



Article

Active Modified Atmosphere Packaging Helps Preserve Quality of Edible Flowers

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Abstract: Edible flowers are becoming increasingly popular as food products, since they give aroma, color, and visual appeal and are also health-promoting compounds. However, they are a highly perishable product, thus post-harvest technologies are needed to extend their marketability. In this study, active (N₂: 100%) and passive modified atmosphere packaging (MAP) technologies were applied to three edible flower species, namely *Begonia grandiflora* ‘Viking’, *Tropaeolum majus*, and *Viola cornuta*, stored at 4 °C. Even if the flowers’ quality decay occurred differently according to the species, active MAP better maintained petal colors and slowed down the edible flowers’ decay than passive MAP by decreasing flower respiration in all three species and sugars consumption in begonia; there was weight loss in nasturtium, and better preserved total phenolic content in begonia and viola. Coupling cold storage with active MAP can be an effective method to extend edible flowers’ post-harvest life.

Keywords: antioxidant activity; malic acid; MAP; post-harvest; sugars; weight loss



Citation: Falla, N.M.; Seif Zadeh, N.; Stelluti, S.; Guarino, V.; Giordano, M.; Cardenia, V.; Zeppa, G.; Scariot, V. Active Modified Atmosphere Packaging Helps Preserve Quality of Edible Flowers. *Agronomy* **2024**, *14*, 2409. <https://doi.org/10.3390/agronomy14102409>

Academic Editor: Rajko Vidrih

Received: 12 September 2024

Revised: 7 October 2024

Accepted: 14 October 2024

Published: 17 October 2024



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1. Introduction

Numerous flower species have been used raw or processed as food to improve the sensory quality of culinary preparations by enhancing their aromas, colors, texture, and taste [1–4].

Nowadays, edible flowers are also becoming increasingly popular for their health properties [1,5–8], leading to considering them as functional or nutraceutical foods [5,9–11]. Depending on floral parts and species, edible flowers can have a high and varied content of bioactive compounds (phenolic compounds, carotenoids, organic acids) associated with beneficial effects on human health, and low fat and protein content, thus being a good choice for food-conscious consumers [12–15]. Phenolic compounds are related to the prevention of chronic degenerative diseases, such as cardiovascular, dysmetabolic, and neurodegenerative diseases as well as cancer by eliciting anti-inflammatory effects, and favorably modulating gut microbiota composition [9,16]. Carotenoids are important precursors of vitamin A and they can reduce various vision and cardiovascular diseases [17,18]. Major organic acids are known for their protective effects against myocardial ischemia/reperfusion injury and antimicrobial properties (e.g., malic acid), their role in diabetes treatment (e.g., succinic acid), and their contribution to the formation of crystalline structures in bones (e.g., citric acid) [19]. The growth in demand for edible flowers is therefore due to the increasing preference of consumers for natural and healthy food products to the detriment of artificial additives, along with new culinary trends, always looking for attractive new foods to decorate and flavor culinary preparations [5,10,20].

However, when consuming edible flowers, caution is needed due to the possibility to develop allergic reactions to specific flower species or parts of them (e.g., pollen) [21,22].

Edible flowers must not be purchased from ornamental nurseries, garden centers or florists because ornamental products are usually treated with pesticides and chemicals not approved for food use, and are therefore not suitable for human consumption [21,22]. In addition, harvesting edible flowers from natural environments is risky without the appropriate botanical knowledge, since similar but toxic species may be present. Attention must also be paid to the collection site, because plants may absorb pollutants such as heavy metals or toxic trace elements from soil and water, with potential health risks for consumers [21,23].

Flowers are highly perishable, since they are plant organs genetically programmed to have a short lifespan [11,24]. Flowers continue living after harvesting, and they have higher respiration rates than other plant organs; therefore, both transpiration and respiration processes cause the rapid establishment of senescence mechanisms, which determine quality losses, i.e., early petal discoloration and abscission, tissue browning, dehydration, wilting of flowers, and the alteration of the flavor due to variations in sugars and organic acids contents [5,25,26].

In addition to visual quality, during post-harvest storage, edible flowers may lose their nutritional values [5,8]. Senescence is a process of progressive oxidative deterioration, and plants counteract the effects of oxidative stress by synthesizing new antioxidants, by utilizing pre-existing pools or activating specific routes to recycle and consume specific molecules [27,28]. Moreover, since flowers are not reserve structures, sugars and organic acids are degraded more quickly due to the respiration processes during storage [25,29,30].

To slow down the establishment of senescence processes, edible flowers are stored and transported at low temperatures, and this is key to prolonging their shelf life [1,31,32]. Low temperatures (4–5 °C) reduce the flowers' respiration rate and the internal breakdown of tissues by enzymes, slow down the growth of microorganisms, and reduce ethylene biosynthesis, which is a key regulator of flower senescence, especially in ethylene-sensitive flowers, and water loss, thus reducing wilting [11,32]. Along with storage temperatures, proper packaging can further extend edible flowers' shelf life, ensuring food protection and safety from harvest to final consumption [1,26,33]. Various technologies are being developed, such as low-temperature storage (refrigeration and freezing), drying (hot air drying, freeze drying), high hydrostatic pressure, and irradiation, focusing on species such as *Calendula officinalis* L., *Tagetes erecta* L., *Rosa* spp., *Dianthus chinensis* L., *Tropaeolum majus* L., and *Viola odorata* L. Modified atmosphere packaging (MAP) technology, which operates by changing O₂ and CO₂ levels within the food package, thereby reducing respiration rates and microbial growth and slowing down enzymatic activity [32], has been successfully applied to extend fruit and vegetable shelf life [26] but has been poorly studied in edible flowers. In broccoli, cauliflowers [34,35] and squash [36], it was demonstrated to preserve visual quality and weight as well as reduce the loss of health-promoting compounds.

In passive modified atmosphere packaging (passive MAP), the atmosphere inside the tray is altered by the interaction between the respiratory rate of the product and the permeability features of the plastic film used. In active modified atmosphere packaging (active MAP), atmosphere modification is achieved by adding or removing gases from the interior of the tray [37].

The objective of this study was to evaluate the effect of passive and active MAP technology coupled with cold storage on the post-harvest performance of edible flowers, namely *Begonia grandiflora* 'Viking', *Tropaeolum majus* L., and *Viola cornuta* L. These species have edible flowers with different forms and colors and are among the most widely consumed.

2. Materials and Methods

2.1. Plant Material

Potted plants of *Begonia grandiflora* 'Viking', *Tropaeolum majus* L., and *Viola cornuta* L. organically grown under plastic tunnels in the nursery "Fratelli Gramaglia" (Collegno, Italy; 45°05'22.4" N, 7°34'26.4" E, 302 m a.s.l.) were transferred in an air-conditioned van

at 19 °C (1 h travel) to the laboratory of the Agrifood Pole (M.I.A.C. Scpa, Mondovì, CN, Italy) for flower harvesting and packaging.

2.2. Packaging and Storage

Fully open flowers of begonia, nasturtium and viola were harvested, weighed, and packed in polypropylene (PP) trays (245 × 175 × 60 mm), heat sealed with a high-barrier film, through an electric semi-automatic benchtop heat sealer (TSS102-R, J Pack Packaging Machines, Val Brembilla, BG, Italy).

One half of flowers of the three species was packed in normal atmosphere (O₂: 21%; CO₂: 0%) as passive MAP; the other half of the flowers was packed in active MAP (N₂: 100%).

The number of flowers per tray varied according to the species: 6 for begonias, 6 for nasturtiums, and 15 for violas, reaching an average weight of approximately 3.48 g, 2.63 g, and 1.89 g, respectively, per tray; 9 replicates per assay were set up.

Flower trays were then transported to the laboratories of the DISAFA Department and stored at 4° C, in a cold storage room, in the dark, and evaluations were performed on day 2, 4, and 7.

2.3. In Package Gas Composition

Headspace gas composition was surveyed in each flower tray during the storage at 4 °C, using a gas analyzer with 0.1% accuracy (Dansensor CheckMate3, Ametek/Mocon, Ringsted, Denmark) until steady-state was attained. Results were expressed as a percentage (%).

2.4. Visual Decay

Flower decay was evaluated visually referring to wilting and petal discoloration symptoms, and rated through a 5-point scale in relation to marketability acceptance, where 5 = excellent (fresh appearance, no signs of wilting); 4 = good (slight signs of wilting); 3 = acceptable (moderate signs of shriveling); 2 = poor (evident signs of shriveling); 1 = very poor (unacceptable due to petals abscission) [38].

2.5. Color Variation

The main colors were assessed through a spectrophotometer (Konica Minolta Sensing, CM-2600d, Osaka, Japan): pink and red in begonia; yellow, orange and red in nasturtium; yellow, violet, purple and dark purple in viola. For each color, three measurements were made using three different flowers, from three different trays. Three colorimetric parameters were assessed, namely L* (brightness), a* (from +a*—red—to −a*—green), and b* (from +b*—yellow—to −b*—blue) [39].

The color differences were expressed as:

$$\Delta E^* = [(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2]^{1/2}$$

where L₁^{*}, a₁^{*}, and b₁^{*} represent the passive MAP values, while L₂^{*}, a₂^{*}, and b₂^{*} represent the active MAP values.

If ΔE < 1 no color difference is apparent to the human eye. Between 1 and 3 minor color differences may be perceived depending on the hue and eye sensitivity while color differences are evident when ΔE > 3 [40].

2.6. Weight Loss

Weight loss was calculated on three trays for each species as the percentage of weight reduction with respect to the initial weight (day 0) according to the following formula:

$$WL = 100 \times [(W_i - W_t)/W_i]$$

where WL is weight loss (%), W_i is the initial flowers' weight, and W_t is the flowers' weight at time t.

On each sampling day, part of the flowers was stored at $-80\text{ }^{\circ}\text{C}$ for further biochemical analysis.

2.7. Plant Extracts

The extraction process was performed using 1 g of fresh flower in 10 mL of acidified ultrapure water ($0.013\text{ N H}_2\text{SO}_4$). The mixture was agitated at 120 rpm in the dark for 30 min. Subsequently, the resulting extract was centrifuged at 10,000 rpm and $10\text{ }^{\circ}\text{C}$ for 15 min and the supernatant was filtered through $0.22\text{ }\mu\text{m}$ cellulosic membrane syringe filters. The extracts were stored at $-20\text{ }^{\circ}\text{C}$ until analysis (malic acid and sugars contents, TPC, antioxidant activity).

2.8. DAD-RID of Sugars and Organic Acids

The analysis of organic acids and sugars was conducted using HPLC-DAD-RI. The HPLC system (Thermo Electron Corporation, Waltham, MA, USA) included an SCM 1000 degasser, a P2000 binary gradient pump, an AS3000 multiple autoinjector, a UV6000LP photodiode array, and an RI-150 refractive index detector, all connected in series. The mobile phase utilized was acidified water ($0.013\text{ N H}_2\text{SO}_4$), employing an isocratic elution method at a flow rate of 0.6 mL/min . A reverse-phase Aminex HPX-87H column ($300\text{ mm} \times 7.8\text{ mm}$) equipped with a Microguard cartridge (Bio-Rad Laboratories, Hercules, CA, USA) operated at $65\text{ }^{\circ}\text{C}$ was employed for the analysis. Data analysis was performed using a ChromQuest 5.0 chromatography data system (Thermo Electron Corporation, Waltham, MA, USA) and quantification was executed utilizing calibration curves derived from injecting analytical-grade external standards injected in the same conditions [41].

2.9. Total Phenolic Content and Antioxidant Activity

The total phenolic content (TPC) of edible flower extracts was determined following the Folin–Ciocalteu colorimetric method [1,42]: $200\text{ }\mu\text{L}$ of extract was mixed with $1000\text{ }\mu\text{L}$ of diluted (1:10) Folin–Ciocalteu’s reagent. Samples were left in the dark at room temperature for 10 min, and then $800\text{ }\mu\text{L}$ of Na_2CO_3 (7.5%) were added. After a further 30 min in the dark at room temperature, absorbance was read at 765 nm by means of a Cary 60 UV–vis spectrophotometer (Agilent, Santa Clara, CA, USA). The results were compared with a calibration curve constructed using gallic acid as a standard ($1.95\text{--}250\text{ mg L}^{-1}$; $R^2 = 0.9982$), and they were expressed as mg of gallic acid equivalents (GAE) per g of fresh weight ($\text{mg GAE g}^{-1}\text{ FW}$).

The antioxidant activity was evaluated through the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay [43,44]. The working solution of DPPH radical cations ($\text{DPPH}^{\cdot}$, $100\text{ }\mu\text{M}$) was obtained by dissolving 2 mg of DPPH in 50 mL of MeOH. The absorbance at 515 nm of the $\text{DPPH}^{\cdot}$ solution was corrected to a value of 1000 (± 0.005) by adding MeOH. Then, $20\text{ }\mu\text{L}$ of flower extract (or extraction solvent for the control sample) was mixed with 1.5 mL of the $\text{DPPH}^{\cdot}$ radical solution. After 30 min in the dark at room temperature, the absorbance was read at 515 nm , by means of a Cary 60 UV–vis spectrophotometer (Agilent, Santa Clara, CA, USA).

The radical scavenging activity was calculated as:

$$[(\text{Abs}_0 - \text{Abs}_1)/\text{Abs}_0] \times 100$$

where Abs_0 is the absorbance of the control sample and Abs_1 is the absorbance of the sample containing the flower extract. The values were plotted against a Trolox calibration curve ($0.0078\text{--}1\text{ }\mu\text{g }\mu\text{L}^{-1}$; $R^2 = 0.9626$). Results were expressed as μmol of Trolox equivalents per g of fresh weight ($\mu\text{mol TE g}^{-1}\text{ FW}$).

2.10. Statistical Analysis

Data of atmosphere, weight, color, bioactive compounds, and antioxidant activity were firstly analyzed through the Shapiro–Wilk normality test and the Levene homogeneity

test ($p > 0.05$). Mean data were then compared using a one-way or two-way ANOVA test, or a *t*-Test by means of SPSS 28 software (version 28.0; SPSS Inc., Chicago, IL, USA), according to the analyzed data. Means were separated according to the Ryan–Einot–Gabriel–Welsch *F* post hoc test (REGWF). The value for statistical significance was $p < 0.05$. Data groups with non-homogeneous variances were compared through a non-parametric Kruskal–Wallis test with stepwise comparison.

The effect of days and packaging on the data of TPC and antioxidant activity was analyzed with a two-way ANOVA and a post hoc Bonferroni test ($p \leq 0.05$), using R-studio software (2024.04.1).

3. Results

3.1. In Package Gas Composition

During the 7-day storage period at 4 °C, in passive MAP packaging, the O₂ percentage decreased and the CO₂ percentage increased in all the three species, except in begonias, where the CO₂ was never detected (Table 1).

Table 1. Oxygen and carbon dioxide percentage variation in *B. grandiflora* ‘Viking’, *T. majus*, and *V. cornuta* packages during cold storage (4 °C) from day 0 to day 7.

Flower Species	Day	Passive MAP				Active MAP	
		O ₂ (%)		CO ₂ (%)		O ₂ (%)	CO ₂ (%)
<i>Begonia grandiflora</i> ‘Viking’	0	21.00	a	0.00		0.00	d
	2	20.23	d	0.00		0.37	c
	4	20.77	b	0.00		1.47	b
	7	20.60	c	0.00		1.93	a
	<i>p</i>	***		ns		***	
<i>Tropaeolum majus</i>	0	21.00	a	0.00	d	0.00	
	2	19.87	b	0.03	c	0.07	
	4	19.67	b	0.47	b	0.10	
	7	19.30	c	1.03	a	0.10	
	<i>p</i>	***		***		ns	
<i>Viola cornuta</i>	0	21.00	a	0.00	b	0.00	b
	2	20.07	b	0.00	b	0.17	a
	4	19.83	b	0.03	ab	0.07	ab
	7	19.83	b	0.20	a	0.17	a
	<i>p</i>	***		***		***	

Data are presented as the mean values. Mean values showing the same letter are not statistically different at $p \leq 0.05$, according to the one-way ANOVA test (*** = $p < 0.001$; ns = not significant).

In active MAP, the O₂ percentage increased in all the three species, even if the differences were not supported statistically in nasturtium flowers, while the CO₂ was null (Table 1).

3.2. Visual Decay

Begonias, nasturtiums and violas lost visual quality (i.e., senescence symptoms related to turgidity and color) over time, as shown in Figures 1 and 2. After 7 days of storage, begonias showed an acceptable overall appearance (rated 3) in passive MAP and a good overall appearance (rated 4) in active MAP; nasturtiums showed a poor overall appearance (rated 2) in passive MAP and a more than acceptable overall appearance (rated 3.7) in active MAP, while violas resulted in a similarly acceptable overall appearance (rated 3 ca.) in both packaging. However, the latter species was better rated in active MAP (4) than in passive MAP (3) at days 2 and 4 of storage.



Figure 1. Visual quality of *B. grandiflora* 'Viking' (rows 1–2), *T. majus* (rows 3–5) and *V. cornuta* (rows 6–9) flowers stored for 2, 4, and 7 days at 4 °C in polypropylene trays, heat sealed with a high-barrier film. Passive MAP = packaging with a high-barrier film and normal atmosphere; active MAP = packaging with a high-barrier film and modified atmosphere. The white bar corresponds to 1 cm in the reality in each image.

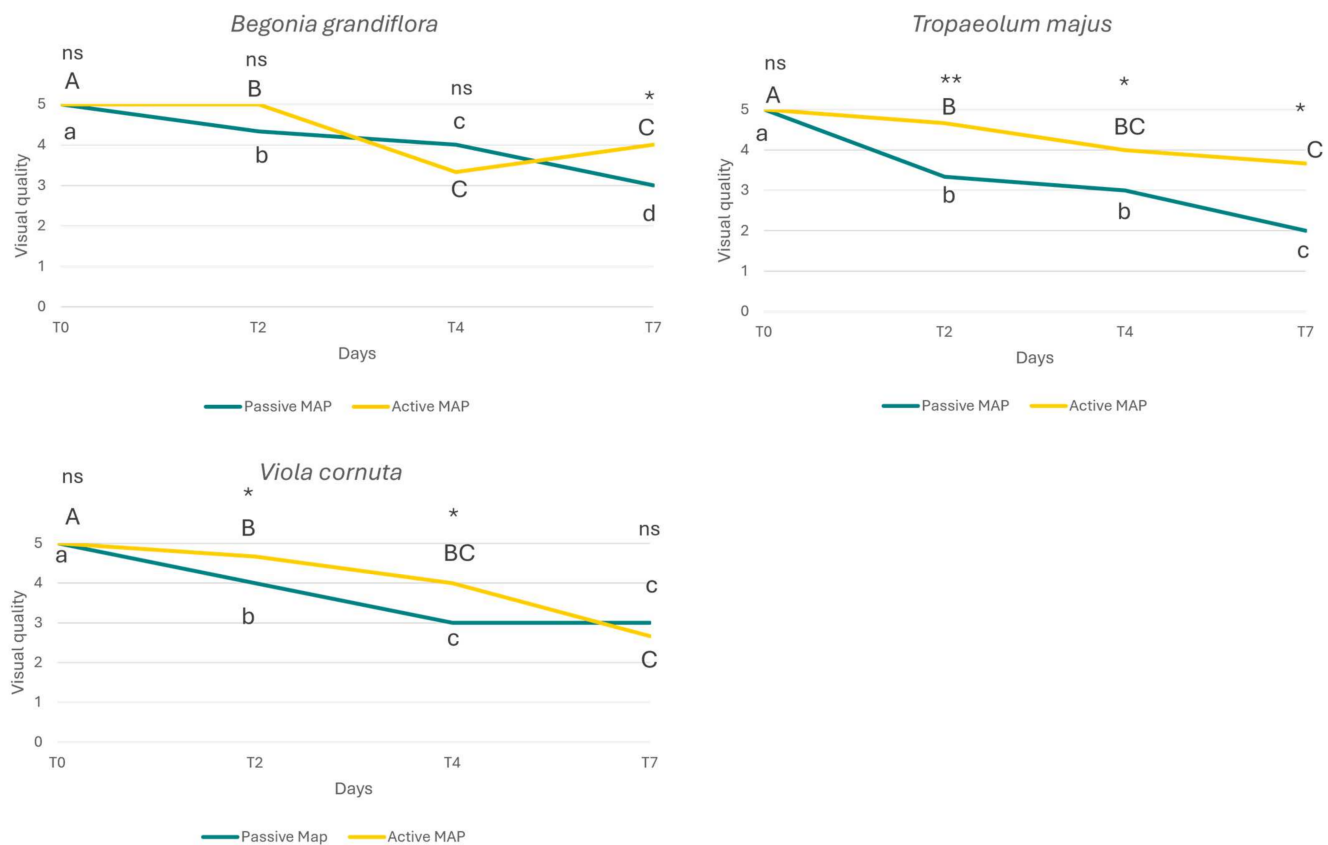


Figure 2. Visual quality differences among *B. grandiflora* ‘Viking’, *T. majus*, and *V. cornuta* during cold storage (4 °C). Passive MAP = packaging with a high-barrier film and normal atmosphere; active MAP = packaging with a high-barrier film and modified atmosphere. Small case letters indicate significant differences in passive MAP over time, while capital letters indicate significant differences in active MAP over time. Asterisks indicate significant differences between passive and active MAP day by day (** = $p < 0.01$; * = $p < 0.05$; ns = not significant).

3.3. Color Variation

During storage, there is a general reduction in all CIELab values for all flowers and packaging: at the end of shelf life, the color is darker due to a reduction in red and yellow (Table 2). The parameter ΔE , which is a combination of L , a and b values, was used to evaluate the color difference between passive and active MAP on days 2, 4, and 7 (Table 2). The ΔE between the two packaging methods is generally already greater than 3 on the second day of storage, except for pink begonias and violet, purple and dark purple violas, for which differences were perceptible after 4 days of storage, and yellow violas, for which the color difference was perceptible after 7 days of storage.

Table 2. CIELab values of *B. grandiflora* ‘Viking’, *T. majus*, and *V. cornuta* flowers during cold storage (4 °C). The ΔE values were evaluated between the two packaging methods for each flower and color.

Flower Species	Color	Packaging		Day 2	Day 4	Day 7	ΔE Day 2	ΔE Day 4	ΔE Day 7
<i>Begonia grandiflora</i> ‘Viking’	Red	Passive MAP	L	50.5	48.8	51.5	7.0	2.1	5.2
			a*	55.3	55.1	54.0			
			b*	22.1	20.8	17.4			
		Active MAP	L	53.2	50.4	50.3			
			a*	55.2	54.6	54.3			
			b*	19.5	19.7	20.3			

Table 2. Cont.

Flower Species	Color	Packaging		Day 2	Day 4	Day 7	ΔE Day 2	ΔE Day 4	ΔE Day 7
<i>Begonia grandiflora</i> ‘Viking’	Pink	Passive MAP	L	73.7	76.1	74.8	1.0	14.5	20.7
			a*	27.9	18.5	16.3			
			b*	1.5	2.5	3.4			
		Active MAP	L	74.5	76.3	76.7			
			a*	27.2	23.9	22.3			
			b*	2.4	2.1	2.2			
<i>Tropaeolum majus</i>	Yellow	Passive MAP	L	76.1	71.5	64.9	34.4	3.0	36.7
			a*	24.9	30.0	35.8			
			b*	103.2	104.9	84.4			
		Active MAP	L	71.3	72.6	65.7			
			a*	31.1	31.8	38.3			
			b*	100.5	103.6	92.5			
	Orange	Passive MAP	L	50.0	44.8	45.8	8.8	20.1	32.8
			a*	62.8	63.8	58.9			
			b*	70.4	58.2	54.2			
		Active MAP	L	47.8	44.9	40.5			
			a*	62.3	63.8	57.9			
			b*	66.9	64.5	48.1			
	Red	Passive MAP	L	22.4	19.1	18.9	25.3	3.7	56.6
			a*	43.4	34.8	25.1			
			b*	29.0	21.3	11.9			
		Active MAP	L	19.4	19.4	20.1			
			a*	39.0	36.2	32.1			
			b*	24.3	23.6	19.9			
<i>Viola cornuta</i>	Yellow	Passive MAP	L	77.4	79.1	72.6	2.6	0.3	19.2
			a*	12.3	11.5	17.5			
			b*	121.0	120.3	112.2			
		Active MAP	L	79.0	79.0	75.8			
			a*	11.9	12.2	12.2			
			b*	119.5	120.6	111.9			
	Violet	Passive MAP	L	41.0	39.5	41.4	1.1	12.7	6.0
			a*	11.7	12.4	10.0			
			b*	−33.9	−34.8	−31.9			
		Active MAP	L	41.7	42.4	39.2			
			a*	10.7	9.1	8.1			
			b*	−33.1	−32.3	−30.0			
	Purple	Passive MAP	L	40.5	45.3	45.1	1.3	74.0	12.1
			a*	34.5	32.8	27.6			
			b*	−19.3	−19.8	−16.8			
		Active MAP	L	39.0	33.5	48.5			
			a*	34.2	35.1	24.4			
			b*	−18.9	−18.2	−15.0			

Table 2. Cont.

Flower Species	Color	Packaging		Day 2	Day 4	Day 7	ΔE Day 2	ΔE Day 4	ΔE Day 7
<i>Viola cornuta</i>	Dark purple	Passive MAP	L	2.5	1.1	3.2	2.0	29.3	12.7
			a*	8.3	8.1	9.0			
			b*	−5.4	−4.2	−7.3			
		Active MAP	L	1.5	2.9	5.2			
			a*	9.9	13.4	13.4			
			b*	−4.6	−9.4	−8.7			

Considering the packaging, there is a greater change in color for passive MAP than for active MAP, as demonstrated by ΔE .

3.4. Weight Loss

Weight remained constant in begonia and in viola flowers in both types of packages (Table 3). Conversely, nasturtium flowers weight decreased both in passive MAP and active MAP packages; however, on day 4, though similar, weight loss was lower in active MAP.

Table 3. Weight loss (WL) percentage of *B. grandiflora* ‘Viking’, *T. majus*, and *V. cornuta* flowers during cold storage (4 °C) from day 0 to day 7.

Flower Species	Packaging	WL (%)						<i>p</i>
		Day 0–2		Day 0–4		Day 0–7		
<i>Begonia grandiflora</i> ‘Viking’	Passive MAP	−2.76		−3.22		−6.03		ns
	Active MAP	−3.51		−4.80		−4.62		ns
	<i>p</i>	ns		ns		ns		
<i>Tropaeolum majus</i>	Passive MAP	−7.72	a	−14.84	ab	−19.28	b	*
	Active MAP	−3.13	a	−3.38	a	−10.42	b	***
	<i>p</i>	*		*		*		
<i>Viola cornuta</i>	Passive MAP	−0.29		−1.69		−4.44		ns
	Active MAP	+7.18		−1.34		−3.87		ns
	<i>p</i>	ns		ns		ns		

Data are presented as the mean values. Mean values showing the same letter are not statistically different at $p \leq 0.05$, according to the REGWF post hoc test. The statistical relevance is provided (*** = $p < 0.001$; * = $p < 0.05$; ns = not significant). Letters are provided only for differences among days in the individual packaging type. The + and − symbols were not calculated through the mathematical formula, but were added so that percentage changes in the table might be interpreted more easily.

3.5. Malic Acid and Sugars Contents

Total sugars and malic acid content showed different ranges: 0.30–9.84 and 0.18–0.33 mg g^{−1} FW in begonia, 15.76–21.66 and 0.20–1.41 mg g^{−1} FW in nasturtium, and 7.03–14.10 and 0.23–2.59 mg g^{−1} FW in viola (Table 4). Generally, no differences were observed due to storage time, except for begonias, where sugars content increased up to day 4 and then decreased, and violas, where there is an increase in malic acid (Table 4). Packaging also did not cause changes, with the exception of begonias, where malic acid was higher in passive MAP and sugars content was higher in active MAP. In this latter species, a significant interaction between the days of storage and the packaging was found for sugars content: in active MAP, the total sugars content increased significantly on day 4 and then decreased.

3.6. Total Phenolic Content and Antioxidant Activity

During storage, TPC ranged from 0.49 to 0.71 mg GAE g^{−1} FW in begonia, from 2.63 to 3.55 mg GAE g^{−1} FW in nasturtium, and from 3.31 to 3.50 mg GAE g^{−1} FW in viola (Table 5). Particularly, in nasturtium, it increased on day 7. Differences emerged in viola between passive and active MAP; however, looking more in detail, in active MAP,

TPC increased in begonia and was constant in nasturtium and viola; in passive MAP, it decreased in viola and was constant in the others. No differences in DPPH were found during storage between passive and active MAP.

Table 4. Variation in malic acid (mg g^{-1}) and total sugars (mg g^{-1}) in *B. grandiflora* ‘Viking’, *T. majus*, and *V. cornuta* according to the days of cold ($4\text{ }^{\circ}\text{C}$) storage (A), the two packaging methods (B), and their interaction ($A \times B$). Data are based on fresh weight (FW).

Days of Storage (A)	<i>Begonia grandiflora</i> ‘Viking’		<i>Tropaeolum majus</i>		<i>Viola cornuta</i>	
	Malic acid mg g^{-1} FW	Total sugars mg g^{-1} FW	Malic acid mg g^{-1} FW	Total sugars mg g^{-1} FW	Malic acid mg g^{-1} FW	Total sugars mg g^{-1} FW
Day 2	0.27 ± 0.10	2.47 ± 3.97 ab	1.11 ± 1.06	17.03 ± 3.52	0.92 ± 0.98 b	8.96 ± 6.03
Day 4	0.33 ± 0.07	5.07 ± 5.30 a	0.77 ± 0.94	20.01 ± 5.12	0.78 ± 0.90 b	10.57 ± 6.44
Day 7	0.23 ± 0.07	0.74 ± 0.43 b	0.57 ± 0.99	16.94 ± 6.48	2.13 ± 0.56 a	10.57 ± 5.79
<i>p</i>	ns	*	ns	ns	**	ns
Packaging (B)	<i>Begonia grandiflora</i> ‘Viking’		<i>Tropaeolum majus</i>		<i>Viola cornuta</i>	
	Malic acid mg g^{-1} FW	Total sugars mg g^{-1} FW	Malic acid mg g^{-1} FW	Total sugars mg g^{-1} FW	Malic acid mg g^{-1} FW	Total sugars mg g^{-1} FW
Passive MAP	0.33 ± 0.07	1.46 ± 3.39	0.84 ± 1.04	16.94 ± 5.41	1.31 ± 1.19	8.04 ± 4.49
Active MAP	0.23 ± 0.08	4.06 ± 4.39	0.81 ± 0.95	19.04 ± 4.82	1.25 ± 0.84	12.02 ± 6.48
<i>p</i>	**	*	ns	ns	ns	ns
Interaction (A $\times$ B)	<i>Begonia grandiflora</i> ‘Viking’		<i>Tropaeolum majus</i>		<i>Viola cornuta</i>	
	Malic acid mg g^{-1} FW	Total sugars mg g^{-1} FW	Malic acid mg g^{-1} FW	Total sugars mg g^{-1} FW	Malic acid mg g^{-1} FW	Total sugars mg g^{-1} FW
Passive MAP						
Day 2	0.33 ± 0.10	3.69 ± 5.90	0.83 ± 1.15	15.76 ± 3.31	1.11 ± 1.19	9.24 ± 7.10
Day 4	0.36 ± 0.04	0.30 ± 0.11	0.73 ± 0.98	18.35 ± 5.09	0.23 ± 0.05	7.03 ± 5.13
Day 7	0.28 ± 0.03	0.39 ± 0.31	0.95 ± 1.43	16.71 ± 8.65	2.59 ± 0.08	7.84 ± 0.21
Active MAP						
Day 2	0.21 ± 0.07	1.26 ± 0.51 b	1.41 ± 1.12	18.29 ± 3.89	0.74 ± 0.93	8.69 ± 6.36
Day 4	0.29 ± 0.08	9.84 ± 1.38 a	0.81 ± 1.13	21.66 ± 5.61	1.33 ± 1.07	14.10 ± 6.33
Day 7	0.18 ± 0.06	1.08 ± 0.10 b	0.20 ± 0.01	17.18 ± 5.48	1.67 ± 0.36	13.28 ± 7.86
<i>p</i>	ns	**	ns	ns	ns	ns

Data are presented as the mean values. Mean values showing the same letter are not statistically different at $p \leq 0.05$, according to the two-way ANOVA post hoc test. The statistical relevance is provided (** = $p < 0.01$; * = $p < 0.05$; ns = not significant).

Table 5. Variation in total phenolic content (TPC) and antioxidant activity (DPPH) in *B. grandiflora* ‘Viking’, *T. majus*, and *V. cornuta* according to the days of cold (4 °C) storage (A), the two packaging methods (B), and their interaction (A × B). Data are based on fresh weight (FW).

Days of Storage (A)	<i>Begonia grandiflora</i> ‘Viking’		<i>Tropaeolum majus</i>		<i>Viola cornuta</i>	
	TPC mg GAE g ^{−1} FW	DPPH μmol TE g ^{−1} FW	TPC mg GAE g ^{−1} FW	DPPH μmol TE g ^{−1} FW	TPC mg GAE g ^{−1} FW	DPPH μmol TE g ^{−1} FW
Day 2	0.49 ± 0.12	6.54 ± 4.23	2.63 ± 0.17 b	3.68 ± 2.79 b	3.32 ± 0.31	18.63 ± 7.35
Day 4	0.69 ± 0.13	8.67 ± 2.30	2.77 ± 0.57 b	4.16 ± 2.93 ab	3.50 ± 0.62	20.54 ± 6.80
Day 7	0.71 ± 0.29	4.25 ± 5.24	3.55 ± 0.48 a	8.52 ± 4.17 a	3.31 ± 0.23	19.39 ± 4.09
<i>p</i>	ns	ns	*	*	ns	ns
Packaging (B)	<i>Begonia grandiflora</i> ‘Viking’		<i>Tropaeolum majus</i>		<i>Viola cornuta</i>	
	TPC mg GAE g ^{−1} FW	DPPH μmol TE g ^{−1} FW	TPC mg GAE g ^{−1} FW	DPPH μmol TE g ^{−1} FW	TPC mg GAE g ^{−1} FW	DPPH μmol TE g ^{−1} FW
Passive MAP	0.60 ± 0.17	4.68 ± 2.90	3.02 ± 0.57	5.62 ± 4.88	3.54 ± 0.45	23.43 ± 4.72
Active MAP	0.66 ± 0.25	8.34 ± 4.53	2.96 ± 0.64	5.67 ± 3.07	3.22 ± 0.29	15.15 ± 3.98
<i>p</i>	ns	ns	ns	ns	*	**
Interaction (A × B)	<i>Begonia grandiflora</i> ‘Viking’		<i>Tropaeolum majus</i>		<i>Viola cornuta</i>	
	TPC mg GAE g ^{−1} FW	DPPH μmol TE g ^{−1} FW	TPC mg GAE g ^{−1} FW	DPPH μmol TE g ^{−1} FW	TPC mg GAE g ^{−1} FW	DPPH μmol TE g ^{−1} FW
Passive MAP						
Day 2	0.51 ± 0.13	5.18 ± 0.74	2.64 ± 0.27	0.72 ± 0.02	3.42 ± 0.42 ab	23.93 ± 3.94
Day 4	0.78 ± 0.13	6.94 ± 1.95	2.96 ± 0.77	4.76 ± 3.51	4.01 ± 0.29 a	25.17 ± 7.13
Day 7	0.50 ± 0.04	0.55 ± 0.24	3.45 ± 0.38	9.76 ± 4.48	3.19 ± 0.17 b	21.18 ± 3.18
Active MAP						
Day 2	0.47 ± 0.13 b	7.89 ± 6.22	2.63 ± 0.08	5.65 ± 1.01	3.22 ± 0.21	13.33 ± 5.94
Day 4	0.60 ± 0.05 ab	10.40 ± 0.68	2.58 ± 0.34	3.27 ± 2.65	2.99 ± 0.30	15.92 ± 0.81
Day 7	0.92 ± 0.29 a	6.72 ± 5.67	3.66 ± 0.62	7.28 ± 4.34	3.44 ± 0.23	16.72 ± 4.77
<i>p</i>	*	ns	ns	ns	**	ns

Data are presented as the mean values. Mean values showing the same letter are not statistically different at $p \leq 0.05$, according to the two-way ANOVA post hoc test. The statistical relevance is provided (** = $p < 0.01$; * = $p < 0.05$; ns = not significant).

4. Discussion

4.1. Visual Decay, Color Variation and Weight Loss

The edible flowers’ high perishability may be due to their respiration rate, as already shown by other horticultural commodities [39]. In this study, active MAP proved to be effective in reducing the respiration rate of the edible flowers, as already observed by Aquino-Bolaños and colleagues [36] on *C. pepo* edible flowers. Indeed, in the packages, O₂ percentage generally increased, although only by a small amount, while CO₂ percentage did not increase, thus carbon dioxide remained null (Table 1), differently from what happens in passive MAP.

Normally, during the senescence process, flowers undergo dehydration and pigment degradation, leading to tissue browning due to the oxidation and polymerization of phenolics into brown pigments [39]. In this study, begonia and viola flowers maintained their weight regardless of packaging type. Conversely, nasturtium flowers lost weight both in passive and active MAP, but lost less weight in active MAP (Table 3) [45]

As expected, CIELab values decreased in all the species during senescence, but they were preserved for longer in active MAP than in passive MAP (Table 2). This type of packaging probably contributed to a better retention of anthocyanins, especially in pink begonias and viola, where no color differences occurred during the first 2 days of storage (Table 2). This is important since color is the most important parameter applied by customers when purchasing edible flowers [45–47]. Consistently, in active MAP, visual quality was also better. Begonia and viola showed a 7-day shelf life, similarly to that found in

Begonia semperflorens and *Begonia elatior* by Demasi et al. [1] and Friedman et al. [48], but they were both rated better (4) in active MAP than in passive MAP (3) (Figure 2).

Nasturtium visual quality was extended by active MAP by approximately twice as much. This species showed a 4-day shelf life when stored in passive MAP, while it had a 7-day shelf life when stored in active MAP (Figure 2). Weight loss of this species on day 4 was lower in active MAP than in passive MAP (Table 3), as similarly previously observed during cold storage of *T. majus* flowers (MAP = 5–10% CO₂; 10% O₂; 80–85% N₂) [49] and baby spinach leaves (MAP = 15% CO₂; 5% O₂; balance N₂) [45]. Active MAP probably better preserved water losses, delaying the degradation of pigments [50]. Active MAP particularly contributed to better maintenance of the yellow and red colors of *nasturtium* flowers (Table 2), thus probably preserving the carotenoid content from degradation due to free radicals, as already observed in other edible flowers, such as broccoli (*Brassica oleracea* var. *italica*) heads stored under a controlled atmosphere (10% O₂, 5% CO₂), and squash edible flowers stored under a modified atmosphere (10%CO₂ + N₂) [34,36]. These findings confirmed what was previously observed in vegetables, e.g., asparagus, carrots and endive, asserting how MAP combined with low temperatures effectively reduced pigment degradation, partly due to delaying senescence processes [51–53].

4.2. Total Sugars and Malic Acid Contents

Usually total sugars and organic acids contained in the petals are expected to decrease as they are the main substrate for respiration during post-harvest storage [36].

One of the major organic acids found in edible flowers, such as dandelion, tulip or dahlia, is malic acid [29].

In *nasturtium* and *viola*, the total sugars and malic acid contents remained constant in both packaging (Table 4); in *begonia*, the interaction between storage time and packaging type highlighted how active MAP better preserved the total sugars content than passive MAP, in accordance with Cefola and colleagues' [54] findings in *C. pepo* edible flowers. Thus, active MAP was more effective in slowing down the respiration process, as witnessed by the inner gas composition, slowing down the sugars' degradation.

Malic acid may have a protective role against cardiovascular and antimicrobial diseases, thanks to its antioxidant activity, together with other numerous bioactive compounds, such as the phenolics [5,8,55].

4.3. Total Phenolic Content and Antioxidant Activity

Edible flowers are generally rich in phenolic compounds [5,8]. *Begonia* showed TPC values lower than other congeneric species, e.g., *B. x semperflorens-cultorum* Hort. (from 1.34 to 2.65 mg GAE g^{−1} FW [1]), or pink *Begonia x tuberhybrida* flowers (4.82 mg GAE g^{−1} of fresh mass—[56]).

Nasturtium showed TPC values ranging from 2.58 to 3.66 mg GAE g^{−1} FW and AOA values ranging from 0.72 to 9.76 μmol TE g^{−1} FW (Table 5), which were similar to the values found by Mlcek and colleagues [56] (3.23 mg GAE g^{−1} FW) and Demasi and colleagues [5,12] (from 4.53 to 14.8 μmol TE g^{−1} FW). Garzón and Wrolstad [57] found higher values (4.06 mg GAE g^{−1} FW; 91.9 μmol TE g^{−1} FW); however, they used acetone as the extracting material, which is probably more efficient in the extraction of phenolics than water [58].

Viola showed TPC values ranging from 2.99 to 4.01 mg GAE g^{−1} FW and AOA values ranging from 13.33 to 25.17 μmol TE g^{−1} FW (Table 4), which were similar to what was previously found in *V. cornuta* (from 1.80 to 8.77 mg GAE g^{−1} FW, [1]), but lower than the values of other congeneric species, e.g., *V. calcarata* L. (from 7.19 to 11.16 mg GAE g^{−1} FW, [10]; from 64.27 to 99.53 μmol TE g^{−1} FW, depending on the color of the flower [10]). The lower values we obtained may be due to the harvest season, i.e., autumn; in fact, it is well known how the harvest season and the climatic conditions affect the production of secondary metabolites and the antioxidant activity, as highlighted in *Rosa* edible flowers [9]. Variations in TPC and AOA were also found in blueberry (*Vaccinium ashei*) leaves [59], as

well as in wild-growing nettle (*Urtica dioica* L.) leaves [60], according to the harvest season. The leaves showed the highest antioxidant activity in May, as well as high concentrations of polyphenols. Since oxidative stress increases with senescence process, polyphenols generally decrease during post-harvest [8]. In this study, considering the three species, in passive MAP, the values were constant or tended to decrease over time, while in active MAP, the values were constant or tended to increase, as previously observed in Red Chard baby leaves stored in N₂-enriched MAP [61]. Thus, active MAP helped to better preserve TPC than passive MAP.

Active MAP probably counteracted free radical production and prevented the acceleration of degradation processes [8]. Similarly, Aquino-Bolaños and colleagues [36], who assessed edible squash flowers under three different gas compositions, found that the controlled atmosphere can maintain the amount of polyphenols and the antioxidant activity during storage.

Therefore, active MAP combined with low-temperature storage showed interesting potential to preserve edible flowers over an extended period of time, by maintaining visual quality and bioactive compounds for longer, thus preserving their beneficial properties for human health. Widening the research on more edible flower species is necessary to enhance the commercial development of this technology.

5. Conclusions

Active MAP coupled with cold storage was effective in maintaining petal colors and slowing down the edible flowers' decay better than passive MAP by decreasing flower respiration in all three species and sugars consumption in begonia; there was weight loss in nasturtium, and it better preserved TPC in begonia and viola. Thus, this technology could make edible flowers available on the market for a longer period of time and on a larger area near the production site. Although this study made use of plastic trays, modified atmosphere technology should be applied to alternative biodegradable/compostable packaging in the future to fulfil the need to replace conventional plastic packaging with bio-based materials.

Author Contributions: Conceptualization, V.S.; methodology, V.S.; investigation, N.M.F., V.G., M.G., N.S.Z. and V.C.; resources, V.S.; data curation, N.M.F., S.S. and G.Z.; writing—original draft preparation, N.M.F. and V.S.; writing—review and editing, N.M.F., S.S., G.Z. and V.S.; supervision, V.S.; funding acquisition, V.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the European Regional Development Fund (ERDF), program Interreg V-A Francia Italia Alcotra (Grant No. 8336 “ANTES-Fiori eduli e piante aromatiche: attività capitalizzazione dei progetti ANTEA ed ESSICA”).

Data Availability Statement: The original contributions presented in this study are included in this article. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors thank Agrifood Pole (M.I.A.C. Scpa, Mondovì, CN, Italy) for packaging services and advice.

Conflicts of Interest: The authors declare no conflicts of interest.

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