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Effect of active and passive modified atmosphere packaging on extending the postharvest life of *Gypsophila paniculata* L. (Bristol Fairy) flowers

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Abstract

Gypsophila paniculata L. 'Bristol Fairy' flowers have a high economic value in the floriculture industry because they are used as cut flowers, decorations and potted plants. Their lifespan is critical in determining quality, market value, and customer satisfaction. This study, carried out at the Agricultural Research Centre (ARC), Giza, Egypt, looked into the effects of active and passive modified atmosphere packaging (MAP) on the postharvest quality of cut Gypsophila flowers during the 2022 and 2023 growing seasons. The following compositions of gases were examined: passive-MAP (78.97 N2, 0.03 CO_2, and 21% O_2), MAP1 (90 N_2, 5 CO_2, and 5% O_2), MAP2 (85 N_2, 10 CO_2, and 5% O_2), MAP3 (80 N_2, 15 CO_2, and 5% O_2) and control (unpacked cut flowers). The findings demonstrated that MAP2 and polyethene bags significantly enhanced water absorption, fresh weight, carbohydrate production, and appearance quality. The average storage life of Gypsophila flowers under passive MAP was 19.07 days, with the longest being 29.42 days with MAP2 and polyethylene bags.

Key words: Active packaging, cold storage, high carbon dioxide, gypsophila, modified atmosphere packages storage, relative fresh weight, water uptake

Introduction

Gypsophila paniculata, L. "Bristol Fairy" belongs to the Caryophyllaceae family also known as baby's breath. Its light, airy masses of small white to pink flowers make it a valuable cut flower in floristry. Often known as perennial gypsophila, popular as cut flowers, gypsophila blooms are typically used as filler in bouquets, arrangements, and bridal bouquets. Gypsophila, annual and perennial flowering plants globally, are ideal for misty borders, beds, edges, rock gardens, and filling shrubbery with delicate blooms. Gypsophila is one of the top ten cut flowers in the international market. In addition, all value involves tinting, drying, and packing dried flowers for decorative floral crafts. The demand for dried flowers has increased due to changes in human lifestyles. Dried flowers have shown a surge in demand in the past decade due to lifestyle changes, making them durable and in high demand year-round (Khenizy *et al.*, 2014; Gadde *et al.*, 2023). Cut flowers face challenges like discolouration, browning, wilting, and senescence, impacting market value. To preserve quality and freshness, reducing postharvest losses and increasing vase life is crucial, as poor management accounts for 25% of cut flower losses (Poonsri, 2017; Arumta *et al.*, 2019; Darras, 2021; Poonsri, 2021a; Faust *et al.,* 2021; Moradinezhad *et al.*, 2023). Dry transportation reduces vase life by water stress but offers space utilization and lower costs. The modified atmosphere package enhances cut flower quality and vase life (Aros *et al.*, 2017; Burana, 2018; Shafique *et al.,* 2021). MAP technology enhances cut flowers' postharvest life by altering package gas composition. Proper storage and packaging choices, including refrigeration, are crucial for maintaining quality and preventing undesirable postharvest physicochemical changes (Guadalupe and Mayanin, 2015; Dorostkar *et al.,* 2022; Hatibarua *et al.*, 2022). Hence, the novelty of this investigation lies in the use of modified atmosphere packaging technology (MAP) for an increased shelf life of gypsophila cut flowers during storage at 2°C. Due to their economic significance, this research focused on the postharvest life of Gypsophila flowers.

Materials and methods

This research was conducted during the two successive seasons of 2022 and 2023) in the Laboratory of Postharvest and Handling of Manufacturing Engineering and Food Packaging Res. Dept., Food Technology, Res. Inst., ARC at Giza, Egypt, and Post-Harvest

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Laboratory of Ornamental Plants and Landscape Gardening Res. Dept., Hort. Res. Inst.; Giza, Egypt to study the effects of active and passive modified atmosphere packaging on the postharvest quality of cut Gypsophila flowers.

Plant material: The study used gypsophila blossoms from a nearby commercial farm called Floramix, picked early in the morning and transported to a laboratory for pre-cooling and cutting. The experiment involved injury-free stems and was conducted in an ambient lab at 18±2°C, 50–55% RH, and 24 hours of fluorescent lamp lighting.

Experimental design and treatments: Gypsophila cut flowers were divided into five groups, and each group was given a distinct gas composition (Table 1). Cut flowers are susceptible to dehydration when conveyance (particularly for neighbourhood markets). Therefore, they are shipped in sealed containers. These circumstances provide a passively modified environment. Because of this, we chose to include passive-MAP and control in the current study so that it could be compared to other therapies. A vacuum pump was used to remove the air from the 20 x 30 cm low-density polyethene (LDPE) bags with a thickness of 0.06 mm. The bags were then sealed. For every treatment, twenty-eight cut flowers and three replications were considered. After injecting the identified gaseous compounds (active MAP), the bags were sealed and kept in a cold environment at 85 ± 5% relative humidity and 2 ± 1°C for twenty days. Subsequently, the blooms were arranged in a 1000 mL glass with 500 mL of distilled water as a holding solution. After that, the flowers were stored at room temperature (20°C) for 20 days. The vase life was assessed using days 0 through 20.

Table 1. Gas composition treatments were applied to Gypsophila cut flowers for 20 days of cold storage at 2 ± 1°C

Treatments	Details
Control	Unpacked cut flowers
Passive-MAP	(78.97 N_2, 0.03 CO_2 and 21% O_2)
MAP1	(90 N_2, 5 CO_2 and 5% O_2)
MAP2	(85 N_2, 10 CO_2 and 5% O_2)
MAP3	(80 N_2, 15 CO_2 and 5% O_2)

Measurements: During the lifespan of the fresh-cut gypsophila, various parameters on flower quality were meticulously documented. These parameters, encompassing The vase life of the cut gypsophila flowers were ascertained by calculating the duration in days until the onset of wilting (Hassan *et al.* 2020). The percentage of flower bud opening was calculated, while daily measurements of gypsophila cut flowers were recorded using a digital balance (accuracy ±0.001 g) to determine the variation in fresh weight percentage. The procedures delineated by Sairam *et al.* (2002) and Moradinezhad *et al.* (2023) were used for documenting water relations, including water uptake. Additionally, parameters such as water loss (g) and water balance (g) were evaluated. The percentage of weight loss was also recorded upon the conclusion of the vase life of the gypsophila.

Furthermore, the total lifespan (Days) was assessed by the framework established by Faragher *et al.* (1984). Appearance quality was systematically evaluated by the methodology established by Leibe and Schiele (2003), where characteristics such as shape, color, position, and stem freshness were scrutinized bi-daily until a threshold score was attained. A series of chemical analyses were conducted after the storage period, including the determination of total chlorophyll content in the leaves (mg/l) employing the methodology described by Moran (1982). The estimation of total carbohydrate content (%) was performed following the protocol articulated by DuBois *et al.* (1956). The Dual Trak model 902 D gas analyzer was used to measure O_2 and CO_2 concentrations within packages, using a rubber seal for testing.

Statistical analysis: The study employed a factorial design within a complete randomized design incorporating two distinct factors. The first factor pertained to cold storage (0, 5, 10, 15, and 20 days) at a controlled temperature of 2°C, while the second factor involved modified atmosphere packaging categorized into six groups as delineated in Table 1. Statistical analyses, including variance analysis, were conducted utilizing the COSTAT computer program, and treatment means were assessed through Duncan's Multiple Range Test at a significance level of 5%, as articulated by Snedecor and Cochran (1980).

Results

Effect of storage period, different MAP pretreatments, and their interactions on several aspects of postharvest quality

Vase life (days): Vase life is crucial for the flower industry, as it determines the attractiveness and value of cut flowers. It is clear from the data in Table 2, that MAP treatments significantly impacted the vase life of gypsophila cut flowers. MAP2 (85 N_2, 10 CO_2, and 5% O_2) treatment showed the most extended vase life, while Passive-MAP and control treatments gave the lowest vase life. Increased cold storage duration decreased vase life, but MAP2 treatment prolonged it due to reduced oxidation, respiration rates, and ethylene production.

Flower bud opening (%): The study revealed that gypsophila cut flower storage durations affect the open rate, with high CO_2 and low O_2 treatments causing delayed senescence and drying. MAP2 (80 N_2, 15 CO_2, and 5% O_2) led to delayed petal opening. According to the results in Table 2, all MAP treatments significantly affected cut flowers opening of the gypsophila, with passive-MAP and control treatments showing the highest open rates in two seasons.

Fresh weight increase (%): The study found that all MAP treatments, including MAP2 (85 N_2, 10 CO_2, and 5% O_2), resulted in better fresh weight percentages than the passive-MAP and the control. MAP2 treatment significantly increased flower weight and water uptake of cut gypsophila flowers. MAP also effectively reduced fresh weight loss, ethylene production, respiration rate, protease activity, and protein degradation (Table 3).

Water relations: The water relations in cut gypsophila flowers during their vase life are depicted in Tables (3&4). The study shows that all MAP treatments significantly impact water uptake in Gypsophila cut flowers, with the highest in MAP2 treatment and the lowest in passive-MAP and control. Also, The study found significant effects of modified atmosphere packaging (MAP) and storage period on water loss in gypsophila cut flowers. Storage for 20 days at 2°C increased water loss, while at 0 day and MAP2 (85 N2, 10 CO_2 and 5% O_2) lowest water loss was recprded. MAP also increased water balance, preventing dehydration and enhancing vase life.

Table 2. Effect of storage period, different MAP pretreatments, and their interactions on vase life (day) and flower bud opening of *Gypsophila* flower

Treatments (MAP) (A)	Storage period in days (B)											
	Vase life (day						Flower bud opening (%)					
	0	5	10	15	20	Mean B	0	5	10	15	20	Mean B
Season 1												
(Control)	14.10 f	12.30 g	8.5 0 ij	5.20 k	3.20 i	8.66 E	15.70 o	56.80 hij	69.20 e	78.10 c	89.20 a	61.80 A
Passive-MAP	18.30 d	14.50 f	11.30 gh	7.40 j	4.20 ki	11.14 D	15.30 o	53.20 l	67.10 f	75.40 d	84.10 b	59.02 B
MAP1	23.30 c	17.50 d	14.80 f	11.10 gh	7.30 g	14.80 C	15.10 o	41.22 m	55.10 jk	57.10 hi	68.12 ef	47.33 C
MAP2	27.50 a	22.90 c	18.30 d	15.20 ef	11.20 gh	19.02 A	15.22 o	38.70 n	53.11	56.20 ij	62.30 g	45.10 E
MAP3	25.30 b	18.20 d	16.60 de	10.10 hi	8.60 ij	15.76 B	15.55o	42.80 m	54.20 kl	58.10 h	67.90 ef	47.71 D
Mean A	21.70 A	17.08 B	13.90 C	9.80 D	6.90 E		15.37 E	46.54 D	59.74 C	64.98 B	74.32A	
Season 2												
(Control)	17.20 fg	15.10 hi	10.60 k	8.40 lm	5.10 n	11.28 E	15.60 o	59.30 h	70.20 e	79.50 c	90.20 a	62.96 A
Passive-MAP	19.10 de	16.50 gh	14.30 i	9.40 kl	7.30 m	13.32 D	15.50 o	56.80 i	68.20 f	73.50 d	86.10 b	60.02 B
MAP1	25.60 bc	20.50 d	16.70 fgh	10.10 kl	8.50 lm	16.28 C	15.20 o	43.27 m	54.50 i	67.80 f	69.30 ef	50.01 C
MAP2	28.10 a	24.90 bc	19.30 ef	16.10 gh	12.30 j	20.14 A	15.10 o	39.21 n	52.40 k	54.60 i	60.10 h	44.28 D
MAP3	26.40 b	23.70 c	20.60 d	14.20 i	9.60 kl	18.90 B	15.10 o	46.87 l	56.70 i	69.60 ef	62.40 g	50.13 C
Mean A	23.28 A	20.14 B	16.30 C	11.64 D	8.56 E		15.30 E	49.09 D	60.40 C	69.00 B	73.62 A	

Means followed by the same letters in a column or raw do not differ significantly according to Duncan's New Multiple Range test at P = 0.05. Control (Open package), Passive-MAP = (78.97 N_2, 0.03 CO_2 and 21% O_2), MAP1= Active MAP (90 N_2, 5 CO_2 and 5% O_2), MAP2= Active MAP (85 N_2, 10 CO_2 and 5% O_2) and MAP3 = Active MAP (80 N_2, 15 CO_2 and 5% O_2)

Table 3. Effect of storage periods, different MAP pretreatments, and their interactions on fresh weight increase and water uptake of *Gypsophila* flower

Treatments (MAP) (A)	Storage period in days (B)											
	Fresh weight increase (%)						Water uptake (g)					
	0	5	10	15	20	Mean B	0	5	10	15	20	Mean B
Season 1												
(Control)	9.20 hi	8.00 ijk	5.30 jkl	4.90 kl	3.90 l	6.26 D	39.14 fg	29.10 hij	27.20 hij	23.30 jk	16.90 k	27.13 C
Passive-MAP	19.20 cd	15.30 efg	14.80 fg	11.80 gh	8.70 hij	13.96 C	35.20 g	27.10 hij	25.10 ij	22.10 jk	17.66 k	25.43 C
MAP1	24.10 ab	19.30 cd	18.80 cde	15.80 def	14.80 fg	18.56 B	55.28 bcd	52.10 cde	45.20	35.20 g	32.20 ghi	44.00 B
MAP2	25.70 a	21.30 bc	20.40 c	17.80 cdef	16.20 def	20.28 A	65.23 a	59.10 ab	52.50 cd	45.10 ef	36.70 g	51.73 A
MAP3	21.30 bc	18.80 cde	17.80 cdef	15.80 def	14.30 fg	17.60 B	56.14 bc	54.80 bcd	48.50 de	38.70 fg	33.70 gh	46.37 B
Mean A	19.90 A	16.54 B	15.42 B	13.22 C	11.58 D		50.20 A	44.44 B	39.70 C	32.88 D	27.43 E	
Season 2												
(Control)	11.20 gh	9.70 gh	7.90 h	6.50 h	5.80 h	8.22 D	45.60 def	39.50 gh	38.40 hi	35.1ohijk	33.5o ijk	38.42 C
Passive-MAP	19.90 cde	17.50 cde	16.90 def	13.50 efg	10.60 fgh	15.68 C	45.70 def	37.20 hig	32.70 kl	32.60 jk	26.90 l	35.02 D
MAP1	21.10 bcd	20.40 bcde	19.80 bcde	19.50 bcde	17.90 cde	19.74 B	65.78 b	57.80 c	49.20 de	48.50 def	45.20 ef	53.3 B
MAP2	29.30 a	26.70 ab	24.80 abcd	23.50 abcd	22.70 abcd	25.4 A	75.28 a	69.20 b	56.20 c	51.10 d	43.60 fj	59.08 A
MAP3	25.00 abc	24.80 abc	23.10 abcd	21.40 bcd	20.10 bcde	22.88 A	66.18 b	59.70 c	47.40 def	48.70 def	36.50 hijk	51.70 B
Mean A	21.3 A	19.82 A	18.50 AB	16.88 BC	15.42 C		59.71 A	52.68 B	44.78 C	43.20 C	37.14 D	

Refer Table 1 for treatment and significance details

Table 4. Effect of storage periods, different MAP pretreatments, and their interactions on water loss and water balance of *Gypsophila* flower

Treatments (MAP) (A)	Storage period in days (B)											
	Water loss (g) and						Water balance (g)					
	0	5	10	15	20	Mean B	0	5	10	15	20	Mean B
Season 1												
(Control)	26.14 ijk	28.11 fjki	46.10 cd	48.20 bc	59.10 a	41.53 A	+13.00 i	+0.99 k	-18.90 m	-24.90 n	-42.20 p	-14.40 E
Passive-MAP	24.20 f	23.60 ijkl	39.80 e	42.10 de	51.10 b	36.16 B	+11.00 j	+3.50 j	-14.70 l	-20.00 m	-33.44 o	-10.73 D
MAP1	18.3o mn	20.9o jklm	25.20 hijk	27.30 fghi	18.43 mn	22.03 C	+36.90 c	+31.20 d	+20.00 h	+7.90 i	13.77 h	+21.95 C
MAP2	15.5o n	18.80 lmn	20.3o klm	24.20 f	15.30 jklm	18.82 D	+49.70 a	+40.30 b	+32.20 d	+20.90	21.40 f	+32.90 A
MAP3	19.3o jhij	22.10 fghi	23.10 fgh	24.10 ijk	17.60 ijkl	21.24 C	+36.80 c	+32.70 d	+25.40 e	+14.60	+16.10 g	+25.12 B
Mean A	20.69 D	22.70 C	30.90 B	33.18 A	32.31 AB		+29.48 A	+21.74 B	+8.8 C	-0.30 D	+-4.87 E	
Season 2												
(Control)	38.20 lm	48.10 g	51.10 e	54.20 c	68.20 a	51.96 A	+7.40 jk	-12.90 n	-12.70 n	-20.70 p	-28.70q	-13.52 D
Passive-MAP	34.20 ijk	43.60 e	49.90 d	52.70 c	65.10 b	49.10 B	+11.50 i	-6.50 m	-17.20 o	-20.10p	-38.20 r	-14.1 E
MAP1	28.40 m	30.90 lm	35.70 hij	37.50 h	42.5 ef	35.00 C	+37.30 c	26.90 e	+7.50 j	+7.70 j	+6.70 k	17.22 C
MAP2	25.60 n	28.60 m	30.70 lm	36.30 hi	40.40 fg	32.32 D	+49.60 a	40.6 b	+25.50 f	+14.80 g	+3.20 l	26.74 A
MAP3	29.40 m	32.00 kl	33.90 ijk	34.80 ij	33.70 jk	32.76 D	+36.70 c	27.70 d	+13.50 h	+13.90	+2.80 l	18.92 B
Mean A	31.16 E	36.64 D	40.26 C	43.10 B	49.98 A		28.5 A	15.16 B	3.3 C	-0.88 D	-10.84 E	

Refer Table 1 for treatment and significance details

Weight loss (%): Data presented in Table 5 depict an increase in the weight loss percentage of gypsophila plants with the prolongation of the storage period. Modified atmosphere packaging (MAP) could help reduce weight loss percentage in gypsophila cut flowers by creating an environment with controlled humidity levels and gas composition.

General appearance (score %): The general appearance of flowers is crucial for marketing, as a change in leaf colour from green to yellow indicates senescence. MAP enhances flower quality during shipment, while gases like oxygen, carbon dioxide, and ethylene impact postharvest quality. Controlled and modified atmosphere packaging are beneficial. Found that the general appearance (GA) of gypsophila plants was affected by all MAP treatments (Table 5).

Total shelf life (days): The study found that modified atmosphere packaging (MAP) significantly extended the total life of cut flowers by providing a controlled atmosphere, preserving their freshness and quality, and enabling extended storage and transportation. The study found that gypsophila blossoms under normal atmospheric conditions had shorter storage life than those under passive and active MAP (Fig.1).

Chemical analyses: Data illustrated in Table 6 found that gypsophila cut flower plants experienced a significant reduction in total chlorophyll content during storage due to chlorophyll degradation and chromoplast transformation. All MAP treatments significantly reduced total chlorophyll loss, with MAP2 (85 N_2, 10 CO_2, and 5% O_2) being the most effective. Untreated gypsophila was more susceptible to loss and yellowing. MAP treatments influenced total carbohydrates percentage, with MAP2 showing a unique trend until the 15th day. These treatments may enhance flower quality by reducing transpiration and CO_2 diffusion.

Gas composition inside the packages: The study found a significant decrease in O_2 and an increase in CO_2 (Table 7) during the storage periods of gypsophila cut flowers, possibly due to CO_2 production during respiration. Active MAP3 (80 N_2, 15 CO_2, and 5% O_2) had lower O_2 levels than passive or untreated MAP, while CO_2 values were higher in active MAP3. This may suppress respiration rate and inhibit certain metabolic processes, maintaining gypsophila flower quality during storage.

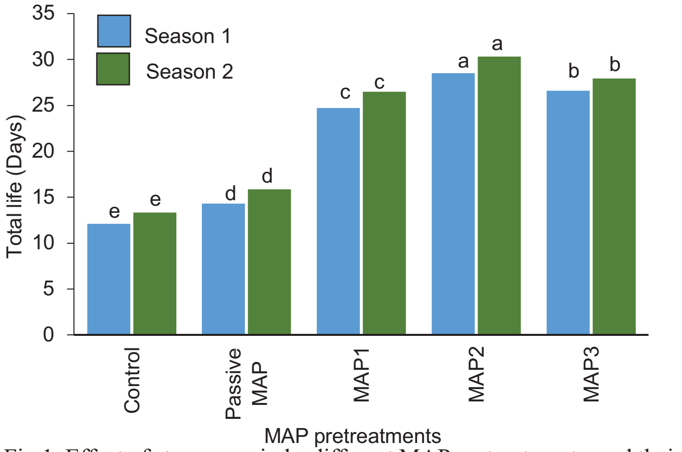

Fig.1. Effect of storage periods, different MAP pretreatments, and their interactions on total life (days) of *Gypsophila* cut flowers during 2022 and 2023 seasons. Control (Open package), Passive-MA*P* = (78.97 N_2, 0.03 CO_2 and 21% O_2), MAP1= Active MAP (90 N_2, 5 CO_2 and 5% O_2), MAP2= Active MAP (85 N_2, 10 CO_2 and 5% O_2) and MAP3 = Active MAP (80 N_2, 15 CO_2 and 5% O_2)

Discussion

Flower vase life is important in determining cut flower quality and postharvest efficiency. Our study revealed that at 85 N_2, 10 CO_2, and 5% O_2, the vase life of gypsophila-cut flowers was prolonged due to reduced oxidation, respiration rates, and ethylene production under high CO_2 and low O_2 conditions. Vase life is crucial for the flower industry, as it determines the attractiveness and value of cut flowers. Obtained data proved that gypsophila-cut flowers vase life increased under MAP, possibly due to reduced respiration rates, ethylene production, and oxidation. Moreover, the extended vase life of fresh-cut flowers under a modified atmosphere with LPDE packaging films was noted in the current study. These findings agreed with (Kitamura and Ueno (2015); Kitamura et al. (2017); Aros et al. (2017); Moradinezhad et al. (2018); Roh et al. (2019); Poonsri (2021b). Also, Ahammed and Li (2022) and Nakayama *et al.* (2023) found that MAP techniques extend cut flower shelf life by preserving their properties under challenging conditions. Cooler temperatures, prevented transpiration, and controlled atmospheres improve quality and vase life. MAP-stored flowers show lower

Table 5. Effect of storage periods, different MAP pretreatments, and their interactions on weight loss and general appearance of *Gypsophila* flowers

Treatments (MAP) (A)	Storage period in days (B)											
	Weight loss (%)						General appearance (score)					
	0	5	10	15	20	Mean B	0	5	10	15	20	Mean B
Season 1												
(Control)	0.00 r	8.20 n	14.40 g	18.50 b	20.10 a	12.24 A	100.00 a	62.41 j	50.11 l	44.74 m	39.11 l	59.30 E
Passive-MAP	0.00 r	9.20 k	11.80 h	15.70 f	18.20c	10.98 B	100.00 a	66.83 h	58.23 k	49.27 l	43.10 m	63.50 D
MAP1	0.00 r	6.50 p	8.90 l	11.00 i	16.20 e	8.52 C	100 .00 a	92.5 bc	89.15 d	76.78 gh	70.09 i	85.70 C
MAP2	0.00 r	5.30 q	7.60 o	8.70 m	10.20 j	6.36 D	100 .00 a	98.25 a	93.47 b	89.29 d	78.48 g	91.90 A
MAP3	0.00 r	6.50 p	8.70 m	11.90 h	17.50 d	8.92 C	100.00 a	93.12 bc	91.09 cd	86.11 e	81.67 f	90.40 B
Mean A	0.00 J	7.14 D	10.28 C	13.16 B	16.44 A		100 A	82.60 B	76.40 C	69.20 D	62.50 E	
Season 2												
(Control)	0.00 k	9.50 fgh	14.90 cd	22.60 d	26.20 a	14.64 A	100 .00 A	65.51 h	51.11 k	33.50 lm	23.14 n	54.65 E
Passive-MAP	0.00 k	7.80 hi	10.10 fg	15.20 cd	24.10 b	11.44 B	100 .00 A	69.81 g	59.53 j	40.11 l	34.55 lm	60.80 D
MAP1	0.00 k	6.70 ij	9.90 fg	12.50 cd	16.60 c	9.14 C	100.00 A	93.53 c	87.45 d	78.47 f	64.76 hi	84.84 B
MAP2	0.00 k	5.50 j	8.60 ghi	9.40 fgh	12.20 cd	7.14 D	100.00 A	97.25 b	95.26 c	88.38 d	79.48 f	92.07 A
MAP3	0.00 k	6.70 ij	9.80 fgh	10.70 ef	16.70 c	8.78 C	100.00 A	94.77 c	83.97 e	72.14 g	63.59	82.89 C
Mean A	0.00 E	7.24 D	10.66 C	14.08 B	19.16 A		100.00 A	84.17 B	75.46 C	62.52 D	53.10 E	

Refer Table 1 for treatment and significance details

Table 6. Effect of storage periods, different MAP pretreatments, and their interactions on total chlorophyll content (mg/g) and total carbohydrates (%)

Treatments (MAP) (A)	Storage period in days (B)											
	Total chlorophyll content (mg/g)						Total carbohydrates (%)					
	0	5	10	15	20	Mean B	0	5	10	15	20	Mean B
Season 1												
(Control)	1.28 n	1.21 p	1.09 s	1.05 t	0.09 u	0.94 E	8.32 ef	6.53 hi	5.78 ij	4.32 k	3.12 l	5.61 D
Passive-MAP	1.42 k	1.33 m	1.22 p	1.14 q	1.11 r	1.24 D	9.30 cd	7.65 fg	6.40 hi	5.30 j	4.10 k	6.55 C
MAP1	1.65 d	1.54 f	1.44 j	1.34 m	1.22 p	1.44 C	10.90 b	8.65 de	7.05 gh	6.90 gh	5.90 ij	7.88 B
MAP2	1.98 a	1.87 b	1.72 c	1.51 g	1.46 i	1.71 A	12.60 a	10.90 b	9.77 c	8.11 ef	7.20 gh	9.72 A
MAP3	1.62 e	1.53 f	1.48 h	1.38 l	1.25 o	1.45 B	10.68 b	9.15 cd	8.85 de	6.68 h	5.68	8.21 B
Mean A	1.59 A	1.50 B	1.39 C	1.28 D	1.03 E		10.36 A	8.58 B	7.57 C	6.26 D	5.20 D	
Season 2												
(Control)	1.26 k	1.19 m	1.15 o	1.07 q	1.04 r	1.14 D	7.15 gh	5.22 kl	4.12 jk	3.50 no	3.16 o	4.63 E
Passive-MAP	1.35 j	1.27 k	1.18 mn	1.17 n	1.09 p	1.21C	8.12 f	6.11 j	5.60 jk	4.90 kl	4.50 lm	5.85 D
MAP1	1.69 b	1.59 e	1.49 g	1.39 i	1.35 j	1.50 B	11.28 c	9.09 e	8.13 f	7.73 fg	6.30 ij	8.51 C
MAP2	1.79 a	1.67 bc	1.66 bc	1.59 e	1.41 h	1.62 A	13.66 a	12.43 b	10.40 d	9.95 d	8.10 f	10.91 A
MAP3	1.68 b	1.62 d	1.54 f	1.42 h	1.22 l	1.50 B	12.84 b	10.12 d	9.76 de	7.18 gh	6.50 ij	9.28 B
Mean A	1.55 A	1.47 B	1.40 C	1.33 D	1.22 E		10.61 A	8.59 B	7.60 C	6.65 D	5.71	

Table 7. Effect of storage periods, different MAP pretreatments, and their interactions on O_2 (%) and CO_2 (%) inside the packages of *Gypsophila* flowers

Treatments (MAP) (A)	Storage period in days (B)											
	O_2 (%)						CO_2 (%)					
	0	5	10	15	20	Mean B	0	5	10	15	20	Mean B
Season 1												
(Control)	21.00 a	21.00 a	21.00 a	21.00 a	21.00 a	21.00 A	0.03 t	0.03 t	0.03 t	0.03 t	0.03 t	0.03 E
Passive-MAP	21.00 a	19.50 b	18.42 c	17.70 d	16.35 e	18.59 B	0.03 t	0.50 o	1.00 r	1.60 q	1.67 p	0.96 D
MAP1	5.00 f	4.80 g	4.76 gh	4.40 k	4.10 m	4.61 C	5.00 s	5.34 n	5.85 m	6.89 l	7.18 k	6.05 C
MAP2	5.00 f	4.72 h	4.47 j	4.34 kl	4.05 m	4.52 D	10.00 j	10.43 i	10.85 h	10.90 g	11.82 f	10.80 B
MAP3	5.00 f	4.60 i	4.32 l	4.10 m	3.69 n	4.34 E	15 .00 e	15.41 d	16.95 a	16.25 c	16.70b	16.06 A
Mean A	11.40 A	10.92 B	10.59 C	10.31 D	9.84 E		6.01 D	6.34 C	6.94 B	7.13B	7.48 A	
Season 2												
(Control)	21.00 a	21.00 a	21.00 a	21.00 a	21.00 a	21.00 A	0.03 t	0.03 t	0.03 t	0.03 t	0.03 t	0.03 E
Passive-MAP	21.00 a	19.15 b	18.36 c	17.49 d	16.25 e	18.45 B	0.03 t	0.40 s	0.80 r	1.40 q	1.53 p	0.83 D
MAP1	5.00 f	4.76 g	4.50 i	4.20 k	3.87 n	4.46 C	5.00 o	5.23 n	5.70 m	6.79 l	7.00 k	5.94 C
MAP2	5.00 f	4.65 h	4.40 j	4.15 l	3.65 o	4.37 D	10.00 j	10.27 i	10.60 h	10.70 g	11.63 f	10.64 B
MAP3	5.00 f	4.39 j	4.00 m	4.00 m	3.56 p	4.19 E	15.00 e	15.21 d	16.07 c	16.10 b	16.30 a	15.74 A
Mean A	11.40 A	10.79 B	10.45 C	10.17 D	9.67 E		6.01 E	6.23 D	6.64 C	7.00 B	7.30 A	

Refer Table 1 for treatment and significance details

weight loss, delayed petal senescence, reduced respiration rates, and enhanced quality.

Regarding the effect of MAP pretreatments, and storage periods on fresh weight percentage, the current study confirmed that MAP2 (85 N_2, 10 CO_2, and 5% O_2) effectively reduced fresh weight loss, ethylene production, respiration rate, protease activity, and protein degradation. These outcomes coincided with the findings of Aros *et al.* (2017) who reported that MAP's ability to maintain flower quality and extend vase life indicates a potentially positive effect on water uptake by reducing dehydration and maintaining hydration levels. Also, these results agree with Panja *et al.* (2018) who reported that cut flowers' weight increases due to water absorption through vessels. On the other hand, many researchers are focusing on water uptake dynamics under MAP conditions that could provide valuable insights into the mechanism behind the improved postharvest performance of flowers Poonsri (2021b) found that MAP treatment of Dendrobium orchids delayed weight loss, retained anthocyanin content, and reduced fresh weight loss, respiration rate, and protein degradation.

Our results declared that water uptake of cut gypsophila flowers was observed after pretreatment with (85 N_2, 10 CO_2, and 5% O_2), possibly due to reduced microorganism populations. Consequently, numerous studies indicate a favorable relationship between vase life and water intake. These outcomes coincided with the findings of Aros *et al.* (2017) who reported that MAP's ability to maintain flower quality and extend vase life indicates a potentially positive effect on water uptake by reducing dehydration and maintaining hydration levels. Also, many researchers are focusing on water uptake dynamics under MAP conditions that could provide valuable insights into the mechanism behind the improved postharvest performance of flowers Poonsri (2021b) found that MAP treatment of Dendrobium orchids delayed weight loss, retained anthocyanin content, and reduced fresh weight loss, respiration rate, and protein degradation. Similar findings were observed in Narcissus cut flowers (Shafique *et al.* 2021).

The current investigation substantiated that MAP treatments can significantly reduce flower dehydration, enhancing shelf life and freshness. They regulate relative humidity within the packaging, reducing water loss. Vase life is crucial for cut flower marketability. MAP also preserves water content and hydration levels by creating a controlled atmosphere, slowing aging processes. Similar findings were observed by (Aros *et al.*, 2017; Poonsri, 2021a)

The study reveals that higher CO_2 and lower O_2 decrease respiration and ethylene generation in cut flowers. Low temperatures and passive MAP can increase their shelf life. However, storage life ends if flowers last less than seven days at room temperature. MAP preserves freshness and quality, increasing total life and allowing extended storage and transportation. These findings agreed with (Yahia and Singh, 2009; Moradinezhad *et al.*, 2018; Roh *et al.*, 2019; Poonsri, 2021b).

Appearance quality is the most important factor in marketing flowers, as a change in leaf color from green to yellow in cut flowers indicates senescence. The study reveals thatMAP treatments significantly impact the appearance of gypsophila plants, highlighting its importance in maintaining flower visual quality and product appeal. MAP regulates humidity and gas composition in packaging, preventing water loss, reducing dehydration, and extending vase life, while slowing down senescence processes. These results align with those reported by (Kubo, 2015 and Shimizu-Yumoto and Ichimura, 2016 ; Aros *et al.*, 2017; Poonsri, 2021a; Nakayama *et al.*, 2023).

Furthermore, our results revealed that all MAP treatments significantly reduced total chlorophyll loss, with MAP2 at (85 N_2, 10 CO_2, and 5% O_2) being the most effective. Untreated gypsophila (control) was more susceptible to chlorophyll and carotenoid loss and yellowing during storage. Our results revealed that the modified atmospheric condition helped conserve total carbohydrates in the flowers, resulting in a longer storage life (Table, 6). These results align with Shimizu-Yumoto and Ichimura (2016) on gladiolus Poonsri (2021a) on *Dendrobium orchids* and Moradinezhad *et al.* (2023) on narcissus flowers. MAP treatments preserve total carbohydrates and reduce protein degradation in flower petals, potentially enhancing quality by reducing transpiration, and CO_2 diffusion, and affecting metabolism and total carbohydrates percentage.

The current study reveals that active MAP3 (80 N_2, 15 CO_2, 5% O_2) has lower O_2 concentrations than passive or untreated MAP, potentially preserving gypsophila flower quality during storage. The study supports previous research indicating that higher CO_2 and lower O_2 can reduce respiration and ethylene generation in cut flowers, while low temperatures and passive MAP increase shelf life (Yahia and Singh, 2009; Moradinezhad *et al.,* 2023; Nakayama *et al.*, 2023).

In conclusion, modified atmosphere packaging (MAP) is a valuable technique for extending the shelf life, preserving quality attributes, and maintaining the appearance of various products. MAP can reduce water loss, slow respiration rates, inhibit ethylene production, and delay senescence processes by controlling the packaging's gas composition and humidity levels. These factors collectively contribute to prolonging the freshness, enhancing the visual appearance, and improving the overall quality of products stored in MAP. MAP is a beneficial tool in floral industries, offering a reliable method to optimize storage conditions and ensure product integrity throughout the supply chain.

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