Effect of thyme essential oil and ethanol on vase life and some physiological traits of alstroemeria (*Alstroemeria* sp.)

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Abstract

Alstroemeria (*Alstroemeria* sp.) is a permanent herbaceous plant species. Fast yellowing of alstroemeria leaves after harvest and before petal shedding is the main factor limiting their vase life. This research investigated the effect of thyme essential oil (0, 50, 100, and 200 mg/L) and ethanol (0, 1, 2, and 4%) on retarding the senescence of cut alstroemeria flowers in a factorial experiment. Various quantitative and qualitative traits particularly vase life, flower opening index, water uptake, fresh weight loss, dry weight percentage, and vase solution and stem-end bacteria population were measured. Thyme essential oil at a concentration of 200 mg/L without ethanol application was most influential on vase life, reduction of bacteria population, and water uptake and exhibited almost acceptable dry weight and flower opening rate. Overall, it is concluded that the suitable application of thyme and ethanol at proper rates is effective in extending the vase life of alstroemeria.

Keywords: carotenoid, chlorophyll, cut flowers, postharvest life, senescence

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Introduction

Alstroemeria (*Alstroemeria* sp.) is a monocot annual or perennial plant from the family Liliaceae (Ghasemi Ghahsareh and Kafi, 2010). This species is popular for its beautiful flowers in a wide range of colors, cold resistance, proper flowering duration and period, and high yield (Banjaw et al., 2017). Cut alstroemeria flowers have recently found a special place in Iran. The fast yellowing of alstroemeria leaves after harvest is the main limiting factor for the vase life in this species (Isapareh et al., 2016).

Various studies have been conducted to identify the physiological needs of flowers, factors affecting the longevity of cut flowers, and chemicals and non-chemicals that can somehow increase their vase lives. On the other hand, due to the adverse environmental impacts of chemicals and sometimes their high prices, researchers have tried to achieve harmless/less harmful and easy-to-access organic products (Vehniwal and Abbey, 2019). In this regard, water balance is a decisive factor determining the quality and longevity of cut flowers. Water stress is induced by the increased level of

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evapotranspiration and vascular blockage, but the main cause of water deficiency is the blockage of the cut flower's stem end by microbes and microorganisms (Basiri et al., 2011). Different disinfectants are used to prevent or reduce microbial contamination of vase solutions.

The use of plant essential oils in the vase solution as an antibacterial and disinfectant agent is a relatively novel idea (Solgi et al., 2009). Since flowers open, their sensitivity to ethylene increases gradually. In alstroemeria, ethylene is involved in flower aging and their ethylene sensitivity increases as aging progresses. Accumulation of bacteria at the stem-end and/or in the vase solution reduces the vase life of cut carnation due to the vascular blockage. The growth of microorganisms and their accumulation in the preservative solutions of cut flowers causes stem blockage, endogenous ethylene synthesis, production of toxins, and finally, acceleration of petal aging (Liu et al., 2009).

Essential oils are the active ingredients of some medicinal plants, which are natural and decomposable. These plant compounds have antimicrobial activity since they contain high concentrations of phenol compounds, e.g., carvacrol, thymol, and eugenol (Khosravi et al., 2016). The use of plant essential oils has been recommended as natural compounds and alternatives for chemicals commonly used in the vase solutions of gerbera (Solgi et al., 2009), rose (Marandi et al., 2011), carnation (Bayat et al., 2011; Bayat et al., 2012), and alstroemeria (Bazaz and Tehranifar, 2011).

Thyme (*Thymus* sp.) is a perennial small-sized plant with thin stems. The fatty essential oil of this species varies with its application, but oils that contain high amounts of thymol and carvacrol are usually known as good oils. Thyme oil and thymol are very strong antibiotics so that thymol is 25 times as strong as phenols (Safaei Khoram et al., 2011). The using thyme essential oils to extend vase life of cut flowers has been reported in the literature [(Oraee et al., 2015), (Solgi et al., 2009); (Tahmasbi Notorki et al., 2011), (Mousavi Bazaz et al., 2011),(Salehi Sardoei, 2013) Fazlalizadeh et al., 2013).

Ethanol is a preservative compound that inhibits ethylene synthesis and reduces ethylene sensitivity. It is also believed that ethanol hinders ethylene production by synthesizing aminocyclopropane-1-carboxylic acid (Patel et al., 2018). Sani et al. (2011) reported that ethanol significantly extended the longevity of cut *Anthurium* flowers. This alcohol acts as an aging inhibitor by mitigating the harmful effects of ethylene, thereby preventing stem-end vascular blockage in the flowers. The present study aimed to explore the effect of ethanol and thyme essential oil as disinfectants in the vase solution on the longevity and some physiological traits of cut alstroemeria in order to introduce the best treatments.

Materials and Methods

This research was conducted as a factorial experiment based on a completely randomized design with 16 treatments including ethanol (at four levels of 0, 10, 20, and 40 mg/L equivalent to 0, 1, 2, and 4%, respectively), and thyme essential oil (at four levels of 0, 50, 100, and 200 mg/L), as well as a control treatment, in three replications and 48 plots, each containing five flowers.

Plant materials

Alstroemeria (*Alstroemeria* sp.) cut flowers were purchased from a commercial producer in Tehran. The harvested flowers were put in a commercial package (separately) and were transported in flower-carrying cartons to the postharvest laboratory of the Islamic Azad University, Rasht Branch during the night. The time interval between the harvest and treatment applications were less than 24 hours. All flowers with two semi-open buds were recut at a height of 52 cm to prevent vascular blockage. Then, the lower leaves in each branch were removed, retaining the higher leaves. After weighing, flowers were put in a vase solution containing distilled water and ethanol and essential oil disinfectant at the pulse step and distilled water and 3% sucrose after the pulse step. Five flowers were placed in plastic pots with the capacity of 0.5 liter and were treated with ethanol and thyme essential oil in a pulsed manner.

Flower storage characteristics

The cut flowers were kept at 20±2 ℃, 65-70% humidity, 15-20 µmol/s/m^2 light, and 12 h of day length. The number of experimental days was equal to the number of the flower vase life.

Vase life

Vase life was recorded in days at the end of the experiment (the withering of the last flower per plot) based on the emergence of such symptoms as petal folding and flower wilting, which led to the loss of attractiveness and marketability.

Water uptake

Evaporation from the surface of the preservative solution was measured using some distilled water-containing vases at the study site. To determine the uptake of water or vase solution, the amount of evaporation and the decline in the vase water were measured with a graduated cylinder. Then, the water uptake by the cut flowers was obtained through the following equation using their mean fresh weight on the first day of the experiment:

$$\text{Solution uptake (ml/g FW)} = \frac{V_{t0} - (E_t + V_{t1})}{FW}$$

in which *Vt0* represents the initial volume of the vase solution (500 mL), *Et* represents mean evaporation from the solution surface, *Vt1* represents the volume of solution remaining on the last day, and *FW* represents the fresh weight of the flowers on the first day.

Fresh weight loss

The cut flowers were weighed with a digital scale at the end of their vase life to determine the fresh weight. Given the initial flower weight and the recut weights, the decline in their fresh weight was obtained by the following equation:

FW decline = Initial FW – (Final FW + Recut weights + Weight of falling parts)

The criterion for withering was the folding of petals to their inside. The bending of 50% of petals, wilting, and paleness signaled the end of vase life.

Dry matter percentage

The fresh weight of the flowers was determined at the end of the vase life. They were oven-dried at 70 ℃ for 24 hours. After weighing, the flowers were put in the oven again and re-weighed 24 hours later. Since no change was observed in the weight of the dried flowers during the 24 hours, they were not put in the oven for another 24 hours. In other words, the samples completely dried in the first 24 hours. The dry matter (DM) percentage of the cut flowers was obtained from the following equation (SADEGHI and Hashemabadi, 2016):

DM% = (DM at the end of vase life/FW) × 100

Decline in degrees Brix (sucrose percentage of the flower branch)

To obtain degrees Brix, small cuts were made at the end of the branches. One or two drops of water in these cuts were put on the glass plate of an ATAGO N-1a refractometer (Japan), and its degrees Brix was read. The decline in degrees Brix was obtained by subtracting the last-day degrees Brix from the first-day degrees Brix.

Stem-end bacteria

Twenty-four hours after the application of the treatments, about 2 cm was cut from the stem end. The samples were washed in deionized water three times to reduce their microbial level. Then, they were crushed and diluted with 0.9% normal saline solution. Then, 0.1 of the solution was put on agar, and the bacterial colonies were counted 24 hours after being kept at 37 ℃ (Liu et al., 2009).

Preservative solution bacteria

Twenty-four hours after applying the treatments, the vase solution was sampled and diluted with 0.9% normal saline solution to reach a population of 30-300 bacterial colonies in each Petri dish. Then, 0.1 mL of the solution was put on agar, and its bacterial colonies were counted after storing at 37 ℃ for 24 hours (Oraee et al., 2011).

Flower opening index (FOI)

FOI was determined by the following equation (SADEGHI and Hashemabadi, 2016):

Table 1
Analysis of variance for the effect of different treatments on the measured traits

S.O.V	Df	Vase life	Fresh weight	Dry weight	Water uptake	Solution bacterium	Stem-end bacterium
Thyme essential oil	3	5.5 ^{ns}	41.59 **	2.62 *	0.045 **	1304.68 **	338.94 **
Ethanol	3	22.15 **	37.38 **	4.50 **	0.029 **	14.18 ^{ns}	2193.38 **
Thyme essential oil × ethanol	9	14.87 **	43.75 *	4.86 **	0.043 **	101.83 *	1056.85 **
Error	32	1.98	0.33	0.74	0.000098	33.77	46.66
C.V. (%)	-	7.15	24.67	6.88	0.61	37.34	22.40

** and * denote significant at 1% and 5% probability levels, respectively; ^{ns} means non-significant.

FOI = (number of closed flowers on the last day ÷ number of open flowers on the last day) ÷ (number of closed flowers on the first day ÷ number of open flowers on the first day)

Petal carotenoids

To extract carotenoids, one flower per plot was sampled on day 5, and its petal carotenoid was determined by the method described in Mazumdar and Majumdar (Mazumdar and Majumder, 2003). On day 5, some symptoms of withering were visible on some petals, but the flowers were not wilted. To this end, 0.5 g of the petal tissue was extracted with 50 mL of 80% acetone (80 mL of acetone and 20 mL of distilled water) in a china mortar. The solution was infiltrated with Whatman filter paper. Then, the absorbance was read at 440, 645, and 663 nm with a spectrophotometer. Finally, carotenoid content was calculated in µg/g FW using the following equation:

Carotenoid = 4.69 + A_{440} – 0.268 × (20.2) (A_{645}) + (8.02) (A_{663})

Chlorophyll *a*, *b*, and total

To extract chlorophyll, one flower per plot was sampled on day 5 to measure chlorophyll *a*, *b*, and total of the leaves by the method of Mazumdar and Majumdar (2003). To this end, 0.5 g of the leaf tissue was extracted with 50 mL of 80% acetone (80 mL of acetone and 20 mL of distilled water) in a China mortar. The solution was infiltrated with Whatman filter paper. Then, the absorbance was read at 660 and 643 nm with a spectrophotometer, and the chlorophyll *a*, *b*, and total chlorophyll contents of the leaves were calculated in mg/g FW using the following equations:

Chlorophyll *a* = 9.93 (A_{660}) – 0.777 (A_{643}); Chlorophyll *b* = 17.6 (A_{643}) – 2.81 (A_{660}); Total chlorophyll = 7.12 (A_{660}) – 16.8 (A_{643})

Data Analysis

The data were analyzed using the MSTATC software package, and the means were compared by the LSD test at P<0.05.

Results

The analysis of variance (ANOVA) for the effect of different treatments on the recorded traits showed that except for the effect of thyme essential oil on vase life and fresh weight and the effect of ethanol on solution bacterial content, all other measured traits exhibited significant differences at the P<0.01 and P<0.05 levels (Table 1).

Based on ANOVA, the interactive effects of the treatments were statistically significant (P<0.01) on all measured traits of the alstroemerias (Tables 1 and 3). The comparison of means showed that the treatments of 200 mg/L thyme essential oil with no ethanol (with a vase life of 23.33 days), 100 mg/L thyme essential oil with no ethanol, and no thyme essential oil with 2% ethanol were the most effective treatments in prolonging vase life versus the control. The first treatment increased vase life by 95.24% compared to the control. But, these three treatments did not differ significantly. The least efficient treatments in increasing vase life were no thyme essential oil with 4% ethanol and 50 mg/L thyme essential oil with 1% ethanol, which were related to vase lives of 33.15 and 16

Table 2
The comparison of means for the effect of thyme essential oil and ethanol on the measured traits

Treatments		Vase life (day)	Decrease in Fresh Weight (g)	Dry Weight (%)	Water Uptake (mg g-1 FW)	Solution Bacterium (Log_{10} CFU ml^{-1})	Stem end Bacterium (Log_{10} CFU ml^{-1})
Thyme Essential Oil (mg/L)	Ethanol (%)						
0.00	0.00	18.67 def	14.66 a	13.17 abcd	1.34 i	350.00 a	710.00 a
0.00	1.00	19.76 cd	14.08 a	13.93 ab	1.40 i	100.67 de	120.33 e
0.00	2.00	21.33 abc	6.79 d	11.45 efg	1.80 a	60.67 e	100.00 e
0.00	4.00	15.33 f	11.23 abc	12.58 bcde	1.64 f	300.00 ab	680.33 a
50.00	0.00	19.33 cd	11.67 ab	13.17 abcd	1.54 g	130.00 de	350.33 d
50.00	1.00	16.00 f	8.46 bcd	10.79 fg	1.45 h	300.00 ab	590.67 ab
50.00	2.00	21.67 abc	11.46 abc	13.34 abcd	1.69 de	60.67 e	70.67 e
50.00	4.00	20.00 bcd	5.70 d	12.06 def	1.67 e	100.00 e	110.33 e
100.00	0.00	22.33 ab	9.51 bcd	14.09 a	1.70 cd	60.67 e	60.67 e
100.00	1.00	19.33 cd	9.35 bcd	13.84 abc	1.75 b	200.00 cd	420.00 cd
100.00	2.00	20.67 bcd	8.70 bcd	12.43 cde	1.69 de	70.33 e	100.33 e
100.00	4.00	20.33 bcd	9.36 bcd	11.46 efg	1.71 c	90.47 e	110.00 e
200.00	0.00	23.33 a	9.38 bcd	13.05 abcd	1.79 a	30.67 e	50.33 e
200.00	1.00	19.33 cd	9.33 bcd	10.63 g	1.69 de	120.33 de	300.67 d
200.00	2.00	16.67 ef	7.53 cd	10.55 g	1.53 g	260.00 abc	560.33 b
200.00	4.00	18.67 def	7.57 cd	13.43 abcd	1.68 e	230.67 bc	500.00 bc

In each column, means with the similar letters are not significantly different at 5% probably level based on LSD test.

Table 3
Analysis of variance for the effect of different treatments on the measured traits

S.O.V	Df	Decrease in °Brix	Flower opening process	Carotenoi	Chlorophyll a	Chlorophyll b	Total chlorophyll
Thyme essential oil	3	4.75 **	0.03 **	0.004 **	8.69 **	1.05 **	15.29 **
Ethanol	3	0.774 **	0.015 **	0.001 **	10.65 **	1.04 **	19.91 **
Thyme essential oil × ethanol	9	1.202 **	0.006 **	0.001 **	4.39 **	0.76 **	8.39 **
Error	32	0.014	0.001	0.00	0.18	0.0	0.002
C.V. (%)	-	9.04	5.50	3.59	10.50	0.92	0.78

** and * show significant at 1% and 5% probability levels, respectively; ns means non-significant.

days versus the control whose vase life was recorded as 67.18 days. These two treatments did not differ significantly either (Table 2).

According to the comparison of means, the control and the treatments involving no thyme essential oil with 1% ethanol, no thyme essential oil with 4% ethanol, 50 mg/L thyme essential oil with no ethanol, and 50 mg/L thyme essential oil with 2% ethanol did not differ significantly and were classified in the same statistical group as they were marked with similar letters. These treatments all exhibited the highest decline in fresh weight. On the other hand, the lowest decline was observed in the treatments of 50 mg/L thyme essential oil with 4% ethanol, 0 mg/L thyme essential oil with 2% ethanol, 50 mg/L thyme essential oil with 1% ethanol, 100 mg/L thyme essential oil without ethanol, 100 mg/L thyme essential oil with 1% ethanol, 100 mg/L thyme essential oil with 2% ethanol, 100 mg/L thyme essential oil with 4% ethanol, 200 mg/L thyme essential oil without ethanol, 200 mg/L thyme essential oil with 1% ethanol, 200 mg/L thyme essential oil with 2% ethanol, and 100 mg/L thyme essential oil with 4% ethanol. These treatment were no significantly different from one another (Table 2).

The comparison of means showed that the maximum dry matter (14.09%) was related to the treatment involving 100 mg/L thyme essential oil without ethanol. However, this treatment did not significantly differ from the other treatments except the treatments with 0 mg/L thyme essential oil and 4% ethanol, 50 mg/L thyme

Table 4
Comparison of means for the effect of thyme essential oil and ethanol on the measured traits

Treatments		Decrease	Flower Opening	Carotenoid	Chlorophyll *a*	Chlorophyll *b*	Total chlorophyll
Thyme Essential Oil (mg/L)	Ethanol (%)	in °Brix (%)	Process	(µg g^{-1} FW)	(mg g^{-1} FW)	(mg g^{-1} FW)	(mg g^{-1} FW)
0.00	0.00	0.58 gh	0.50 bcde	0.096 bc	3.62 efgh	1.42 j	4.68 j
0.00	1.00	0.47 h	0.48 de	0.48 gh	4.38 c	1.78 f	6.16 e
0.00	2.00	1.08 ef	0.39 g	0.64 fg	5.09 b	1.99 d	7.09 d
0.00	4.00	1.45 d	0.39 g	0.086 cde	3.42 efgh	1.73 g	5.15 h
50.00	0.00	0.47 h	0.53 bcd	0. 138 a	3.57 defg	1.96 e	5.52 f
50.00	1.00	2.34 b	0.45 ef	0.093 bcd	2.89 ghi	1.37 f	4.24 l
50.00	2.00	0.57 gh	0.053 bcd	0.108 b	2.53 i	1.30 l	3.83 n
50.00	4.00	1.00 f	0.41 fg	0.073 ef	2.85 hi	1.32 l	4.16 m
100.00	0.00	1.23 e	0.49 cde	0.075 ef	3.02 fghi	1.45 i	4.48 k
100.00	1.00	1.11ef	0.47 e	0.076def	3.74 cde	1.79 f	5.54 f
100.00	2.00	0.73 g	0.48 de	0.075 ef	6.32 a	2.33 c	8.64 c
100.00	4.00	0.75 g	0.46 ef	0.079 def	4.26 cd	1.78 f	5.02 i
200.00	0.00	1.48 d	0.54 bc	0.046 h	2.50 i	1.31 l	3.81 n
200.00	1.00	1.87 c	0.65 a	0.049 gh	6.94 a	3.08 a	10.01 a
200.00	2.00	2.80 a	0.55 b	0.044 h	6.84 a	2.88 b	9.71 b
200.00	4.00	2.77 a	0.50 bcde	0.086 cde	3.74 cdef	1.53 h	5.27 g

In each column, means with the similar letters are not significantly different at 5% probably level based on LSD test.

essential oil with 1% ethanol, 50 mg/L thyme essential oil with 4% ethanol, 20 mg/L thyme essential oil with 1% ethanol, 40 mg/L thyme essential oil with 1% ethanol, 200 mg/L thyme essential oil with 1% ethanol, and 200 mg/L thyme essential oil with 2% ethanol. The lowest dry matter (10.63 and 10.55 g) was obtained from 200 mg/L thyme essential oil with 1% ethanol and 200 mg/L thyme essential oil with 20 mg treatments, respectively (Table 2).

The highest water uptake was related to 0 mg/L thyme essential oil with 2% ethanol and 200 mg/L thyme essential oil with 0 mg/L ethanol (8.1 and 79.1 mg/g FW, respectively), not differing significantly from one another while they were significantly different from the other treatments of the study. The lowest water uptake was 40.1 mg/g FW related to 0 mg/L thyme essential oil with 1% ethanol, showing an insignificant difference from the control but significant differences from the other treatments of the study (Table 2).

Comparison of means indicated that the highest vase solution bacterial pollution (350 Log_{10} CFU mL) was observed in the control, and the lowest bacterium count (67.30 Log_{10} CFU mL) belonged to 200 mg/L thyme essential oil without ethanol, which was 23.91% lower than that of the control. Also, the highest stem-end bacterium population was 710 Log_{10} CFU mL related to the control while the lowest record (33.50 Log_{10} CFU mL) was related to 200 mg/L thyme essential oil with 0 mg/L ethanol, 91.92% lower than that of the control (Table 2).

Comparison of means also showed that the highest value of °Brix was related to 200 mg/L thyme essential oil with 2% ethanol and 200 mg/L thyme essential oil with 4% ethanol, showing no significant difference from one another while both were significantly different from the other treatments of the study. The lowest record was obtained from 0 mg/L thyme essential oil with 1% ethanol and 50 mg/L thyme essential oil without ethanol, differing from one another and also 50 mg/L thyme essential oil with 2% ethanol not significantly different from these treatments while being significantly different from the other treatments of the study (Table 4).

The highest FOI was obtained from 200 mg/L thyme essential oil with 1% ethanol, which was different from the other treatments significantly, and the lowest index was recorded in 0 mg/L thyme essential oil with 2% ethanol and 0 mg/L thyme essential oil with 4% ethanol treatments, differing from one another insignificantly but

being significantly different from the other treatments of the study (Table 4).

The comparison of means showed that the highest carotenoid content was related to the treatment involving 50 mg/L thyme essential oil without ethanol, which differed from all other treatments, significantly. The lowest concentration was obtained in the treatments containing 200 mg/L thyme essential oil without ethanol and 200 mg/L thyme essential oil with 2% ethanol. These two treatments showed no significant differences from one another and from the interactions of 0 mg/L thyme essential oil with 1% ethanol and 200 mg/L thyme essential oil with 1% ethanol (Table 4).

Comparison of means for the data on chlorophyll *a* revealed that the highest value was related to the interaction of 200 mg/L thyme essential oil with 1% ethanol, but it did not differ from 200 mg/L thyme essential oil with 2% ethanol significantly. Moreover, comparison of means for the data on chlorophyll *b* showed that 200 mg/L thyme essential oil with 1% ethanol resulted in the highest level of chlorophyll *b*, differing from all other treatments significantly. On the other hand, the lowest level of chlorophyll *b* was obtained from 50 mg/L thyme essential oil with 2% ethanol albeit showing no significant differences from treatments involving 50 mg/L thyme essential oil with 4% ethanol and 200 mg/L thyme essential oil without ethanol. In addition, the highest total chlorophyll content was obtained from 200 mg/L thyme essential oil with 1% ethanol, differing from all other treatments significantly, whereas the lowest total chlorophyll content was related to 50 mg/L thyme essential oil with 1% ethanol and 200 mg/L thyme essential oil without ethanol, differing from one another insignificantly but showing significant differences from the other treatments of the study (Table 4).

Discussion

The most important effect of plant essential oils is the prolongation of longevity, which is related to its antimicrobial activity and the inhibition of the growth of microorganisms and subsequently, the inhibition of xylem blockage (Shanan, 2012). Mousavi Bazaz et al. (2011) showed that the use of peppermint essential oil at the concentration of 50 mg/L extended alstroemeria vase life by 2.03 days. Thyme essential oil increased preservative solution uptake and improved rose flower diameter and weight. It also reduced the withering of flowers and leaves, thereby increasing vase life, significantly (Mirdehghan et al., 2013). Plant essential oils containing carvacrol and thymol had positive effects as antimicrobial compounds on the vase life and quality of cut gerbera flowers (Solgi et al., 2009). The essential oil of dill and black cumin increased water uptake, relative flower weight, and vase solution of waxflowers (Damunupola et al., 2010). Also, the essential oil of bitter oranges and Lawson cypress extended the vase life of alstroemerias (Razi, 2017). These studies agree with our findings regarding the significant effect of thyme essential oil on the vase life of cut alstroemerias. Bayat et al. (2011) reported that the treatments including the essential oils of *Thymus vulgaris*, *Satureja hortensis*, and *Carum copticum* and also combined treatments of ethanol and essential oils did not influence the vase life and marketability of carnations significantly, which is inconsistent with our findings regarding the effect of thyme but is consistent with our findings regarding the effect of ethanol. Sani et al. (2011) found that different concentrations of ethanol significantly extended the vase life of cut Anthurium flowers, which is consistent with our results.

Ethanol increased the fresh weight of cut *Anthurium* flowers (Sani et al., 2011). The effect of ethanol and methanol on cut carnations showed that the relative fresh weight and relative development of the flowers had a positive and significant correlation with their longevity (Sani et al., 2011). Mousavi Bazaz and Tehranifar (2011) reported an increase in the fresh weight of cut alstroemeria flowers with the use of plant essential oils in the vase solution. Application of plant essential oils in the preservative solution of cut roses cv. 'Grand' improved their fresh weight by improvement in water relations (Shanan, 2012). The use of 500 mg/L of *Carum capticum* essential oil increased the fresh weight of cut roses versus the control ((Marandi et al., 2011). All these reports about the effect of plant essential oils on increasing fresh weight were consistent with the results of the present study.

The antibacterial and antifungal effects of plant essential oils are related to their chemical compounds, such as alcohol, phenols, aldehydes, etc. Essential oil of Indian carnations, cinnamon, ginger, and fennel reduced microbe populations and extended the longevity of cut gladiolus flowers (Hegazi and Gan, 2009). The essential oils of fennels, geraniums, lavender, and basil reduced xylem blockage, and cinnamon essential oil reduced microbial population (Shanan, 2012). Plant essential oils inhibit microbial activity by their antimicrobial effect and disrupting the functioning of the respiratory chain in pathogens and eventually kills them (Solgi et al., 2009). Hosseini Darvishan et al. (2012) found that the use of rosemary and thyme essential oils influenced the flower opening of cut roses significantly and positively. In a study on the effect of *Carum copticum* and *Satureja hortensis* essential oils, Jalili Marandi et al. (2011) demonstrated that the use of these disinfectants improved the FOI of cut roses compared to the control. These findings are in agreement with our results as to the effect of ethanol and plant essential oils on improving the FOI of cut flowers.

A decisive indicator of postharvest quality of cut flowers and their marketability is the pigments of plant petals. The most important pigments, which are important for the longevity of cut flowers, are carotenoids and anthocyanins (Hassanpour Asil and Karimi, 2010). Antimicrobial compounds were effective in preserving pigments in cut carnation (Kazemi and Ameri, 2012). The application of disinfectants at low rates increased the pigment contents of cut gladiolus flowers (Mohammadi et al., 2011). Applying 10 mg/L SNP + 50 mg/L *Thymus daenensis* essential oil + 4% sucrose was related to the highest carotenoid content of *Lilium* cut flowers (Tahmasbi Notorki et al., 2011). Zamani et al. (2011) found that the use of vase life-prolonging compounds was effective in preserving and increasing the pigments of cut chrysanthemums. These findings corroborate our results. Thyme essential oil increased chlorophyll content in cut chrysanthemums (Zabihi et al., 2013). Lisianthus cut flowers exhibited the highest significant increase in leaf chlorophyll when treated with 50 ppm thyme essential oil (Pouria Nejad et al., 2012). The essential oils of cinnamon and carnation preserved leaf greenness index of cut alstroemerias cv. 'Jamaica' (Fazlalizadeh et al., 2013). The use of disinfectants and thyme essential oil in the preservative solutions of lisianthus cut flowers increased their chlorophyll contents (Kazemi et al., 2012)). The role of disinfectants in preserving the pigments of cut flowers can be attributed to their positive effect on inhibiting the activity of microorganisms and increasing water uptake, which affects petals directly and their pigments indirectly (Hashemabadi, 2011). Therefore, the significant effect of plant essential oils on increasing chlorophyll content in these studies is consistent with our findings.

It was found that 200 mg/L thyme essential oil without ethanol was the most effective treatment for extending vase life, reducing bacteria populations, and enhancing water uptake, and the results were quite favorable with respect to dry weight and flower opening index. The thyme essential oil 200 mg/L extended the vase life of the cut flowers about 5 days. Overall, it can be concluded that the correct use of thyme essential oil and ethanol at proper rates is effective in improving the vase life of alstroemerias.

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