectively. Ciprofloxacin and Streptomycin (30 µg/mL) were used as the positive control, whereas DMSO served as the negative control. After that, Petri plates were adequately sealed and kept at 37°C overnight. The zones of inhibition were recorded after 24 h of treatment.

Statistical analysis

Data analysis was conducted using SPSS 17.0. Probit analysis assessed antioxidant activity, while two-way ANOVA evaluated treatment effects (AAEO at varying concentrations) on shelf life and quality parameters. Tukey's post-hoc test was used for multiple comparisons.

Results

Phytochemical analysis of the AAEO: The phytochemical composition of AAEO was previously characterized and reported in our previously published paper, which utilized GC-MS (Rizvi *et al*., 2023). The analysis revealed 38 constituents, accounting for 99.99% of the total oil, with sesquiterpenes at 61.01% and monoterpenes at 17.92% being the dominant classes. The EO yield was 0.46% w/w. The dominant constituents recorded in the EO included guaiol, α-bisabolol, carveol, chamazulene, limonene-6-ol, pivalate, and geranyl α-terpinene (Table 1).

Weight loss and TSS: The primary physical change observed in the apricot fruits during storage was weight loss. This was calculated by subtracting the initial weight from the final weight at different intervals. The weight loss was significant across all treatments, with T0, T1, and T2 showing substantial losses within the first three days. T3 and T4 followed suit by the sixth day, primarily due to fungal growth and moisture loss. However, T5 and T6 exhibited significantly lower weight loss, with values of 3.06 g and 2.64 g, respectively, over the nine days. This reduction in weight loss indicates that the essential oil coatings, particularly in the higher concentrations, helped retain the apricots' mass. Additionally, the total soluble solids (TSS) concentration increased across all samples during the storage period. This increase reflects the natural ripening process, where soluble sugars accumulate. TSS is a physical measure of the sugar content in the fruit, and it was noted that T5 and T6 had lower TSS values (2.58°Bx and 2.25 °Bx, respectively) compared to other treatments by the ninth day (Table 2).

PH, ascorbic acid, total sugar, and titratable acidity: Over the storage duration, the pH of apricots rose in all treatments, with the control group showing a larger and faster increase compared to the other treatments. Over 9 days at ambient temperature, the pH of both coated and uncoated apricots significantly increased from 4.8 to 5.3 (p<0.05). Ascorbic acid levels significantly decreased during storage. The reduction was most pronounced in T5 (from 65.85 ± 0.03 to 62.08 ± 0.05) and T6 (from 65.93 ±

0.02 to 62.17 ± 0.03) over 9 days. Titratable acidity, reflecting the presence of organic acids, also decreased gradually in all treatments. The most significant decrease was observed in T5 (from 2.28 ± 0.09 to 1.87 ± 0.08) and T6 (from 2.27 ± 0.06 to 1.95 ± 0.05) over 9 days. The control sample exhibited a more rapid decline in titratable acidity compared to the treatments (Table 3).

The total sugar content increased overall during storage. The control group exhibited a more rapid increase in sugar content compared to the essential oil treatments. No significant differences were noted between T0 and T1 during the 0-3-day interval. However, between 0 and 6 days, the sugar content rose in T3 and T4 from 64.93 mg/100g to 66.41 mg/100g and from 64.89 mg/100g to 66.38 mg/100g, respectively. Slight increases were observed in T5 and T6 from 64.95 mg/100g to 66.18 mg/100g and from 64.87 mg/100g to 66.17 mg/100g, respectively, over 9 days (Table 3).

Table 1. The phytochemical analysis of *A. absinthium* essential oil collected from the highlands of Skardu, Baltistan (Rizvi *et al*., 2023).

Peak #	RT[a]	Compounds name[b]	Relative %	KI (Exp)[c]	KI (Lit)[d]	ID[e]
1	12.351	Camphor	0.862	1147	1148	MS,RI
2	13.291	Terpinen-4-ol	0.619	1172	1179	MS,RI
3	21.838	Caryophyllene	1.683	1416	1427	MS,RI
4	22.976	Santolinatriene	0.94	1452	---	MS
5	23.811	α-copaene	3.505	1478	1470	MS,RI
6	24.054	Germacrene-D	0.45	1486	---	MS
7	24.754	β-bisabolene	2.669	1508	1505	MS,RI
8	26.599	Caryophyllene oxide	2.102	1570	---	MS,RI
9	26.737	(-)-spathulenol	1.936	1575	1575	MS,RI
10	26.861	α-santalol	3.481	1579	1582	MS,RI
11	27.559	Guaiol	19.33	1602	1596	MS,RI
12	27.837	Cedrol	2.693	1612	1610	MS,RI
13	28.356	4-epi-cubedol	0.676	1631	1627	MS,RI
14	28.64	Cubenol	1.886	1641	1652	MS,RI
15	29.011	γ-eudesmol	1.187	1654	1652	MS,RI
16	29.113	8-epi- γ -eudesmol	1.136	1657	1653	MS,RI
17	29.269	Geranylisobutyrate	2.755	1663	1685	MS
18	29.844	α-bisabolol	8.833	1683	1684	MS,RI
19	31.067	Chamazulene	5.943	1728	1710	MS,RI
20	31.455	Longifolenaldehyde	0.925	1742	---	MS
21	32.355	Methyl hinokiate	0.953	1776	---	MS
22	32.92	Tetrakis(1-methyl)-pyrazine	2.261	1797	1797	MS,RI
24	36.568	Cubedol	1.159	1941	1939	MS,RI
25	36.748	Geranyl-p-cymene	1.629	1948	---	MS
26	37.999	Nerolidol-epoxyacetate	1.123	1999	---	MS
27	38.176	Geranyl-α-terpinene	5.636	2007	---	MS
28	39.549	Spathulenol	0.734	2066	2071	MS,RI
29	40.341	Heneicosane	1.601	2100	2100	MS,RI
30	40.507	Phytol	1.211	2107	---	MS
31	41.557	Limonen-6-ol, pivalate	5.371	2154	---	MS
32	41.721	Carveol	6.167	2161	---	MS
33	43.784	1-ethyl-4-methoxy-benzene	0.633	2256	---	MS
34	43.922	Carvacrol	1.293	2262	2252	MS,RI
35	44.735	Tricosane	1.483	2300	---	MS,RI
36	44.931	1-Heptatriacotanol	1.027	2309	---	MS
37	48.786	Pentacosane	2.102	2500	---	MS
38	52.539	Heptacosane	1.203	2700	---	MS
39	56.106	Nonacosane	0.796	2899	---	MS
		Total identified	99.9			
		Oil yield (%)	0.41			
		Monoterpenes	17.92			
		Sesquiterpenes	61.01			
		Others	21.06			

[a] Retention time.
[b] Compounds are listed in order of their retention time
[c] Retention index relative to C_7-C_{40} *n*-alkanes on a DB-1 (30 m x 0.22 mm i.d., 0.25 µm film thickness)
[e] Identification methods: RI, based on comparison of calculated RI with those reported in Adams or NIST 08 and previous literature

Table 2. Effect of *A. absinthium* essential oil on weight loss and total soluble solids (TSS) of apricots during storage.

Storage time (days)	AAEO concentration	0 days	3 days	6 days	9 days	Mean
Weight loss	T_0 Control	0.00 ± 0 o	10.13±0.97a	ND	ND	5.06 B
	T_1(only emulsion)	0.00 ± 0 o	9.43 ± 0.45 a	ND	ND	4.71 C
	T_2 (1 µL/mL)	0.00 ± 0 o	9.40 ± 0.37 a	ND	ND	4.70 C
	T_3 (2.5 µL /mL)	0.00 ± 0 o	4.12 ± 0.34 ef	5.22 ± 0.09 g	ND	3.11 D
	T_4 (5 µL /mL)	0.00 ± 0 o	4.03 ± 0.23 lm	5.16 ± 0.05 kl	ND	3.06 E
	T_5 (7.5 µL /mL)	0.00 ± 0 o	2.15 ± 0.11 lmn	3.38 ± 0.4 mn	10.02 ± 0.29a	2.64 F
	T_6 (10 µL /mL)	0.00 ± 0 o	2.12 ± 0.11 lmn	3.75 ±.0.02 mn	4.51 ± 0.03 h	2.59 G
TSS	T_0 Control	19.71 ± 1.45w	21.53 ± 0.23b	ND	ND	20.60 A
	T_1(only emulsion)	19.67 ± 0.57w	21.42 ± 0.36b	ND	ND	20.54 B
	T_2 (1 µL /mL)	19.68 ± 0.53w	21.28 ± 0.34b	ND	ND	20.48 C
	T_3 (2.5 µL /mL)	19.67 ± 0.50w	20.88 ±0.32d	22.06 ±0.09kl	ND	20.35 DE
	T_4 (5 µL /mL)	19.64 ±1.41vw	20.63 ± 0.99cd	22.04 ± 0.09jk	ND	20.30 E
	T_5 (7.5 µL /mL)	19.66 ± 0.55w	20.13 ± 0.04kl	21.14 ± 0.04g	21.54 ±0.05jk	20.23 F
	T_6 (10 µL /mL)	19.65 ±0.49wx	20.03 ± 0.97kl	20.97 ± 0.73gh	21.46 ± 0.04l	20.18 G

Mean numbers in the same column followed by the same letter are not significantly different Tukey's, $p<0.05$ test
[a–g] Significant differences at $p<0.05$ level according to Tukey's, $p<0.05$ test
ND not detected due to spoilage

Table 3. Changes in pH, ascorbic acid, titratable acidity, and total sugar content of coated apricots with different concentrations of *A. absinthium* essential oil during storage.

Storage time (days)	AAEO concentration	0 days	3 days	6 days	9 days	Mean
pH	T_0 Control	4.87 ± 0.98h-k	5.05 ± 0.34cde	ND	ND	4.96 A
	T_1(only emulsion)	4.86 ± 0.82cde	5.03 ±0.32c-f	ND		4.95 A
	T_2 (1 µL /mL)	4.86 ± 0.80i-l	5.02 ± 0.29c-g	ND	ND	4.95 A
	T_3 (2.5 µL /mL)	4.86 ± 0.83h-l	4.92 ± 0.23c-g	5.13 ± 0.05h-l	ND	4.91 CD
	T_4 (5 µL /mL)	4.86 ± 0.83i-l	4.91 ± 0.45be-i	5.10 ± 0.07f-j	ND	4.90 CD
	T_5 (7.5 µL /mL)	4.86 ± 0.79i-l	4.89 ± 0.53aa	4.96 ± 0.03a	5.03 ± 0.09bcd	4.89 DE
	T_6 (10 µL /mL)	4.87 ± 0.74h-l	4.88 ± 0.49g-k	4.95 ± 0.02ab	5.02 ± 0.12bcd	4.88 E
Ascorbic acid	T_0 Control	66.07 ± 0.08a	61.10 ± 0.08b-f	ND	ND	63.70 B
	T_1(only emulsion)	66.07 ± 0.82a	61.12 ± 0.06a-f	ND	ND	63.72 C
	T_2 (1 µL /mL)	66.05 ± 0.81a-f	61.14 ± 0.05a-f	ND	ND	63.74 C
	T_3 (2.5 µL /mL)	65.11 ± 0.75a	63.67 ±0.07a-d	61.76 ±0.07a-d	ND	63.48 A
	T_4 (5 µL /mL)	65.07 ±0.72abc	63.84 ± 0.04a-e	61.75 ± 0.05ad	ND	64.12 DE
	T_5 (7.5 µL /mL)	65.85 ±0.70abc	65.02 ± 0.05abc	64.46 ± 0.06a-f	62.08 ± 0.05a-d	64.75 E
	T_6 (10 µL /mL)	65.93 ±0.02ab	65.22 ± 0.03abc	64.57 ±0.03a-f	62.17 ±0.03a-d	64.78 E
Titratable acidity	T_0 Control	2.28 ± 0.11bc	1.98 ± 0.32k	ND	ND	1.07 C
	T_1(only emulsion)	2.32 ± 0.13bc	2.03 ± 0.19jk	ND	ND	1.07 C
	T_2 (1 µL /mL)	2.30 ± 0.09bcd	2.08 ± 0.17ijk	ND	ND	1.07 C
	T_3 (2.5 µL /mL)	2.31 ± 0.19bcd	2.14 ± 0.21f-i	2.03 ± 0.07ijk	ND	1.60 B
	T_4 (5 µL /mL)	2.32 ± 0.10b	2.17 ± 0.17efg	2.07 ± 0.05h-k	ND	1.63 B
	T_5 (7.5 µL /mL)	2.28±0.09bc	2.22 ± 0.18b-e	2.11 ± 0.06g-j	1.87 ± 0.08m	2.12 A
	T_6 (10 µL /mL)	2.27 ± 0.06bcd	2.22 ± 0.15b-e	2.12 ± 0.04f-i	1.95 ± 0.05 l	2.12 A
Total sugar	T_0 Control	64.95 ± 0.01mn	66.78 ± 0.05kl	ND	ND	65.86 A
	T_1(only emulsion)	64.97 ± 0.06mn	66.68 ± 0.0i-l	ND	ND	65.82 A
	T_2 (1 µL /mL)	64.94 ± 0.03mn	66.47 ± 0.09lm	ND	ND	65.70 B
	T_3 (2.5 µL /mL)	64.93 ± 0.05mn	65.51 ± 0.07b l	66.41 ± 0.09cde	ND	65.61 C
	T_4 (5 µL /mL)	64.89 ± 0.06mn	65.47 ± 0.08lm	66.38 ± 0.07d-g	ND	65.58 D
	T_5 (7.5 µL /mL)	64.95 ± 0.05mn	65.22 ± 0.06m	65.65 ± 0.04jkl	66.18 ± 0.04ab	65.32 F
	T_6 (10 µL /mL)	64.87 ± 0.03nm	65.02 ± 0.03mn	65.53 ± 0.02kl	66.17 ± 0.02cde	65.28 G

Mean numbers in the same column followed by the same letter are not significantly different Tukey's, $p<0.05$ test. a–g Significant differences at $p<0.05$ level according to Tukey's, $p<0.05$ test
ND not detected due to spoilage

Table 4. The radical scavenging activity of *Artemisia absinthium* essential oil.

Plant material tested	LC_{50} (mg/mL)	AAI
AAEO	0.291	2.74
Quercetin	0.314	2.54

Sample concentrations: 1 mg/mL; 0.5 mg/mL; 0.1 mg/mL; control
Values are expressed as the mean (n = 3); LC_{50} = concentration resulting in 50% inhibition
AAI antioxidant index
Quercetin was used as a positive control

DPPH assay: The DPPH radical-scavenging activity of AAEO was 0.291 mg/mL with an $LC_{50,}$ which is shown in Table 4. The estimated result was quite close to that of the positive control, quercetin, which had an LC50 of 0.314 mg/mL. According to the antioxidant activity index (AAI), AAEO exhibited the highest antioxidant activity (AAI = 2.75), surpassing that of quercetin (AAI = 2.54).

Antifungal activity: The results indicated that AAEO at 10 µL/mL resulted in 98.23% inhibition of the mycelial

growth of *P. italicum.* The concentration of 1 µL/mL exhibits the minimum inhibitory effect, and increasing the AAEO concentration further enhances the inhibitory effect. However, *P. italicum* was more sensitive than *C. albicans* as the AAEO concentration increased from 0 to 10 µL/mL. Furthermore, our investigation showed that edible coatings containing AAEO in T_5 and T_6 had significant antifungal activity against *P. italicum* and *C. albicans,* as shown (Table 5).

Anti-bacterial activity: The antibacterial activity of AAEO was presented in Table 6. Each concentration of essential oil curtailed the proliferation of bacterial species, with the area of inhibition expanding as the concentration of essential oil increased. The essential oil concentration of 5µL inhibited *E. coli* growth, with an area of inhibition of 12 ± 0.02 mm. In contrast, the zone of inhibition was 15 ± 0.87 mm for 10 µL and 22 ± 0.09 mm for 15 µL, which was equivalent to the standard control. The zone of inhibition against *S. aureus* was 14 ± 0.33, 16 ± 0.23, and 20 ± 0.65 mm for concentrations of 5 µL, 10 µL, and 15µL, respectively. Similarly, against *P. mirabilis,* the zone of inhibition was calculated as (13 ± 0.09), (15 ± 0.99), and (18 ± 0.19) mm, which were considerably lower than the standards used.

Table 5. Anti-fungal activity of *Artemisia absinthium* essential oil.

Concentration (µL/ mL) of AAEO	*P. italicum* growth inhibition (%)	*C. albicans* growth inhibition (%)
0.00	0.00a ± 0.00	0.00a ± 0.00
1.00	6.76b ± 2.98	4.76b ± 3.92
2.50	54.32c ± 2.12	21.03c ± 2.90
5.00	63.65d ± 1.76	39.65d ± 1.43
7.50	80.02e ± 0.87	64.01e ± 1.43
10.0	98.23 f ± 0.83	85.76f ± 0.98

[a–f] Significant differences according to Tukey's, $p<0.05$
Values are presented as mean ± SD

Table 6. Anti-bacterial activity of *Artemisia absinthium* essential oil.

Species	Zone of inhibition (mm)				
	AAEO (µL/ mL)			Standards	
	5	10	15	Azithromycin 25 µg	Ciprofloxin25 µg
E. coli	12 ± 0.02	15 ± 0.87	22 ± 0.09	22 ± 0.09	50 ± 0.04
S. aureus	14 ± 0.33	16 ± 0.23	20 ± 0.65	31 ± 1.2	42 ± 0.06
P. mirabilis	13 ± 0.09	15 ± 0.99	18 ± 0.19	41 ± 1.3	50 ± 0.09

Values are presented as mean ± SD
Azithromycin and Ciprofloxin were used as positive controls

Discussion

Essential oils have complex chemistry, dominated by biologically active monoterpenes and sesquiterpenes (Hegazy *et al*., 2025). These compounds have diverse uses as food additives, preservatives, antimicrobial agents, medicines, and pesticides (Ben Miri, 2025). Essential oils from various plant parts (flowers, leaves, roots) enhance flavor and aroma in foods, cosmetics, and other products (Sobhy *et al*., 2025). More than 300 EOs from families like *Asteraceae, Lamiaceae*, and *Verbenaceae* are used globally (de Sousa *et al*., 2023). Recent trends focus on developing eco-friendly coating materials to enhance the shelf life of fruits and vegetables (Dong *et al*., 2024). Plant extracts and EOs are ideal due to their non-toxic and eco-friendly nature (Ju *et al*., 2019). Our current study aimed to investigate the effect of AAEO coating on the shelf life of fresh apricots. Similarly, the genus *Asteraceae* contains biologically active terpenes with various biological activities (Maurya *et al*., 2021). The EO chemical composition of the same species of plants grown under different geographical and climatic conditions exhibited variations, as well as other biological activities (Lechkova *et al*., 2024). Similarly, our previous study reported that the AAEO composition includes thujone, guaiol, α-bisabolol, carveol, chamazulene, and caryophyllene (Table 1) (Rizvi *et al*., 2023).

Our present research agrees with the findings of (Mditshwa *et al*., 2023), who studied that the edible coating formulation includes Arabic gum, lemongrass oil, sodium caseinate, and cinnamon oil applied on guava fruit during storage, and they affect sugar and firmness, slowly increasing and enhancing shelf life up to 40 days. Similarly, in our research work, the edible coating of AAEO also improved the shelf life of apricots during a nine-day storage period, when trials were kept at room temperature. In contrast, the wholesomeness of the coated apricots declined gradually from 3 to 6 days of storage in T1, T2, T3, and T4. Additionally, apricots in T_5 and T_6 with concentrations (7.5 and 10 µL/mL) of AAEO were significantly influenced by the total sugar content, titratable acidity, ascorbic acid, pH, TSS, and shelf life of fresh apricots during the storage period of up to 9 days. We found that TSS increases more in the control group as compared to the treatment group. TSS increases due to conversion into simple sugar from carbohydrates and softening of tissue due to the formation of sugar (soluble) such as fructose, glucose, and sucrose in apricots (Xu *et al*., 2021). We found that the pH in the control group increased rapidly compared to the treatment groups during the storage interval. Similarly, another study found that the pH value of fresh mangoes during storage did not show significant variation in coated mangoes with a nano-

multilayer alginate-chitosan coating. In contrast, in the control, the concentration gradually increased over time (Boonsiriwit *et al*., 2021). The amount of ascorbic acid continuously decreases in control and coated apricots due to metabolic reactions, autoxidation, and the conversion of organic acid into sugar during respiration (Shaukat *et al*., 2023). Similarly, we found that the amount of Ascorbic acid in fresh apricots was lost more rapidly than in coated apricots with increased storage time. Regarding titratable acidity, it was recorded that the coated apricot slowly declines in acidity compared to the uncoated apricot. Our results regarding titratable acidity followed the previous work (Singh, 2024). Similarly, a 2% calcium chloride (CaCl2) solution in distilled water extends the shelf life of apricot fruit stored at 4°C ± 1°C for 21 days (Khaliq *et al*., 2023). Our results indicated that AAEO at a 10 µL concentration increases the shelf life of apricots by 9 days under ambient temperature, with the added benefit of being eco-friendly and safe for consumption compared to calcium chloride.

Due to the high value of their antioxidant activity, aromatic plant extracts are widely utilized in the food industry as a preservative (Skendi *et al*., 2022). In our study, the AAEO exhibited a higher antioxidant activity index compared to quercetin, used as a control. Our investigation revealed that AAEO has antifungal properties against *P. italicum* and *C. albicans.* Previously*,* AAEO had demonstrated positive results in inhibiting mold growth, specifically that of *Candida*, *Aspergillus,* and *Fusarium* spp. (Tian *et al*., 2022), and act as a fumigant to protect the stored products (Grzyb *et al*., 2025). Similarly, previous studies indicated that chamazulene has a strong antifungal effect (Svetlana Vasylievna *et al*., 2015). The EO in our study was also dominated by chamazulene (5.94%), which may be the possible reason for having strong antifungal activity against fungal strains.

The extracted oil from *A. absinthium* exhibited a growth-inhibitory effect on our selected bacterial strains. We observed that as the essential oil content increased, the oil's ability to suppress bacterial growth also increased. According to previous studies, various varieties of *Artemisia* essential oil have been shown to possess antibacterial activity (Mashraqi *et al*., 2024). The effect of inhibiting the growth of bacterial and fungal strands is due to the presence of significant components. In our study, the major components of AAEO were guaiol, α-bisabolol, carveol, chamazulene, limonene-6-ol, pivalate, and geranyl-α-terpinene. Similarly, previous studies reported that these dominant constituents in EO exhibited antimicrobial and antifungal activities (Akhtar and Kumar, 2025). Essential oils exhibit various mechanisms to extend the shelf life of fruits and display antimicrobial activity (Milutinović, 2024). They can inhibit ethylene production, reducing fruit ripening and senescence (Alonso-Salinas *et al*., 2024). Essential oils rich in antioxidants, such as tea tree oil and rosemary oil, can scavenge free radicals and reduce oxidative stress (Reddy *et al*., 2025). Furthermore, EOs such as cinnamon, clove, and oregano can damage bacterial cell membranes, cause cell lysis, and ultimately lead to cell death (Yousuf *et al*., 2021). They can also inhibit enzymes essential for microbial growth and survival (Perumal *et al*., 2022) and interfere with quorum sensing, a process that regulates microbial behavior and communication (Yousefi *et al*., 2024). In developing countries, this approach can be advantageous in extending the shelf life of fruits at a more affordable price, particularly in cases where synthetic food additives and preservatives are not readily accessible. Essential oils are of utmost significance globally for ensuring food safety and purity, and they positively impact human health.

The AAEO from Skardu, Baltistan, Pakistan, is rich in guaiol, α-bisabolol, carveol, and chamazulene. At concentrations of 7.5 µL/mL and 10 µL/mL, it effectively extended the shelf life of apricots stored at room temperature while preserving their quality parameters. The AAEO antioxidant and antimicrobial properties likely contributed to this extension. Future research should focus on developing cost-effective and safe EO formulations, such as nano-emulsions, encapsulation, and nanoparticles, for human use (Khaliq *et al*., 2023).

Authors' contributions

Conceptualization: SAHR and RB. **Data curation:** SAHR, RB, and KH. **Formal analysis RB and KH**. **Funding acquisition:** SAHR, FAAM, and MAW. **Investigation:** SAHR, **RB, and KH. Methodology:** RB and SAHR. **Project administration:** SAHR. **Supervision:** SAHR. **Writing-original draft:** RB and KH. **Writing-review & editing:** SAHR and RB.

Data availability: The data sets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Declaration of use of AI Technologies: All the authors declare that we have complied with the relevant guidelines and regulations regarding the use of AI technologies in academic research.

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