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To cite this article: Luana Fernandes, Jorge A. Saraiva, José A. Pereira, Susana Casal & Elsa Ramalhosa (2019) Post-harvest technologies applied to edible flowers: A review, Food Reviews International, 35:2, 132-154, DOI: [10.1080/87559129.2018.1473422](https://doi.org/10.1080/87559129.2018.1473422)

To link to this article: <https://doi.org/10.1080/87559129.2018.1473422>



Published online: 16 May 2018.



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Post-harvest technologies applied to edible flowers: A review

Edible flowers preservation

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ABSTRACT

This review intends to summarize the current knowledge on the post-harvest technologies applied to edible flowers, to help producers to increase their market share and to inform consumers on the technologies that are available to maintain edible flowers' quality and safety. Emerging post-harvest technologies as High Hydrostatic Pressure (HHP) or irradiation have given good results. Freeze- or vacuum-drying has shown to be highly effective in the preservation of flowers' bioactive compounds in comparison with classical drying approaches. While osmotic dehydration is already in use, the application of edible coatings and films can be a healthier alternative, without increasing solute contents.

KEYWORDS

Drying; edible flowers; high hydrostatic pressure; post-harvest technologies; shelf-life

Introduction

Flowers have held an eminent place in art, religion, health, and culinary since ancient times. Particularly, the popularity of edible flowers has increased since the late 1980s. The market of edible flowers is becoming more important due to the increased number of recipe books, magazine articles, and websites on the theme, as well as to the growth of research on their nutritional and bioactive potential.^[1,2] However, the market for edible flowers still receives less attention than that of other products, such as vegetables and fruits, because the production of edible flowers is still low and it is still a niche market.

Edible flowers are highly perishable, with short shelf life of 2–5 days after harvest^[3], with early petal abscission and discoloration, flower wilt, dehydration, and tissue browning. Compared with other types of flowers, edible flowers are more vulnerable than cut flowers used for decoration purposes, because their stems are cut very short and they are stored without additional water supply. Although some publications recommend that flowers should be harvested in the same day that they will be consumed, this advice limits their commercial viability.^[4] Until now, no guidelines have been established for storage of edible flowers and few detailed studies have been done on the factors that limit their quality.^[3] Presently, most edible flowers are sold fresh, packaged in small, rigid plastic (or plastic wrapped) packages and placed next to fresh herbs in refrigerated sections.^[5] Pansy,

borage, rose, centaurea, nasturtiums, begonia, carnation, and hibiscus are examples of edible flowers that are normally used to garnish dishes. The most common postharvest methods applied to these edible flowers are refrigeration, drying, canning in sugar, and preservation in distillates. Nevertheless, other edible flowers are more known by consumers as vegetables, such as artichoke, broccoli, and cauliflower, even though these are inflorescences. The food industry preserves these species at low temperatures and through suitable packaging, transportation, and maintenance of storage atmosphere.

However, this industry is very interested in improving marketability of edible flowers, not only as fresh but also as processed products. In this sense, the application of new food preservation technologies able to increase the shelf life of edible flowers will bring important economic benefits, beyond allowing the preservation of the product quality for longer periods of time. So, the aim is to review the current knowledge on the most advanced post-harvest technologies applied to edible flowers, in order to help producers to increase their market share, and allow their transportation over wider geographical areas, showing also to the scientific community the fields that require further studies. Simultaneously, the present review also aims to inform consumers on the technologies that are available to preserve edible flowers' quality and safety.

Edible flowers

Until now, no official lists of edible flowers have been published by any international body, but according to Lu et al. ^[6], there are 97 families, 100 genera, and 180 species of edible flowers worldwide. Several edible flowers usually eaten by consumers are not recognized as flowers, as artichoke (*Cynara scolymus*), broccoli, and cauliflower (*Brassica oleracea*), being considered vegetables. Also, several flowers usually used for ornamental purposes have edible parts, including pansy (*Viola x wittrockiana*), centaurea (*Centaurea cyanus*), borage (*borage officinalis*), rose (*Rose* spp.), nasturtiums (*Tropaeolum majus*), and hibiscus (*Hibiscus rosa-sinensis*). Flowers of some fruit trees can also be used in cuisine, such as elderberry blossoms (*Sambucus* spp.) and citrus blossoms (orange, lemon, lime, grapefruit, kumquat). Moreover, some herb flowers are also edible, namely alliums (leeks, chives, garlic), thyme (*Thymus vulgaris*), summer savory (*Satureja hortensis*), marjoram (*Origanum majorana*), mint (*Mentha* spp.), and common sage (*Salvia officinalis*).

The importance of improving edible flowers market

Edible flowers can be part of a diversification plan for market gardeners, especially organic growers, since most of them cannot survive by growing only edible flowers. So, edible flowers are usually grown in conjunction with other cultures, such as cut flowers and herbs, to complement growers' incomes and create opportunities for value-added products. Nowadays, the price varies with the flower and state in which it is sold. For example, the price of 20 fresh pansies (20 flowers) is 6.80 euros in the Spanish company "Flores frescas" (0.34 euros/unit) and of six fresh calendulas is 2.46 euros in the New Zealand company "Kahikatea Farm" (0.41 euros/unit). Furthermore, flowers subjected to post-harvest treatment are generally sold at a higher price than fresh (e.g., 12 crystallized violas cost 19.70 euros in the English company "Meadowsweet flower", corresponding to 1.6 euros/unit).

Around the world there are a lot of companies that are dedicated to edible flowers selling, such as Fleurs et saveurs, ERVAS finas, Meadowsweet flower, BloomBites, and Green farm, whose production has been increasing. In addition, there are some campaigns that promote the consumption and production of edible flowers. For example, “The Herbs of Brussels” in Belgium; “Food safety: Edible flowers” in Thailand; “Look & Taste” in Netherlands and “Essai fleurs comestibles: Transfert et communication” in France. In this sense, edible flowers have become a culinary trend, referred to in international culinary magazines, such as Bon appetit “How to use edible flowers in salads, cocktails, and more”^[7] and Food and Wine “The Edible Flower”.^[8] The clients of edible flowers are gourmet restaurants and their associated food service operations, and grocery stores. So, to eat edible flowers is a new trend, described as one of the “six trends of food and drinks in summer”.^[9] Consequently, the consumption of edible flowers is expanding around the world. This market needs to increase the production, to guarantee better quality and to have more variety of flowers, as well as with longer shelf life.

Compared to other kinds of flowers, edible flowers are more vulnerable to postharvest quality loss than cut flowers, because their stems are cut very short and they are stored without additional water supply. Nowadays, edible flowers are often packed in containers and must be used within 2–5 days after harvest, which requires air transportation to reach most regions before the end of their shelf life. Thus, to find new ways of increasing their shelf life is a big challenge.

Post-harvest technologies

The increasing application of edible flowers in various food commodities demands for new technological approaches to improve their distribution and marketing efficiency as fresh products or minimally processed products. Prolonging post-harvest storage, while preserving the whole quality of edible flowers, will benefit their industrial development, as well as consumers’ health. Therefore, the food industry is investing considerable resources to develop new technologies that can maintain all properties and quality of edible flowers, and to meet consumers’ expectations. This section describes some conventional techniques used in edible flowers’ preservation, as well as emerging nonthermal methods (ex: high hydrostatic pressure (HHP) and irradiation) and packaging approaches. As some edible flowers, such as artichoke, broccoli and cauliflower (*B. oleracea*), are not frequently recognized as edible flowers by the consumers, they will be discussed separately from the other edible flowers.

Low temperature storage

Temperature is one of the most important environmental factors limiting the shelf life of fruits, vegetables, and herbs.^[10] Until this moment, the main technologies used by the industry of edible flowers are cold storage (refrigeration and freezing) and hot-air drying, as will be detailed below.

Cold storage delays flower senescence and quality deterioration during storage. Storage at low temperatures is associated with an increase of flowers’ shelf life, because there is a reduction of respiration and internal breakdown of tissues by enzymes, reduction of water loss and wilting, slower growth of microorganisms, and reduction of ethylene production.^[11]

Several studies dealing with freezing and refrigerated storage have been conducted, with their most important details and conclusions assembled in [Tables 1](#) and [2](#). Regarding

Table 1. Post-harvest technologies applied to edible flowers.

Post-harvest technologies	Edible flowers	Treatment/storage conditions	Reference
Low temperature	Borage (<i>Borago officinalis</i>)	Polyethylene bags, −2.5 to 20°C	[5]
	Heartsease (<i>Viola tricolor</i>) Nasturtium (<i>Tropaeolum majus</i>)	Polyethylene bags, at −2.5, 0, 2.5, 5, 10, 20°C	[5]
	Pansies (<i>Viola × wittrockiana</i>)		
	Pumpkin (<i>Curcubita pepo</i>)	2.5 and 5°C, 2 weeks	[4]
	Runner bean (<i>Phaseolus coccineus</i>)	Polyethylene bags at −2.5, 0, 2.5, 5, 10, 20°C	[5]
	Drying methods	Black locust (<i>Robinia pseudoacacia</i>)	Sun (3 days, 35°C), hot-air (60°C), freeze (−80°C for 12 h) and microwave-vacuum (1500 W, 70 kPa) drying
Carnation (<i>Dianthus chinensis</i>) (red and pink)		Freezing (−35°C, 2 and 4 h) + vacuum drying (27, 37, and 47°C, 0.004–0.007 kPa)	[23]
Daylily (<i>Hemerocallis disticha</i>)		Hot-air (50°C) and freeze-drying	[20]
Marigold (<i>Tagetes erecta</i>)		Freeze (FD) (48 h), hot air (HA) (60°C for 4 h) and combined far-infrared radiation with hot-air convective (FIR-HA) drying	[21]
Purple coneflower (<i>Echinacea purpurea</i>)		Freeze (−55°C for 4 days), vacuum microwave with full vacuum (1 kW for 47 min) and air (70°C for 13 h; 40°C for 55 h; 25°C for 1 week) drying	[24]
		Vacuum freeze (VFD), cool wind (CWD) (30°C), and hot air (HA) (40, 55, or 70°C) drying	[22]
Rose (<i>Rose</i> spp.) (red and pink)		Freezing (−35°C, 2 and 4 h) + vacuum drying (27, 37 and 47°C, 0.004–0.007 kPa)	[23]
High Hydrostatic Pressure (HHP)		Borage (<i>Borago officinalis</i>)	75, 150 and 450 MPa, 5 and 10 min
	Camellia japonica (<i>Camellia japonica</i>)	75 MPa, 1 and 5 min 100 MPa, 5 min	
	Centaurea (<i>Centaurea cyanus</i>)	75, 100, 200, and 300 MPa, 5 min	
	Pansies (<i>Viola × wittrockiana</i>)	75 MPa, 5 and 10 min	
	Purple coneflower (<i>Echinacea purpurea</i>)	600 MPa, 2 and 5 min	[38]
	Irradiation Ionising	Borage (<i>Borago officinalis</i>)	⁶⁰ Co (0, 0.3, 0.6, 0.8, and 1.0 kGy)
Carnation (<i>Dianthus chinensis</i>)			
Heartsease (<i>Viola tricolor</i>)		⁶⁰ Co (0.5, 0.8, and 1 kGy), room temperature	[59]
Nasturtium (<i>Tropaeolum majus</i>)		⁶⁰ Co (0.5, 0.8, and 1 kGy), room temperature	[58]
Sweet alyssum (<i>Lobularia maritima</i>)		⁶⁰ Co (0, 0.3, 0.6, 0.8, and 1.0 kGy)	[57]
Wood violet (<i>Viola odorata</i>)		⁶⁰ Co (0, 0.3, 0.6, 0.8, and 1.0 kGy)	[57]

T: Increased; I: Decreased.

Table 1, relative to edible flowers not including artichoke and *Brassica* species, good results have been obtained with temperatures at −2.5°C (ex. borage), 2.5°C (heartsease, nasturtium, pansies, and pumpkin) and 5°C (pumpkin) for up to two weeks. It must be

Table 2. Post-harvest technologies applied to artichoke, broccoli and cauliflower.

Post-harvest technologies	Edible flowers	Treatment/storage conditions	Reference
Low temperature	Artichoke (<i>Cynara scolymus</i>)	0, 2, 5, 7, and 10°C for 14 days	[15]
	Broccoli (<i>Brassica oleracea</i> var. <i>italica</i>)	–20°C and –30°C for 30 and 50 min, respectively The frozen products, packed in polythene bags, were stored for 12 months at both temperatures. Cooled room (2°C with 95% RH), top-iced (4 kg of flaked ice then placed in 2°C storage), or hydro-cooled (12 min using water at 1°C) for 14 days First experiment: Four treatments: – hydro-cooling alone – hydro-cooling combined with wrap – non-cooling and no wrap – non-cooling but with wrap Storage conditions 3, 10, and 17 days at 1°C and placed afterward at 13°C. Second experiment: 1 or 5°C, 95% relative humidity for a period of 10 days.	[16] [13] [14]
Drying methods	Cauliflower (<i>Brassica oleracea</i> var. <i>botrytis</i>)	2, 13, and 23°C over 144 h –20°C and –30°C for 30 and 50 min, respectively. The frozen products, packed in polythene bags, were stored for 12 months at both temperatures. Traditional technology: blanching (95–98°C, approx. 3 min) + freezing (–20 and –30°C) Modified technology: cooking (boiling water, 6 min) + freezing (–20 and –30°C) Storage for: 0, 4, 8, 12 months at –20 or –30°C. –24°C for 3, 6, 12 months	[12] [16] [17]
	Broccoli (<i>Brassica oleracea</i> var. <i>italica</i>)	Hot-air (37, 42, 45, 48, 50°C for 1 or 3 h) Storage conditions: At 20°C for 4 days Osmotic dehydration: 40% (w/w) syrups of trehalose, 35°C, 2 h Ultrasound assistant osmotic dehydration for 10, 20, 30, and 40 min	[25] [27]
Edible coating	Cauliflower (<i>Brassica oleracea</i> var. <i>botrytis</i>)	Osmotic dehydration: salt and sucrose (cane sugar), alone and in combination (optimum condition: 3% salt and 6% sucrose for 12–16 h at 4°C) Osmotic dehydration: salt concentration (5–25%), temperature (40–90°C), ratio of brine to material (2–4, w/w) and time (5–180 min) (optimum condition: 12% (w/w) brine, 80°C, 5 min in 2 times)	[28] [29]
	Artichoke (<i>Cynara scolymus</i>)	Dipping: citric acid and calcium chloride solution Coating: Sodium alginate with citric acid After, packaging in: – multilayer-film (All-PE) – biodegradable monolayer film (NVT2) – oriented polypropylene film (OPP) Storage conditions: 4°C for 6 days	[32]
	Broccoli (<i>Brassica oleracea</i> var. <i>italica</i>)	Chitosan coating	[33]

(Continued)

Table 2. (Continued).

Post-harvest technologies	Edible flowers	Treatment/storage conditions	Reference
		Chitosan and chitosan enriched with bioactive compounds (bee pollen, ethanolic extract of propolis, pomegranate dried extract and resveratrol) and essential oils (tea tree, rosemary, clove, lemon, oreganum, calendula, and aloe vera) coatings	[34]
		Chitosan or carboxymethyl-cellulose (CM) with or without a previous application of a mild heat shock of 1.5 min at 50°C	[31]
Edible film	Cauliflower (<i>Brassica oleracea</i> var. <i>botrytis</i>)	Methyl cellulose-based edible films of various compositions	[35]
High	Broccoli	180 MPa, -16°C and 210 MPa, -20°C	[39]
Hydrostatic Pressure (HHP)	(<i>Brassica oleracea</i> var. <i>italica</i>)	50–500 MPa, 15–60°C between 4–90 min	[40]
		100–500 MPa, 20–40°C, 15 or 35 min	[41]
		Blanching + 210 MPa at -20.5°C or 210 MPa, liquid N ₂	[43]
		600 MPa, 25 and 75°C, 10, 20 and 40 min.	[44]
		400 and 600 MPa, 2 min	[45]
		0.1–600 MPa, 25–45°C, 30 min	[73]
		0.1 and 800 MPa, 20°C, 10 min	[42]
	Cauliflower (<i>Brassica oleracea</i> var. <i>botrytis</i>)	400 MPa, 5°C, 30 min.	[47]
		200 MPa, 5 min	[46]
		200, 300, 350, and 400 MPa, 5°C, 30 min	[48]
Irradiation	UV Broccoli (<i>Brassica oleracea</i> var. <i>italica</i>)	UV-B (4.4, 8.8, and 13.1 kJ m ⁻²)	[53]
		UV-C (4, 7, 10, and 14 kJ m ⁻²)	[51]
		UV-C (8 kJ m ⁻²)	[54]

†: Increased; ‡: Decreased.

emphasized that temperatures lower than -2.5°C have not been tested until now in this type of edible flowers. However, the effect of temperature on each flower must be studied in an independent way because, for example, no good results were obtained for the scarlet runner bean flowers when temperatures between -2.5 and 20°C were applied for two weeks. Furthermore, the parameter most evaluated until now has been the visual quality/appearance. On the other hand, more parameters have been determined in artichoke, broccoli, and cauliflower when stored at low temperatures, such as vitamin C, phenolics, weight loss, lipid peroxidation, total carotenoids, and β-carotene, among others. In general, refrigeration is also an efficient approach for artichoke, broccoli, and cauliflower. For example, a temperature at 2°C does not accelerate the deterioration and lipid peroxidation of broccoli buds when compared to 13 or 23°C. [12] Furthermore, fast cooling after harvest has been tested in broccoli, with the aim to reduce the metabolic activity that can result in deterioration. [13] Among the different methods of rapid cooling that have been applied to broccoli, hydro-cooling alone, or combined with wrapping with perforated film, has given good results, with lower weight losses, firmness maintenance, and color retention. [13,14] In artichoke, vitamin C content decreased (approx. 28–34%) after 14 days of storage under the assayed temperatures (0, 2, 5, 7, and 10°C), while chlorogenic, 1,4-dicaffeoylquinic, and 4,5-dicaffeoylquinic acids contents increased in the internal bracts after storage, particularly at 2, 5, and 7°C. [15]

Regarding freezing, this has been tested mostly with cauliflower and broccoli. It was observed that the freezing process itself did not cause vitamin C loss.^[16] However, during storage, a small reduction on vitamin C content in broccoli (15–18%) and cauliflower (6–13%) were observed, slightly lower at -30°C than at -20°C .^[16] When freezing cauliflower, it seems to be advantageous to previously immerse it in boiling water for 6 min instead blanching at $95\text{--}98^{\circ}\text{C}$ (approx. 3 min) in order to retain the vitamin C, antioxidant activity, polyphenols, total carotenoids, and β -carotene.^[17] Another study in cauliflower concluded that long-term freezing storage (12 months) did not significantly affect the total aliphatic and indole glucosinolates in this flower.^[18]

In summary, different temperatures have different effects on the quality and appearance of each type of edible flowers, with the possibility to increase the shelf life of some of them by decreasing the storage temperature. However, more studies should be done in the future for specific applications and over a higher range of temperatures.

Drying

Drying is an important process for handling foods to prolong their shelf life, as well as to inhibit enzymatic degradation, prevent the growth of microorganisms, and reduce weight for cheaper transport and storage. There are many different drying methods, some of them already used in edible flowers, such as hot-air drying, freeze drying, vacuum microwave drying, cool wind-drying, sun drying, and osmotic drying, as well as those involving combinations of these (Table 1). Among them, drying by application of heat (ex. hot-air drying and sun drying) is a classical approach, as for tea petal preparation, but it has some drawbacks, such as undesirable biochemical and nutritional changes in the processed product that may affect its overall quality.

Most of the studies in edible flowers have tested different methods of drying and have evaluated their effects on flowers' quality (Table 1). Black locust flowers submitted to freeze drying had higher antioxidant activity (DPPH radical scavenging, reducing power, and hydroxyl radical scavenging ability) when compared to sun drying, hot-air drying and vacuum-microwave drying.^[19] When comparing freeze drying with hot-air drying, the first process resulted in a lower loss of carotenoids in daylilies^[20] and the highest levels of lutein and lycopene in marigold.^[21] Freeze drying also retained more bioactive compounds (caffeic acid derivatives and total phenolics) in purple coneflower.^[22] Regarding red rose and carnations, higher vacuum-drying temperatures resulted in stiffer flowers and a greater color change.^[23] Nevertheless, generally good results have been obtained with freeze drying.

Sun-dried black locust flowers had the worst antioxidant activities and phenolic content^[19], suggesting that sun drying may cause loss of important bioactive compounds. The use of high temperatures (ex. 70°C) in hot-air convective drying may also cause losses of caffeic acid derivatives^[22,24] and total phenolics^[22] in purple coneflowers. However, in marigold the highest β -carotene content was obtained when applying hot air convective drying (60°C , 4 h).^[21]

Concerning vacuum-microwave drying, its ability to retain the color of purple coneflower and caffeic acid derivatives content when compared to conventional air drying has been reported by Kim et al.^[24] Black locust flowers subjected to vacuum-microwave drying also had high total phenolic content and iron-chelating ability, showing vacuum-microwave drying to be a more economical method than freeze drying because it only

requires minutes instead of hours or days. ^[19] This makes it an interesting technology to be studied more in the future. Combining far-infrared radiation with hot-air convection drying allowed the color preservation of marigolds, and maintained the highest values of phenolic compounds, as well as of lutein and lycopene, when compared to untreated flowers (fresh). ^[21]

Regarding broccoli, cauliflower, and artichoke, hot air drying has only been applied to broccoli inflorescences (Table 2). Broccoli heads treated with hot air at 48°C for 3 h presented an important delay in their senescence at 20°C and contributed to the maintenance of an overall better quality (retention of chlorophyll content and higher contents of sugars, proteins, and antioxidants). ^[25] Another drying process that has been applied to broccoli and cauliflower is osmotic dehydration, which is a water removal process involving soaking foods in a hypertonic solution. It is also used as a pre-treatment before other processes, to improve the quality of the final product and to reduce the water activity inhibiting the microbial growth. ^[26] Until now, no studies have been done on the effect of osmotic dehydration on edible flowers, but some works have been conducted in inflorescences, such as broccoli ^[27] and cauliflower. ^[28,29] The osmotic solutions used in those works were sweet (ex: trehalose ^[27] and sucrose ^[28]), salty (ex: sodium chloride), ^[28,29] and in combination. ^[28] Until now, the studies done on cauliflower investigated the optimum conditions of osmotic dehydration, considering the quality of the final product. Jayaraman et al. ^[28] reported that the optimum treatment consisted in soaking in 3% salt and 6% sucrose for 12–16 h at 4°C, giving a shelf life increase from 3 to 12 months at ambient temperature when packaged in paper-foil-polythene laminate. On the other hand, Vijayanand et al. ^[29] reported a much faster process, using 12% (w/w) salt at 80°C for 5 min (twice). The concentration of the osmotic solution, temperature, agitation, osmotic solutes, and food pieces size are factors that affect the osmotic process. In broccoli, the only study on osmotic dehydration performed until now evaluated the effectiveness of osmotic dehydration alone or assisted with ultrasound (method applied to increase the mass transfer rate). ^[27] Compared with the normal osmotic dehydration during 2 h, an ultrasound-assisted dehydration for a shorter time (30 min) increased the water loss, caused higher accumulation of trehalose and decreased the mobility of water in the broccoli cell tissue; however, when applying an ultrasound treatment time of 40 min, opposite results were observed. Thus, these data showed the important role of the time treatment in ultrasound-assisted osmotic dehydration process, being necessary to perform more studies in the future.

In conclusion, drying methods can affect the quality of edible flowers, but these changes can be minimized by the appropriate design and choice of the drying process based on specific flowers properties, technological availability, and economic impact.

Edible films and coatings

Edible films and coatings are distinct methods used by the food industry. A film can be defined as a thin skin formed and then applied to the product (e.g., through casing with a biopolymer solution prepared separately from the food that is later applied to), while coating is a suspension or an emulsion applied directly on the surface of the food, leading to the subsequent formation of a coating. ^[30] However, both are generally based on biological materials, such as proteins, lipids, and polysaccharides. Presently, both methods are already used in fruits and vegetables, acting mainly as a barrier against gas transport and microorganism growth. ^[31] Regarding edible coatings, no studies have been done on

edible flowers and a few works have been published on artichoke and brassicas (Table 2). Some polysaccharides have been included in edible coating formulations like alginate^[32], chitosan,^[33,34] and carboxymethyl-cellulose.^[31] Concerning alginate coating, its application on artichoke showed the best results in terms of shelf life (increased microbial stability) in comparison with dipping in citric acid/calcium chloride solution.^[32]

Furthermore, these authors also stated the importance of choosing a correct packaging material, with better results (higher microbial stability and increased shelf life) obtained with the biodegradable monolayer film (NVT2) than multilayer-film (All-PE) and oriented polypropylene film (OPP). The effectiveness of chitosan to improve the microbiological and sensory quality of fresh cut broccoli was evaluated by Moreira et al.^[33], regarded as a viable alternative to control the microbiota present in minimally processed broccoli because the growth of total coliforms, psychrotrophic, and mesophilic aerobes was substantially inhibited during the whole storage period tested. Furthermore, coated broccoli samples had acceptable scores in all sensory parameters examined until the end of storage, without appearance of undesirable odors and with higher quality levels than control samples. A similar study^[34] also showed that chitosan coating enriched with essential oils (tea tree, rosemary, clove, lemon, oreganum, calendula, and aloe vera) and bioactive compounds (bee pollen, ethanolic extract of propolis, pomegranate dried extract, and resveratrol) had significant antibacterial properties. Again, the application of chitosan coatings alone or enriched did not introduce negative effects on the sensory attributes of minimally processed broccoli.^[34] Ansorena et al.^[31] also studied the effect of chitosan and carboxymethyl-cellulose coatings on several quality parameters (weight loss, texture, color, microbial load, ascorbic acid, total chlorophyll, browning potential, and sensory quality) of fresh-cut broccoli during refrigerated storage, and explored if there was any additional benefit in a combined treatment of mild heat shock followed by edible coating. They concluded that chitosan coating effectively maintained quality attributes and extended shelf life of minimally processed broccoli, but chitosan coating after a mild heat shock showed the best performance for long-term refrigerated storage of minimally processed broccoli. Thus, chitosan and alginate coatings, alone or enriched with biopreservatives or combined with other technologies can be a good post-harvest technology to increase the shelf life and improve the quality of edible flowers. However, in the future more studies must be done on edible coatings to better understand the effect of other materials and to evaluate their role on other edible flowers species.

Concerning edible films, only a study in cauliflower has been published, with the aim to evaluate the effects of methyl cellulose-based edible films with variable amounts of stearic, ascorbic, and citric acids, on oxygen (O_2) permeability.^[35] The authors observed that films containing ascorbic acid or citric acid applied to cauliflower slowed down browning reactions, as well as the polyphenoloxidase activity and vitamin C losses when compared to uncoated ones and with films without antioxidants.^[35] Also here, studies involving other types of edible flowers are required.

High hydrostatic pressure

High hydrostatic pressure is an emerging nonthermal food processing method that subjects liquid or solid foods, with or without packaging, to pressures between 50 and 1000 MPa.^[36] HHP has shown considerable potential as an alternative technology to heat

treatments, in terms of assuring safety and quality attributes in minimally processed food products. Some studies of HHP treatments in edible flowers have been done, evaluating the effect on physical (e.g., color and texture) and nutritional characteristics, as well as on microbial and enzymatic inactivation. Among edible flowers, only two studies have been done (Table 1). On the other hand, much more work on the HHP application to broccoli and cauliflower have been performed (Table 2).

Regarding edible flowers (Table 1), these have different cellular structures, which cause a different behavior when submitted to HHP. For example, borage and camellia showed an unacceptable appearance (loss of structure and firmness) after HHP application, while centaurea presented good appearance at 100/5 MPa/min; however, the shelf life did not increase.^[37] On contrary, pansies submitted at 75/5 or 75/10 MPa/min maintained good appearance over 20 days of storage at 4°C, as well as HHP induced the production of bioactive compounds. This phenomenon might be associated with structural alteration of the cells provoked by the HHPs, yielding a higher amount of extracted metabolites or a physiological response of the flower to stress conditions at higher pressurization levels.^[37] The effect of HHP on the retention and bioactivity of natural phytochemicals present in *Echinacea purpurea*, as well as the microbial load, were studied by Chen et al.^[38] They reported that HHP significantly reduced the microbial contamination in flowers without affecting the retention of phytochemical, such as chicoric, caftaric and chlorogenic acids, and total alkalamides.

On broccoli (Table 2), the effect of HHP in enzymatic inactivation has been studied by some authors.^[39–42] A pressure of 210 MPa at –20°C was insufficient to inactivate peroxidase and polyphenoloxidase^[39], whereas pectinmethylesterase, β-galactosidase and α-rabinofuranosidase were inactivated by HHP.^[42] Furthermore, the application of HHP may induce cell permeabilization, favoring glucosinolate conversion and hydrolysis of health promoting products.^[40] Concerning the effect of HHP treatment on physical attributes, Fernández et al.^[43] concluded that blanched and high-pressure treated broccoli followed by freezing presented better texture than conventional frozen ones, without great changes in color and flavor. Furthermore, Butz et al.^[44] reported that no detectable effects on green color (chlorophyll *a* and *b*) were observed after long treatments at 600 MPa and 75°C. Regarding the effect of HHP on antioxidant activity, pressures at 400 and 600 MPa did not affect the antioxidant properties of broccoli when compared to raw.^[45]

On cauliflower, the effect of HHP on folate bioavailability (monoglutamate form) was examined by Melse-Boonstra et al.^[46] They detected a 2–3 fold increase of monoglutamate folate form in cauliflower, but also a substantial loss of total folates. In addition, blanching before or after HHP led to great losses on monoglutamate folate content, perhaps due to direct solubilization in the water. Préstamo and Arroyo^[47] reported lower structural changes in cauliflower treated at 400 MPa for 30 min at 5°C than in spinach, since in the latter, more cell membrane damage occurred, with greater loss of nutrients. The resistance of microorganisms subjected to HHP was studied in cauliflower by Arroyo et al.^[48] A pressure of 300 MPa, 5°C for 30 min was sufficient to decrease the viable aerobic mesophiles below the detection limit.

In summary, HHP can be a promising technology on edible flowers and inflorescences, to maintain their quality for long periods of time. However, each flower shows a different behavior to pressure, making it necessary to perform further studies in order to better understand the effects of HHP on each type of flower.

Irradiation

Irradiation applied to plant cells has been a topic of extensive research. [49,50] This technology is a physical process used to inhibit or destroy undesirable microorganisms without involving antimicrobial additives or products of microbial metabolism as preservative factors. However, irradiation processes can be based on different mechanisms, namely, nonionizing radiation (ex: less energetic UV radiation) and ionizing radiation (ex: gamma rays, electron beams, and X-rays).

Ultraviolet radiation

Recently, sub-lethal doses of ultraviolet (UV) have been assayed as a possible postharvest technology. This technology, based on the concept of hormesis, establishes that it is possible to obtain a beneficial effect on the application of a low or sublethal dose of an agent capable of inducing physical or chemical stress. [51] UV light can be divided into three types: UV-A (320–400 nm), UV-B (280–320 nm), and UV-C (200–280 nm). [52] With the exception of broccoli inflorescence (Table 2), no studies have examined the effect of the postharvest application of UV radiation on edible flowers. Broccoli irradiated with UV-B (peak emission at 312 nm) showed an effective inhibition of chlorophyll degradation during storage, suggesting that the effect could be due to the suppression of chlorophyll-degrading enzyme activities. [53] Similar results have been obtained in broccoli irradiated with UV-C (peak emission at 254 nm) [51], with a lower activity of chlorophyll peroxidase and chlorophyllase when compared to control. Thus, UV-C treatments could be a useful nonchemical method to delay chlorophyll degradation, reduce tissue damage and disruption, as well as to maintain antioxidant capacity. [51] In a similar way, treated broccoli florets with UV-C showed higher phenolic and ascorbic acid contents, antioxidant activity and soluble sugars, as well as a reduced number of bacterial and mold populations than control (samples not subjected to UV-C treatment, loosely covered with the same PVC film and stored under the same conditions as the irradiated ones). [54] To explain these results, the authors suggest that the activity of phenylalanine ammonia lyase might have been enhanced, a key regulatory enzyme of the phenylpropanoid metabolism, explaining the higher values of phenols. Furthermore, the UV-C treatment induced a lower rate of decrement in ascorbic acid than the control. Thus, UV treatments can be applied as a postharvest technology to broccoli, since they reduce tissue damage and microbial load, while maintaining the nutritional quality. Nevertheless, it is necessary to test the effect of these UV treatments and to adjust the doses for other edible flowers, because each flower will have a specific behavior when facing UV radiation.

Ionizing radiation

Ionizing energy can be used as a postharvest treatment to delay ripening or senescence of plant foods, although a severe legal control must be followed. According to the Codex General Standard for Irradiated Foods [55], ionizing radiation for food processing is limited to high-energy photons (gamma rays from the radionuclides ^{60}Co or ^{137}Cs ; X-rays generated from machine sources operated at or below an energy level of 5 MeV; electrons generated from machine sources operated at or below an energy level of 10 MeV). It is a process recognized as a safe technology by several authorities, such as World Health Organization (WHO), International Atomic Energy Agency (IAEA), and

Food Agriculture Organization (FAO).^[56] Irradiation is able to extend the shelf life of perishable products, to improve hygienic quality, to perform disinfestation of insects, and to guarantee food safety.^[56] Presently, spices, herbs, and dry vegetable seasonings are irradiated in various countries as a way of preservation.^[56]

Until now, few studies have focused on the effect of irradiation on the quality and composition of edible flowers. Koike et al.^[57] (Table 1) evaluated the physical tolerance to gamma-rays of some edible flowers and reported that *Borago officinalis* is not tolerant to a dose of 0.3 kGy (dose necessary to eliminate insects). In contrast, *Dianthus chinensis*, *Viola tricolor*, *Viola odorata*, and *Lobularia maritima* showed tolerance to gamma rays doses up to 1 kGy. So, flower tolerance to ionizing irradiation varies from species to species. Furthermore, high doses of gamma irradiation caused petal withering, browning, and injury in edible flowers.^[57] Concerning the effects of ionizing irradiation on the antioxidant activity and phenolic composition of edible flowers, only two studies have been published. One of them tested nasturtium flowers, and the authors concluded that antioxidant activity did not decrease significantly by irradiation; on the contrary, some irradiated samples (1 kGy) showed higher antioxidant activity than the corresponding control (0 kGy).^[58] The other study done in *V. tricolor* showed that, in general, gamma-irradiated samples gave higher amounts of phenolic compounds independently of the applied dose, and the antioxidant activity was also higher in the irradiated samples when compared to the control (0 kGy).^[59] No explanation was given to this behavior; however, we can suppose that the secondary metabolism was enhanced by irradiation. Furthermore, these results only report on *Viola tricolor*, making it necessary to perform other studies for other flowers' species.

In conclusion, ionizing irradiation may be applied in doses that do not cause changes in the visual appearance, antioxidant activity, and bioactive compounds of edible flowers. However, further studies on the effect of irradiation in disinfestation and reduction of microbial loadings of edible flowers must be performed.

Packaging alternatives

Plants use the carbon dioxide (CO₂) from the environment to produce sugars and O₂, which can later be utilized as a source of energy for plant growth. The high perishability of edible flowers is generally proportional to their respiration rates.^[4,60] According to Jones^[61], flowering plants have a relative high rate of respiration. After harvest, some factors contribute to induce changes in respiration rates of edible flowers, such as temperature^[62], time of harvest,^[63] and packaging.

The principal roles of packaging, in the case of edible flowers, are to protect them from desiccation and to preserve their frail structure, as well as to isolate them from the external environment and to reduce their exposure to pathogens and contaminants. Currently, fresh ornamental edible flowers (ex: pansies, borage, centaurea) are often packed in clam-shell containers and must be used within two to five days after harvest. In this case, there is no atmosphere control at the beginning; however, in other situations the atmosphere that surrounds the product may be changed, such as in controlled atmosphere and modified atmosphere packaging. Fresh edible flowers of vegetables (ex: broccoli, artichokes) must be used within 10 and 14 days for broccoli or 2–3 weeks for artichokes at 0°C and 95–100% relative humidity after harvest^[64], but when they are packaged, the shelf life may be prolonged as reported in the next section.

Without atmosphere control

Until now, there are no studies done on edible flowers focused on the role of different plastic films on flower properties, without changing atmosphere at the beginning. So far, the works carried out have focused on artichoke, broccoli, and cauliflower (Table 3). Artichoke's packing in different films, such as perforated polypropylene (PP; control), polyvinylchloride (PVC), low density polyethylene (LDPE), and microperforated PP films, caused different effects on flower quality, but all were beneficial because of the weight loss reduction in comparison with control. [65] However, artichoke packed in LDPE, PVC, and PP showed lower vitamin C (addition of ascorbic acid and dehydroascorbic acid) contents compared to the control. This may be due to the higher CO₂ levels found in the packages with these films than control, which decreased the dehydroascorbic acid content. Concerning different types of packaging, those with low CO₂ values (PVC and LDPE films) increased the content of phenolic compounds when compared to packages with higher CO₂ levels (PP1, PP2, and PP3 films). These authors observed that the phenolic profile changed with storage time, with a large increase of 1,5-dicaffeoylquinic acid (diCQA)+3,5-diCQA linked to the phenylpropanoid pathway. The authors concluded that LDPE was the best film to be used for maintaining artichokes' quality. Furthermore, microperforated and nonperforated films reduced microbial growth and enhanced the total polyphenol content, especially for the heads treated with the antibrowning solution, namely 1.0% ascorbic acid and 0.2% citric acid, when compared to those not treated with the antibrowning solution and packaged in the microperforated film. [66] On the other hand, storage under ozonized atmosphere for 3–4 days improved microbiological quality, maintained nutritional quality and enhanced artichoke's polyphenol content. [67,68] Even though ozone treatments induce an increase of respiration rate (producing a significantly higher O₂ decline), an undesired effect, in some flowers' species it can be successfully applied without significant metabolic consequences. So, the exposure to ozone should be analyzed for each flower because they have different sensitivity.

Similar studies have been done in broccoli and cauliflower, but with different film materials. Regarding broccoli, those packaged in microperforated and nonperforated films had prolonged storability up to 28 days with high quality attributes and health-promoting compounds (total antioxidant activity, ascorbic acid, and total phenolic compounds), while unwrapped broccoli (control) could only be stored for 5 days. [69] Similar results have been reported by Jia et al. [70], who showed that the shelf life of broccoli was extended, and its postharvest deterioration was reduced when stored at 4 and 20°C, packaged in polyethylene bags (40 µm thick, 20 cm × 30 cm) without holes (M1), and with two microholes (750 µm in diameter, one on each side of the bag) (M2), when compared to control (open boxes). Concretely, the polyethylene bags extended the shelf life of broccoli florets from 10 days (control) to 28.5 days (M1) and 19.1 days (M2) at 4°C, and from 2.5 days (control) to 7.2 days (M1) and 5.6 days (M2), at 20°C.

Furthermore, the contents of chlorophyll and ascorbic acid were maintained when using PP film packages (two holes, each of 0.3 µm diameter) during 4 days of storage. [68] Nath et al. [72] verified that broccoli packaged in PP film bags, with 10 pin holes, stored at 4°C, were able to retain the maximum of phytochemicals during storage for up to 144 h. These results suggest that perforation of the packaging is a solution to control the atmosphere inside it, as the holes are a way of steering a continued transport of O₂ into the packaging. At the same time, CO₂ can get out of the packaging, decreasing the rate of atmosphere modification. However, the effect of perforation in quality and shelf life of

Table 3. Packaging strategies for artichoke, broccoli and cauliflower.

Type	Edible flowers	Packaging	Conditions	References
Packaging strategies	Artichoke (<i>Cynara scolymus</i>)	Perforated polypropylene (Control) Low density polyethylene (LDPE) Polyvinylchloride (PVC) Three microperforated polypropylene films (PP)	LDPE (PO ₂ *: 2.1 PCO ₂ *: 4.6 20 µm) PVC (PO ₂ : 3.7 PCO ₂ : 8.4 12 µm) PP1 (PO ₂ : 1.8 PCO ₂ : 2.8 35 µm) PP2 (PO ₂ : 2.3 PCO ₂ : 3.5 35 µm) PP3 (PO ₂ : 3.9 PCO ₂ : 5.1 35 µm) Storage conditions: 5°C for 8 days	[65]
		Polypropylene films: Non-perforated Microperforated Macroperforated Perforated plastic (PP)	Ordinary atmosphere Storage conditions: 4°C; 790–795% relative humidity (RH), for 3, 6, 9, 13 and 16 days	[66]
			Storage conditions: (I) unwashed raw materials, stored at room temperature (II) unwashed raw materials, stored in a cooling chamber without ozone insufflations (III) immersion in ozonized tap water, stored in a cooling chamber without ozone insufflation (IV) immersion in ozonized tap water, stored in a cooling chamber with ozone insufflation for 3 days and without ozone insufflation for the last 4 days (V) immersion in ozonized tap water, stored in in cooling chamber with ozone insufflation for 7 days.	[67,68]
		PET trays (23 × 17.5 × 22cm ³) and packaged into a semi-permeable polyolefin film	Thickness: 19 mm; O ₂ permeability: 37007cm ³ /m ² /24 h; Carbon dioxide permeability: 11100cm ³ /m ² /24 h.	[76,77]
	Broccoli (<i>Brassica oleracea</i> var. <i>italica</i>)	Polypropylene films: Macro-perforated (Ma-P) Microperforated (Mi-P) Non-perforated (No-P)	Storage conditions: 4°C, 90–95% RH, 0 (production day), 4, 7, and 11 days. Ma-P (PO ₂ : 0.082 PCO ₂ : 0.18 20 µm) Mi-P (PO ₂ : 0.127 PCO ₂ : 1.27 20 µm) No-P (PO ₂ : 0.082 PCO ₂ : 0.18 25 µm) Storage conditions: 1°C, 28 days	[66]

(Continued)



Table 3. (Continued).

Type	Edible flowers	Packaging	Conditions	References
		Polyethylene bags with no holes (M0), two microholes (M1) and four macroholes (M2)	Storage conditions: 4 or 20°C	[75]
	Perforated PP		Storage conditions: 5°C, 75% relative humidity (RH), cold room for 4 days	[71]
	PP film with 10 pin holes		Storage conditions: ambient (15 ± 1°C, 55 ± 2% RH), and refrigerated (4 ± 0.5°C, 50 ± 2% RH) storage for 144 h	[72]
	Plastic perforated trays		PP PO ₂ :0.066	[73]
	PP		PCO ₂ : 0.25 35 µm	
	LDPE		LDPE PO ₂ :0.56 PCO ₂ : >2.3 23 µm	
	PVC		(with an ethylene absorbing sachet)	
			PVC PO ₂ : 2.9 PCO ₂ : >8.8 10 µm	
			Storage conditions:	
			(I) 7 days at 10°C	
			(II) 3 days at 4°C, followed by 4 days at 10°C.	
			PVC 14 µm	
	Cauliflower		LDPE 11, 15 and 20 µm	[74]
	(<i>Brassica oleracea</i>		Special LDPE 11 µm	
	var. <i>botrytis</i>)		Storage conditions: 7 days, 1.5°C, 95% RH	
			Shelf life simulation: additional 2.5 days at 20°C	
			(A) Perforated PVC 12 µm	[75]
			(B) Non-perforated PVC PO ₂ 1.3 12 µm	
			(C) Microperforated oriented PP PO ₂ 2.3 36 µm	
			Storage conditions: 4 or 8°C for 20 days	
Controlled atmosphere (CA)	Broccoli		CA conditions:	[81]
	(<i>Brassica oleracea</i>		2% O ₂ + 6% CO ₂ .	
	var. <i>italica</i>)		Control = air	
			Storage conditions: 4°C for 2, 4, 5, and 6 weeks	
			CA conditions: 10% O ₂ + 5% CO ₂	[82]
			Application of 1-methylcyclopropene (1-MCP)	
			Control: air, under storage conditions	
			Storage conditions: 1–2°C, 85–90% relative humidity for 2, 6, 13, 20, and 27 days.	
			+ 20°C, 2 and 4 days	
			CA: 3% O ₂ + 5% CO ₂	[83]
			Ambient air: #~20.5% O ₂ , 0.03% CO ₂	
			Storage conditions: 0°C for 0, 14, 28, 42, and 56 days	

* PO₂ – O₂ permeability; PCO₂ – CO₂ permeability, expressed in (×10⁻¹⁰ mol s⁻¹·m⁻²·Pa⁻¹); I: Increased; II: Decreased

flowers depend on whether the size of the holes are adapted to the flower's specie, the type of packaging film and storage temperature. Another study with the same flower, reported that broccoli packaged in LDPE that contained an ethylene absorber (5% O₂, 7% CO₂) stored for 7 days at 10°C (condition I) and 3 days at 4°C followed by 4 days at 10°C (condition II) were the samples with the appearance most similar to fresh broccoli. [73] In cauliflower, Artés and Martínez [74] concluded that the weight loss was considerably lower for all LDPE films (11, 15, and 20 µm) than for PVC film, and among the LDPE films the best results were obtained by using 11 µm LDPE. These results were probably due to the lower water vapor transmission rate of the various LDPE films than that in the PVC film assayed. [74] Furthermore, among three types of films, namely, perforated PVC, nonperforated PVC, and microperforated oriented PP for packaging minimally processed cauliflower, Simón et al. [75] verified that the three films allowed an acceptable cauliflower appearance without off-odor over 20 days of storage at 4 or 8°C. In particular, the atmosphere generated within nonperforated PVC film reduced the microbial counts but increased cauliflower yellowing, compared with the perforated PVC film.

According to Friedman et al. [78] (Table 4), different flowers show a different behavior during the same storage conditions, with the packaged flowers in PET boxes better preserved than wrapping the trays with PVC. In general, packaging with different films improved the physical protection and also reduced the spread of pathogenic organisms, but some materials are more suitable for certain edible flowers. It is necessary to study each in particular. Edible carnations and snapdragons placed in PP trays showed O₂ decline and accumulation of carbon dioxide (CO₂) and ethylene in both flowers. Flowers stored in these conditions presented a significantly reduced weight loss, aided in maintaining their visual quality and fresh appearance, reduced wilting, and extended the shelf life and prevented abscission in snapdragon. [3]

In conclusion, until now different plastic films were tested in edible flowers and they had different effects on their shelf life and microbial and nutritional quality. The use of some films can be a way to extend the shelf life and maintain the quality attributes of edible flowers; however, it is always necessary to perform experiments to evaluate the most appropriate for each situation.

With atmosphere control

Controlled (CA) and modified atmosphere packaging (MAP) are technologies used by the industry for extending the shelf life of foods, especially fruits, and vegetables. [79] These

Table 4. Modified atmosphere packaging for edible flowers.

Type	Edible flowers	Packaging	Conditions	References
Modified atmosphere (MAP)	Nasturtium (<i>Tropaeolum majus</i>)	PVC PP with or without modified atmosphere	3–5% CO ₂ + 10–13% O ₂ Storage conditions: 2°C and 4–5°C	[78]
	Begonia (<i>Begonia semperflorens</i> and <i>Begonia elatior</i>) Rose (<i>Rose</i> spp.)	Transparent polyethylene terephthalate (PET)		
	Carnation (<i>Dianthus caryophyllus</i>) Snapdragon (<i>Antirrhinum majus</i>)	PP 1-Methylcyclopropene + PP (1-MCP+PP) Current commercial packaging (COM) (plastic clamshell containers)	Storage conditions: 5°C for 14 days	[3]

↑: Increased; ↓: Decreased.

technologies are able to reduce the respiration rate of the product, reduce microbial growth and retard enzymatic spoilage by changing the surrounding gaseous environment of the food.^[80] In Tables 3 and 4 are described the studies performed until now on CA in broccoli and cauliflower, as well as on MAP in edible flowers, respectively.

A controlled atmosphere storage is a commercial system in which the gas concentrations of O₂, CO₂ and nitrogen, as well as the temperature and humidity of a storage room are regulated.^[79] Until now, few studies have been performed on CA storage of edible flowers, focusing mainly on broccoli and cauliflower. Storage of broccoli florets for 4 weeks or more under a CA 2% O₂ + 6% CO₂ extended the shelf life and improved retention of green color and chlorophyll, when compared with florets stored in air, all at 4°C, because low O₂ and high CO₂ levels reduce the respiration rate.^[81] Broccoli stored under a CA of 10% O₂ and 5% CO₂ maintained the visual quality and reduced the loss of health promoting compounds such as, phenolics, carotenoids, and vitamin C, when compared with air storage, all at 2°C.^[82] Cauliflower stored in CA (3% O₂ + 5% CO₂) also resulted in a lower weight loss, a slower decline in the lightness values, and no significant differences on the hue angle values, when compared with cauliflower stored in air.^[83]

MAP is a technique of sealing actively respiring food product in polymeric film packages with modified O₂ and CO₂ levels within the package.^[84] In edible flowers, only one study using this methodology has been done, namely on nasturtium packaged in CO₂ (3–5%) and O₂ (10–13%), with good results due to flowers' quality improvement evaluated by visual appearance.^[78]

In the last decades, 1-methylcyclopropene (1-MCP) has been added to the list of options for extending the shelf life and quality of plant products^[82], because it is a nontoxic antagonist of ethylene, which binds and blocks ethylene receptors, protecting flower from ethylene effects such as, petal senescence and/or petal abscission. 1-MCP combined with MAP, or even CA, has been used in edible flowers such as edible carnations, snapdragons and broccoli. 1-MCP helped to maintain the fresh appearance, reduce wilting and extend the shelf life of carnations and snapdragons, as well as to prevent abscission in the last flower.^[3] However, in broccoli, the 1-MCP samples showed a higher decrease in chlorophyll pigments than CA (10% O₂ + 5% CO₂) at the end of storage, being the latest technology suitable to extend broccoli quality during storage and shelf life.^[82] Concretely, CA increased the total phenolic content during cold storage until 13 days, which may be due to the stress caused by the controlled atmosphere storage. It also reduced the loss of chlorophylls, the carotenoids remained constant until the end of storage, and the antioxidant activity showed a smaller decrease in comparison to other samples (control and 1-MCP).

In summary, storage conditions and packaging methods have significant effect on biochemical characteristics of edible flowers. However, each flower has a different behavior, so it is necessary to perform more studies for each flower species at different storage conditions.

Practical uses of edible flowers after the application of post-harvest technologies

Most of the postharvest technologies applied to edible flowers had the main objectives of increasing their shelf life and maintaining their physic-chemical properties, as well as making the edible flowers market more competitive. Postharvest technologies, such as low

temperatures, edible coatings, and packaging, might result in products with similar characteristic to fresh flowers. This would allow flowers to be sold as “ready to eat” products, to include in salads, soups, and desserts. Dried edible flowers are already a product sold in some stores, such as: Petite Ingredient (Australia), Maddocks Farm Organics (United Kingdom), and ERVAS Finas (Portugal). Dried flowers are also sold as ingredients to make teas, embellish drinks, cocktails, and to be included in bakery products.

The irradiation of edible flowers allows the food industry to ensure that the product is microbiologically safe, because irradiation is a technology that controls microbes and other organisms that cause foodborne diseases. Irradiated edible flowers can be used, as fresh and ingredients in prepared foods, as already happens with the herbs and spices. Regarding HHP, there are already some food companies that use HHP in some edible flowers like broccoli and cauliflower in the formulation of smoothies and ready-to-eat meals. For example, the Juicy Line-Fruity Line® in Holland manufactures juices and smoothies of broccoli-apple-lemon and broccoli-orange-lemon.

Conclusion and future trends

In conclusion, various post-harvest technologies are available and may be used on edible flowers in order to extend their shelf life, while maintaining their quality. In particular, emerging post-harvest technologies as HHP or irradiation show promising results for increasing the shelf life of minimally processed edible flowers. Freeze drying or vacuum drying have shown to be highly effective in the preservation of flowers’ bioactive compounds, in comparison with classical drying approaches, but they require great economical inputs. While osmotic dehydration is already in use, the deposition or application of edible films and coatings can constitute a healthier alternative, without increasing the nutritional impact with sugars or salt, while also better preserving the characteristics of the fresh products.

The edible flower industry must be aware of the post-harvest technologies available and should be prepared to adopt those that are more appropriate to their products. This review assembled the most important technologies tested and applied, showing that most studies are still restricted to broccoli and cauliflower, with continued research and development needed worldwide to find better ways of increasing the stability and shelf life of other edible flowers, as these behave in different manners.

Funding

The authors acknowledge the Portuguese Foundation for Science and Technology (FCT, Portugal) for the financial support provided by the research grant SFRH/BD/95853/2013 and FCT/MEC for the financial support to QOPNA research Unit [FCT UID/QUI/00062/2013], through national funds and when applicable co-financed by the FEDER, within the PT2020 Partnership Agreement, and to REQUIMTE through the Project PEst/UID/QUI/50006/2013. The authors are also grateful to FCT (Portugal) and FEDER under Program PT2020 for financial support to CIMO [UID/AGR/00690/2013].

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