REVIEW ARTICLE Agricultural Reviews, Volume 42 Issue 2 : 145-155 (June 2021)

Post-harvest Handling and Senescence in Flower Crops: An Overview

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10.18805/ag.R-1992

ABSTRACT

Floriculture is an in bloom industry comprises of cut flowers, loose flowers and cut greens. Flowers are climacteric which makes them defenseless for huge post-harvest losses. Senescence is a process that follows physiological maturity and leads to death of the whole plant, organ, tissue or a cell. It is one of the imperative factors determining the longevity of the flower. Post-harvest quality of flowers is affected by the pre-harvest factors, stage of harvest and also by postharvest factors. To have better post-harvest life, indulgence of crop-specific management practices is important.

Key words: Cut flowers, Factors, Longevity, Post-harvest handling, Senescence.

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How to cite this article: Verma, J. and Singh, P. (2021). Post-harvest Handling and Senescence in Flower Crops: An Overview. Agricultural Reviews. 42(2): 145-155. DOI: 10.18805/ag.R-1992.

Submitted: 01-04-2020 **Accepted:** 05-01-2021 **Online:** 12-03-2021

Floriculture is a branch of agriculture that deals with the cultivation of flowers which are traded throughout the world. In India, congenital conditions are available to produce all sorts of flowers throughout the year by taking advantage of diverse agro-climatic conditions. During 2017-18 India has exported 20703.47 MT flowers of worth 50731.22 lac (Anonymous, 2018). Apart from agro-climatic advantage our country also enjoys the geographic advantage of being situated between two big markets Europe and South-East Asia, which makes trade easy. Govt. of India has identified floriculture as the sunrise industry in terms of its export potential and has setup flower auction center in Bangalore. The scope of the floriculture industry is increasing day by day with an increase in living standards. Floriculture industry comprises cut flowers, loose flowers, cut green, nursery plants and dry flowers. APEDA is responsible for promoting export-oriented cut flower industry in India by giving subsidies. But major handicap for this industry is highly perishable nature of flowers. Cut flowers are vulnerable to high post-harvest losses up to 50 percent of the farm value (Singh *et al*., 2007). Post-harvest handling is a process that starts at farmer level. Without delay, after harvest, many treatments are given to the flowers to enhance their vase life which fulfills florist as well as consumer demands and ultimately gives higher turnover. In this review, different factors affecting post-harvest life and senescence processes will be discussed.

Need for post-harvest handling

Flowers are the most beautiful creation on the earth, valued for their beauty. Therefore it becomes very important to handle flowers properly to maintain their quality and freshness for as long as possible to get high market price and consumer satisfaction. But it is not easy because a flower is a complex organ composed of different morphological units like sepals, petals androecia and gynaecium and each varies in their specific physiological requirements which make it difficult to handle as compare to other horticulture produce like fruits and vegetables. Flowers remain alive even after harvest and continue their metabolic activities which lead to the depletion of carbohydrates, rapid deterioration due to micro-organisms (Witte and Van Doom 1991), rise in temperature and respiration rates and water stress and (Sankat CK, Mujaffar, 1994) and increased accumulation of ethylene (Da Silva, 2003). These factors are responsible for the deterioration of harvested flowers. Most people likes to enjoy them in their natural beauty and appearances for a long time having the socioeconomic value of flowers intact (Zamani *et al*., 2011). So to avoid these adverse effects there is a need for appropriate post-harvest handling technologies.

Factors affecting post harvest quality and longevity of flowers

It is difficult to determine the postharvest life of a flower as it is influenced by many factors *viz*., Pre-harvest factors, Stage of harvest and Post-harvest factors (Salunkhe *et al*., 1990).

Pre- harvest factors

Genetic/inherent make up

Diversity in genetic makeup causes variations in water uptake, fresh weight, flower diameter and stem lignification, *etc.* eventually creates difference in vase life of different

flowers or different varieties of the same flowers. Even genetic difference can be observed between different cultivars of the same crop as given in Table 1. Significant difference in vase life at varietal level has been reported in many flowers like rose cultivars which showed huge difference in vase life from 4.5 to 18.8 days at 21°C (Macnish *et al*., 2010).

Growing conditions

The postharvest life of the flowers is highly dependent on growing conditions as they influence the phenotypic characteristics of the crop (In *et al.,* 2016). Flowers grown under different growing conditions showed a difference in their vase life even after maintaining similar post-harvest conditions (In *et al*., 2007).

Light

Plants use light as a source of energy during photosynthesis. Light regulates several physiological processes. Light determines the amount of carbohydrates in the plants during growth and development which in due course will determine vase life of the cut flowers. For most of the flowers optimum light requirement is between 3000-8000 foot-candle and any fluctuation in light can have adverse effects on flower quality (Bhattacharjee and De, 2005). Low light/shade can cause excessive elongation of flower stems (Armitage *et al.,* 1990), stem bending in Carnation, bent neck in Rose and delayed flowering. Wherein, high light intensity causes scorching of foliage/flower buds, dropping of leaves and petal senescence. Early flowering was reported in eleven herbaceous ornamental plants when in addition to natural light, 25-50 µmol m^{-2} s^{-1} light intensity was provided for 18 h daily as compared to plants grown only in ambient light (Erwin and Warner, 2002). Similarly, Supplemental light resulted in early flowering in geranium (Armitage and Tsujita, 1979) and overall reduction in production time (Quatchak *et al.,* 1986). In the case of rose supplemented light source has been reported to cause early anthesis (Tsujita, 1987). Supplemental light increases the total light received by the plant which results in higher plant photosynthetic efficiency (Nemali and Van Iersel, 2004). Carnations are most sensitive towards light at 4-6 leaves stage to have good quality flowers (Salunkhe *et al.,* 1990). Short day and long day plants behave differently towards additional source of light. Craig and Runkle (2013) reported delay flowering in SDPs, such as chrysanthemum and dahlia under incandescent and LED lights whereas, Mills-Ibibofor *et al*., 2019, reported two week early flowering in *Liatris spicata*'Kobold' under LED light. So based on market requirement flowering can be programmed using artificial light source.

Temperature

There is a great dealing between temperature and flowering in plants. High temperature is responsible for flower inhibition as it weakens the floral signal (Su *et al*., 2001) wherein, optimum temperature can positively affect flowering in plants (Adams *et al*., 1999). Each crop has its specific temperature requirements for its better growth. As in *Hydrangea macrophylla* 24°C was found best for intermodal elongation by Nordli *et al*., (2011). Likewise Li *et al.* (2019) reported 20°C as optimum temperature for gerbera cultivars with enhanced plant height, root length, biomass accumulation, leaf area and photosynthetic rate. Temperature fluctuations can causes many probles in ornamental plants *viz*., Softening of flower scrapes in roses (Dole, 1999), Bluing of petals in Rose (rise in temperature leads to breakdown of protein and release of ammonia, which ultimately increases cell pH causing bluing of roses) (Sheela, 2008). Treatment of rose cut flowers with a solution containing sugar and biocide such as HQC can prevent bluing of roses. Another problem observed in carnation is Calyx Splitting. There are many factors responsible for this disorder *viz*., Genetic, environment, nutrition, but incidence is more when temperature difference of more than 9°C is there between day and night (Singh *et al*., 2007). It can be controlled by maintaining high nitrate to ammonia ratio during period low of temperature, use of rubber bands on younger buds or use of less prone cultivars: Espana, Carboret, *etc.*

Humidity

The amount of water vapours in the air represents humidity. This is helpful in maintaining the plant temperature bycontrolling water loss from the plant's surface. High humidity results in high photosynthesis (Bunce, 1984) but also can cause fungal disease *viz*., white rust and grey mold in

Table 1: Difference in vase life of different varieties of same flower.

Cut flower	Cultivar	Vase-life (days)	References
Carnation	Alma	16.33	
	Sorisso	6.67	Shiragur *et al.* 2004
Chrysanthemum	Arka Swarna	16.00	
	Chandrika	6.00	Baskaran *et al.* 2010
Gerbera	Aventura and Tropic blend	21.00	
	Onedin	9.00	Javad *et al.* 2011
Gladiolus	IIHR-G-12	14.20	
	Urmil	8.97	Mahawer *et al.* 2013
	American Beauty	9.67	
	Moon Magic	5.39	Sarkar *et al.* 2014
Rose	Calibra	14.50	
	Bridal Pink	4.00	Ichimura *et al.* 2002

chrysanthemum whereas, low humidity can cause browning of leaf edges, thin leaves, chilling injury and more water loss, eventually leads to senescence. Roses are kept best when grown at low humidity level (Mortensen and Gislerod, 1999) wherein fluctuating air humidity can cause powdery mildew in roses (Wheeler, 1978). Thus, it's clear that water stress can limit the vase life of flowers (Bhattacharjee and De, 2005) and flowers grown at different humidity levels will have deviation in their vase life (Chamani and Wagstaff, 2018).

Carbon dioxide

The main component of plant dry matter is carbon (45%). It is taken up by the plants from the atmospheric air through stomata and fixed through the process of photosynthesis. It is present in very low concentration of 0.03% in the atmosphere (Kumar *et al.,* 2002). Therefore, CO_2 enrichment is beneficial for ornamental plants as it enhances photosynthetic efficiency and in turn, increase yield and flower quality (Niu *et al*., 2000). A CO_2 concentration from 700 to 900/ ppm is mostly advocated in greenhouses (Mortensen, 1987). Though the amount of CO_2 required for optimum growth varies from crop to crop. CO_2 fortification results in fresh cells and tissue formation, promotes lateral expansion and stimulates organ primordia at the shoot tip. Plant CO_2 use efficiency depends on sinks strength, competence of nitrogen, water use and photosynthetic capability (Pritchard *et al*., 1999). CO_2 fortification has been reported to increase the weight and height of chrysanthemum (Tanigawa *et al*., 1993) and rose (Mortensen and Moe, 1992). In a study 1000/ ppm, CO_2 was found to have a positive effect on flowering of Phalaenopsis (Kromwijk *et al.,* 2014), similar results were reported by kim *et al.* (2017).

Stage and time of harvest

Optimum harvest stage for a cut-flower is the one at which harvested buds can open fully and have satisfactory display life after distribution as given in Table 2. Flowers should be harvested at the optimum stage of maturity but it varies with species, cultivar, prevailing temperature conditions, distance to market and consumer requirement. If too immature buds are harvested, they will not open properly and if harvested at an over-mature stage, will wither quickly (Bhattacharjee and De, 2003). Harvest includes the decisions like when, where and how to cut. All these operations need to be done skillfully. The best time to harvest the flowers is the coolest periods of the day when there is no dew or water on the plant surface. Usually, time in the morning after the dew has dried or evening time is a suitable. However, morning harvest is beneficial over the afternoon (lowest temperature and high water content) and full-day is available for packaging and distribution (Nowak and Rudnicki, 1990). Some general rules of thumb for harvest are; spike type flowers-harvest when one-fourth to one-half of the individual florets are open; daisy type flowers-harvest when flowers are fully open. Standard carnations ship better and last longer when harvested at the bud stage while miniature carnations when atleast one flower per stem is open (Reid, 2004).

Post-harvest factors

About two-thirds life of the cut flowers depends on postharvest factors (Gast, 1997). Pre-harvest conditions have a considerable effect not only on the quality and longevity of cut flowers, but also on the response to postharvest treatments.

Temperature

High temperature accelerates bud opening and flower senescence, high respiration rate during post-harvest life, shorting vase life. while, low temperature delay all physiological processes even slow down flower ethylene production, therefore, flowers should be stored at low temperatures to enhance post harvest life of flowers.

Humidity

Flowers should be stored at high humidity up to 90-95%, especially flowers with large foliage on their stem to prevent water losses. Flower starts showing wilting symptoms even at 10-15% loss of fresh weight. Sufficiently high humidity

Table 2: Optimal stage of harvesting for different cut flowers (adopted from Armitage, 1991).

Name	Type	Stage of harvest
Rose	Red and Pink cultivar	First two petals beginning to unfold.
	Yellow Cultivar	Slight earlier than red and pink.
	White Cultivar	Slightly later than red and pink.
Carnation	Standard Spray	Paintbrush stageAt least two flowers fully open
Chrysanthemum	Standard Spray	Outer petal fully elongated 50% of flowers show colour
China aster, Dahlia, Gaillardia Marigold, Zinnia		fully open flowers
Daffodil, Narcissus		"Goose neck" stage
Gerbera		Two outer row of disc florets are perpendicular to stalk
Gladiolus		1 to 5 buds showing color
Goldenrod		one-half florets open
Pansy		almost open flowers
Lilies		colored buds
Tuberose		majority of florets open

helps in reducing water loss from the leaf surface, maintain petal turgiditythereby, prolonging the vase life of flowers (Doi *et al*., 2000). It was reported that high RH (90- 95%) during storage of cut anthurium enhance vase life (Paull, 1987) whereas, in case of heliconia 90% RH was found best (Banuelos-Hernandeza *et al*., 2016). Water loss or insufficient uptake due to unfavorable postharvest conditions (low humidity and high temperature) is one of the key reasons for the reduction of flower durability (Van Meeteren and Aliniaeifard, 2016).

Water relations

Water content in flowers is one of the important factors defining their post-harvest life (In *et al*., 2007). It is even more important to use good quality water (based on pH and EC) for vase solutions as poor quality water contain phytotoxic elements and micro-organism which may cause blockage in vascular bundles. Initially water uptake is high in cut stems but it decreases with time, it could be due to blockage of the vascular system by microbes (Vahdati *et al.* 2012) or due to air emboli. This blockage can be minimized either by use of biocides which impedes the growth of bacteria or fungi or re-cut 2-3 cm stem from base to avoid air blockage. Adverse water relation can cause problems *viz*., Limp necks in roses, stem break in gerbera, *etc*. For avoiding limp neck in roses use 5 µl/l of 1-MCP has been reported by Chamani, 2006 as enhances water uptake. Stem break in Gerbera is a major problem causing huge losses. The major reason is water imbalance due to blockage of stem by bacteria. For the control pre-treatment with Sodium hypochlorite or Silver nitrate (1000 ppm) for 10 minutes is advisable which prevents microbial growth in vase solution (Singh *et al*., 2001). Similarly, BA at low concentration (50 mg/l) in the pulse method has the potential to avoid stem bending in gerbera by maintaining good water uptake in stem (Danaee *et al*., 2013). Similarly, Eucalyptus *and Rosa damascena essences* at 200mg/l with 4% sucrose also gave positive results in terms of vase life and qualitative traits in gerbera cut flowers (Nahrabadi *et al.,* 2015). In another study, Helaly (2019) reported combined treatments (storage at 5±1°C (0-time), pulsing solution of STS + Sugar + 8-HQS and holding solution of Sugar + 8-HQS + Ascorbic acid) significantly increased the vase life and water balance of *Gerbera jamesonii.*

Conditioning

This is a simple technique in which flowers are kept loosely in a big container of water with ensured aeration around flowers. The main purpose is to restore the turgidity of cut flowers that is lost during storage and transport. For conditioning purpose, de-mineralized water plus germicides are used. Hydration can be improved by using water with acidic pH (4.5-5.5) by using citric acid or wetting agent like tween 20 (0.01 to 0.1%).

Pre-cooling

It is a process of removal of excess field heat to bring down respiration rate which leads to enhanced post-harvest quality. Pre-cooling prevents rapid loss of water from the plant surface and decreases sensitivity towards ethylene. All flowers should be pre-cooled immediately after harvest by placing them in cold storage without packing or in open boxes until they reach the desired temperature. Immediate pre-cooling prevent microorganism growth, thus, proper pre-cooling reduces spoilage and retards loss of pre-harvest freshness and quality (Becker and Fricke, 2002). There are different methods for pre-cooling in flowers *viz*., hydro cooling/refrigeration, forced air cooling.

Floral preservatives

These are the chemicals added to water to make flowers last longer. Floral preservative constitutes water, sugar, biocides and growth regulators which are used in pulsing, bud opening and holding solutions (Table 3, 4) to enhance quality (flower shape, size, colour and opening) or vase life of flowers (Balas *et al*., 2006). Acidic water with pH (3.0-3.5) is used to decreases microbial growth (Mehraj *et al.*, 2013a) whereas, sugar is used as artificial source of additional food after harvest helping in opening of flower buds *viz*., carnation rose and gladiolus, improves water balance (Pun and Ichimura, 2003) and also decreases sensitivity towards ethylene as in case of carnation (Mayak *et al*., 1977). Sugar preferably accumulates in petals increasing osmotic potential in petals in tandem accumulation of water in the petals, raising the turgidity of petals and in due course enhancing vase life of the flowers. Sugar alone can promote microbial growth, hence combined with biocides. Some of the commercially available floral preservatives are; Floralife, Rogard/Silgard, Chrystal, Prolong, Oasis, Vita Flora, *etc.*

In a study, ethanol 2%+ 2.5% Sucrose gives the best result for all quality parameters of *Rosa Hybrida cv.* Black Magic which was on par with Aluminium sulfate 100ppm + 2.5% Sucrose with maximum vase life reported upto18 days (Hajizadeh *et al*., 2012). In the case of Gerbera *cv. Maron Dementine* Sucrose 4% + silver nitrate @ 40ppm treatment was found best all quality parameters when kept at room temperature with 75% relative humidity (Danaee *et al.,* 2013). It might be due to antimicrobial and anti-ethylene properties of silver nitrate, addition to this sucrose delays the degradation of proteins and improve water balance thus

Table 3: Types of floral preservatives (adapted from Singh *et al.,* 2013).

Pulsing solution	Bud opening solution	Holding solution
Pre-shipment/ pre-storage treatment	Solution, in which immature buds of	Hold flower continuously, till
Short duration (16-24 hr)	many flowers can be made to open	termination of their vase life
Sugar is the main component	Lower concentration of sucrose is used	Level of sucrose is low
Higher level of sucrose	(2-5%)	(0.5- 1%)

helps in maintaining quality. In carnation, (*Dianthus caryophyllus L.*) sucrose 10% + 8-HQC 300 ppm + $GA_3$50 ppm gave the best result with maximum vase life of 11.80 days (Sharma *et al.,* 2015). This is due to antimicrobial properties of 8-HQC which avoided vascular blockage, further GA_3 with sucrose facilitate the better intake of water and accumulation of total soluble sugars in the petal cells that might helped to have longer vase life. In yellow gerbera, vase life was extended by 8 days when Salicylic Acid + Chitosan (100-ppm), used as a preservative solution (Mehraj *et al*., 2016). Chitosan act as an additional source of energy and salicylic acid impedes microbial growth thereby preventing vascular blockage. Similarly, there are many reports where vase life of cut flowers was enhanced by use of floral preservatives *viz*., Gladiolus (Mehraj *et al*., 2013a), Chrysanthemum (Mehraj *et al.,* 2013b), Gerbera (Pavana *et al*., 2015a), Rose (Pavana *et al.,* 2015b), Orchid (Pavana *et al.,* 2015c), Tuberose (Jamal Uddin *et al*., 2015) and vanda (Khunmuang *et al.,* 2018).

Refrigerated storage

Refrigerated storage is the most widely used storage method for cut flowers. There are two main types of refrigerated storage as mentioned in Table 5 with suitable temperature for different crops (i) Wet storage is the most commonly used method in cut flowers, in this method stems, are stored with their basal portion dipped in water or preservative solution and temperature is maintained between 2-4°C. This method is used to hold the flower for short duration (Singh *et al*., 2013). (ii) Dry storage method is used for long term storage (more than a week) and is based on the principle of moisture retention. Fresh flowers are sealed in plastic sleeves/ bags or boxes lined with butter paper and before sealing flowers can be treated with preservative solutions. It has been reported that bud-cut carnation can be dry-stored as long as up to 6 months (Goszczynska and Rudnicki, 1982). Whereas, another study found that quality of rose var 'Mercedes' stored better in dry storage at 2.5°C for 10 days than wet storage (Faragher *et al*., 1984). Another investigation found dry storage temperature of 5°C and 2°C are best for gerbera and rose-cut flowers respectively (Makwana *et al*., 2015; Patel *et al*., 2016). Likewise, Jadhav and Gaurav (2018) reported rose flowers kept at cold storage (4°C) in a holding solution of 7% Sucrose + 0.5% Citric acid + 0.5% Aluminium sulphate recorded the highest level of bud tightness, storage-life (days) and minimum petal-curling, head bending, petal-drop *i.e.* overall improvement in post harvest life of flowers.

Table 4: Different germicide used in floral solutions (adopted from Gast, 1997).

Germicide Type	Common Name	Concentration
8-hydroxyquinoline sulphate	8-HQS	200-600 ppm
8-hydroxyquinoline citrate	8-HQC	200-600 ppm
Silver Nitrate	$AgNO_3$	10-200 ppm
Silver Thiosulphate	STS	0.2-4 ppm
Thiobendazole	TBZ	5-300 ppm
Quartenary ammonium salts	QAS	5-300 ppm
Aluminium sulphate	$Al_2 (SO_4)_2$	200-300 ppm

Table 5: Wet and dry storage temperature for major cut flowers (adopted from Singh *et al*., 2013).

Crop	Dry Storage temperature	Wet storage temperature
Carnation	0 to 1°C	4°C
Chrysanthemum	1°C	4°C
Gerbera	2°C	4°C
Gladiolus	4°C	4°C
Rose	0.5 to 2°C	2 to 5°C

Grading, packing and transport

Grading is a process of categorization of flowers based on their quality *viz*., appearance, strength as well as length of stem, harvest maturity, color and size of buds as SAF grades are followed in flowers at international levels (Table 6.1-6.7). After grading bunches of flowers are prepared and then packed in long flat telescopic corrugated fiberboard boxes in layers. Flower heads are kept in both the directions of the boxes to utilize space properly. Newspapers are placed between different layers of the flowers to prevent injury to the flowers from each other. Packaging offers an alternative way for enhancing the post-harvest life of the flowers until flowers reaches to the ultimate users. Different wrapping materials are used for flower crops *viz*., Cellophane paper**,** Butter paper**,** CFB papers**,** Aluminum laminated foil**,** Polyethylene sheet, *etc*. After packaging flowers are sent in refrigerated vans and cargo space to distant markets in the boxes which should be about twice the width and the width should be about twice the height of the box. Prashanth and Chandrasekar (2010) evaluated different packaging material for extending vase life of gerbera, among all the treatment plastic sleeves for whole scape + 20% ventilation + CFB + TP (tissue paper) and NP (news paper) recorded highest

Table 6.1: Rose. SAF (Society of american florist) grades for different flowers (Table 6.1-6.7).

Types	Stem length (cm)	Bud size (cm)
Large-flowered variety (Hybrid tea)	60-90	3-3.5
Small-flowered variety (sweetheart)	40-50	2-2.5
Stage of harvest	Harvest when one or two outer petals begin to unfurl from tip and calyx reflexed	
Number of stems in bundle-20 stems/bundle		
Box size-120x45x25 cm 80 stems/box "CFB" box		
Free from- crown gall, petal bluing (ethylene toxicity)		

Table 6.2: Gerbera.

Grade	Stem length (cm)	Flower diameter (cm)	Flower colour	Preference (%)
1.	More than 60 cm	More than 12 cm	Pink	40
2.	50-60	11-10	Reddish orange	20
3.	40-50	10-9	Orange	20
4.	30-40	9-8	Red	15
5.	Below 30	8-7	Yellow	5

Stage of harvest when ray florets completely elongated.

Number of flowers in bundle-50 flowers in CBF box.

Box size-100x30x10 cm.

Table 6.3: Carnation.

Grade		Minimum flower Diameter (mm)	Minimum stem length (cm)
Blue	Tight	50	55
(fancy)	Fairly tight	62	
	Open	75	
Red	Tight	44	43
(standard)	Fairly tight	56	
	Open	69	
Green	Tight	None	30
(short)	Fairly tight	None	

Table 6.4: Gladiolus.

Grade	Spike length (cm)	Minimum No. of florets
Fancy (Grade A)	107	16
Special (Grade B)	96-107	14
Standard (Grade C)	81-96	12
Utility (Grade D)	<81	10

Table 6.5: Chrysanthemum.

Grade	Minimum flower diameter (mm)	Minimum stem length (cm)
Blue (Fancy)	140	76
Red (Special)	121	76
Green (Short)	102	61

Table 6.6: Orchid

Grade	No. of flowers/spike
A	3-5
B	6-8
C	9-11
D	>11

Table 6.7: Anthurium.

Grade	Size of the spike	
	Holland (Inches)	USA (cm)
Extra large	>6	>15
Large	5-6	13-15
Medium	4-5	10-13
Small	3-4	8-10
Miniature/Tiny	<3	<8

vase life (2.71 and 2.68 days respectively) due to more water balance. In another study effect on rose var. 'Sun King revealed T_1 (Polypropylene 24µ) treatment effective in enhancing the post-harvest life of cut roses by creating a modified environment (Makwana *et al*., 2015). Similarly, in another investigation, Polypropylene 24µ was reported as best wrapping material for gerbera cut flowers (Patel *et al*. 2016) whereas, Cellophane was found as best wrapping material for carnation (Sharma *et al*., 2015) due to moisture retentive nature of cellophane that helps in maintaining turgidity. In the same way, study was conducted on tuberose and the higher freshness index of florets for all cultivars under study was recorded when florets were packed in 100 µ thick polyethylene bags with 0% ventilation (Khongwir *et al*., 2019).

Flower senescence

Flowering is a most striking and magnificent event in the life cycle of the plant. It is followed by senescence which ultimately leads to death. Senescence is derived from a Latin word 'Senescere' which means 'to grow old.' It is a process that follows physiological maturity and lead to death of the whole plant, organ, tissue or a cell (Watada *et al*., 1984). The study of the process of Senescence in the plants is known as Phytogerontology. Among all other plant organs, petals are the ones with the shortest life cycle. Petal senescence occurs due to the Programmed Cell Death (PCD) (Da Silva, 2003). It is controlled by the multiple genes. PCD occurs in plants due to several reasons *viz*., developmental process, pathogen (biotic stress) induced, abiotic stress-induced (Van Doorn and Woltering, 2008). Senescence is expressed differentially in different flowers as fading of petal colour (carnation and petunia), bluing (rose) and abscission (sweet pea and snapdragon). The process of senesce is greatly accelerated by ethylene in most cases (Halevy, 1986). Senescence is of different types (Table 7).

Ethylene

Ethylene is a phytohormone which plays decisive role during petal senescence of climacteric flowers**.** Commercially many anti-ethylene agents available *e.g*.: amino-oxy acetic acid, amino ethoxy vinyl glycine, methoxyvinyl glycine, 1-methyl cyclopropane, which can be used to delay flower senescence (Van Altvorst and Bovy, 1995). Sleepiness of petals is a condition caused by ethylene in flowers like carnation and morning glory causing upward curling of petals.

Pollination speeds up ethylene production in carnation flowers causing early loss of cut flowers (Mayak and Dilley, 1976). So in order to avoid/ delay carnation flower senescence, it is advisable not to store pollinated flowers with unopened buds and flowers should be stored in modified storage in 4% CO_2. Some other adverse effects of ethylene in other flower crops can be seen in form of loss of turgidity (petunia and some orchids), change in colouration (Roses), abscission of buds or petals (snapdragon, geranium and sweet pea).

Patterns of flower senescence

Flowers show difference in their sensitivity towards ethylene (Wu *et al*., 2017). Sensitivity for ethylene even varies with the physiological age of the flowers (flowers are less sensitive towards ethylene when immature and increasingly become perceptive with age). Change in sensitivity level is associated with the change in physiological processes within the plant (Beyer, 1984), environmental conditions (high temperature and water stress) *etc.* In some flowers endogenously produced ethylene regulates flower senescence and exogenous application of ethylene will only accelerate the process of senescence *e.g.* Carnation, Orchids, Petunia, *etc*, known as ethylene dependent pathway of senescence. Whereas, in other flowers little amount of ethylene is produced during senescence and even exogenous ethylene does not accelerate flower senescence *e.g.* Gerbera, Gladiolus, Chrysanthemum, *etc* known as ethylene independent pathway of flower senescence (Woltering and Van Doorn, 1988).

Flower senescence in carnation

In carnation, petals contribute significantly towards ethylene production during natural senescence. Ethylene production starts in gynoecia immediately after pollination. In senescing carnation flowers, the expression of ACS and ACO genes (and ethylene production) starts in the ovary followed by the style and petals (Have and Woltering, 1997). Thus as signal proceeds, leading to autocatalytic production of ethylene in different parts of flowers but major and inductive role is played by the ethylene produced in gynoecium. Therefore by simply removing gynoecium flopwer vase life can be enhanced in (Shibuya *et al*., 2000). Many genes associated with flower senescence in carnation has been identified *e.g.* DcACO1, DcACS, DcACS1, DcACS2 and DcACS3 (Satoh and Waki, 2006).

Changes associated with flower senescence

Postharvest senescence is an integral part of the normal development cycle of the plants and it is a highly regulated process that involves structural, biochemical and molecular changes in the plant tissue (Shahri, 2011). Major pigments contributing to the colours of flowers are carotenoids, flavonoids and to some extent chromoplast. These all pigements undergoes changes during aging. Green chloroplasts are converted into large chromoplasts similarly, change in the composition of carotenoids can be observed *e.g.* Bird of paradise (Simpson *et al.,* 1975). In some cases changes in pigments are manifested as browning o petals (due to oxidation of flavones, leuco-anthocyanin and other phenols leading to accumulation of tannins) *e.g*. roses orange-yellow var. 'Masquerade', first turns pink, then deep red due to an increase in anthocyanin content which is up to tenfold (Shisa and Takano, 1964). In flowers like rose, geranium, petunia and carnation red colour changes to blue during aging owing to a slight increase in vacuolar pH. In roses, proteolysis leads to the accumulation of ammonia causing an increase in pH which leads to bluing of roses. But this proteolysis can be decreased by supplying additional source of carbohydrates (sugar) to the cut flowers.

Physiological changes during petal senescence

Flower development and petal expansion are two main phases in life cycle of the flowers during which the rate of respiration is high. Thses phases are ultimately followed by senescence during which the rate of respiration is low (Bhattacharjee and Pal, 1999). Further, there is loss of turgidity, increase in ethylene production (Halevy, 1986), yellowing of leaves (Chrysanthemum), wilting, Loss of dry matter (rose and carnation) results in no recoverable condition and early loss of cut flowers (Norman *et al*., 2017).

Biochemical changes

Virtually all cell, tissues and organs are subjected to senescence with age and progressively biochemical changes are expressed. This can be in the form of increase in production of reactive oxygen species (Panavas and Rubenstein, 1998), hydrolysis of cell component, loss of carbohydrate, protein content (Stephenson and Rubenstein, 1998), nucleic acid (Woodson 1987) and loss of membrane permeability causing leakage of pigments, sugars and mineral ions (Ahmad and Tahir, 2016) ultimately leads to death/senescence. Changes are also manifested in form of change in enzyme activities as senescing rose petals express increased activity of both phospholipase A and phospholipase D (Borochov *et al*., 1982) whereas, in carnation petals, lipase and phospholipase C activity has been found to increase as senescence progress (Burger *et al.,*1986).

Table 7: Types of senescence in plants **(**adopted from Leopold, 1961).

Overall senescence(Monocarpism)	Progressive senescence	Top senescence	Deciduous senescence
This kind of senescence occurs in annual plants when the entire plant gets affected and dies *e.g.* Most of the annuals	This kind of senescence is gradual. First, it occurs in old leaves followed by new leaves then stem and finally root system. It is common in annuals.	It occurs in aerial parts of plants. It is common in perennials, underground and root system remains viable *e.g.* Bulbous plants	It is common in deciduous plants and occurs only in leaves of plants, bulk of the stem and root system remains alive *e.g. Salix babylonica*

Pre-harvest treatment with calcium is effective in extending the post-harvest life of rose cut flowers by maintaining normal function and structure of membrane. In another study, the effect of ascorbic acid (AsA) on vase life and petal senescence in rose cut flowers (*Rosa hybrida*) *cv. 'Royal* Class was studied by Abri *et al*., 2013. Flowers treated with 4 mM AsA gives maximum vase life of 8 days as AsA enhanced the vase life of Royal Class roses by maintaining higher activity of SOD and reducing oxidative stress such as lipid peroxidation and LOX activity during flower senescence. Amino-oxy acetic acid (AOA) and amino ethoxy vinyl glycine (AVG) are effective in enhancing the vase life by acting as inhibitors of ethylene. Malondialdehyde (MDA) amount increases in flowers after harvest and is responsible for senescence. Lou *et al*., 2020 reported use of inorganic salts like $CaCl_2$ in the holding solution can reduce the contents of MDA in carnation flowers leading to slow down the aging by increasing the resistant in carnation flower stems. Similar effect of silica nanoparticles preservative solution was reported by El-Serafy (2019) in cut roses.

Genetic engineering for long vase life

Ethylene is synthesized from the flower petals during senescence. ACC oxidase and ACC synthase are two main enzymes responsible for ethylene production. Therefore using genetic engineering aACS and aACO technology postharvest life of cut flowers can be enhanced.

In flower crops use of genetic engineering for enhancing vase life is mounting. Transgenic carnation plants harbouring the *etr1* gene showed delayed senescence with a three-fold increase in vase life (Bleecker and Schaller, 1996). In another case, transgenic torenia flowers were developed by down-regulation of *ACO* in *Torenia fournieri.* The average vase life of transgenic flower was found between 2.7-7.1 days as compared to wild-type with 2.0 days (Aida *et al*., 1998). Efforts were made to transformed petunia with a mutated *ers* (an ethylene receptor gene) of *Brassica oleracea.* Resultant transgenic plants retained turgidity and pigmentation for longer period than non-transgenic plants (Shaw *et al.,* 2002). Kosugi *et al.* (2002) studied senescence and gene expression of transgenic non-ethylene producing carnation flowers (*sACO-1*). Flowers of transgenic line remain fresh over 10 days whereas non-transgenic line started showing wilting symptoms after 5 days. In another study, transgenic morning glory flowers (with suppressed EPHEMERAL1 (EPH1) showed twice the longevity than non-transgenic flowers (Shibuya *et al*., 2014). *PhHD-Zip*, a homeodomain-leucine zipper (HD-Zip) transcription factor was suppressed in petunia by virus-induced gene silencing lead to improved post-harvest life in petunia as it resulted in accumulation of transcripts *ACO1*, *ACO4* and *ACS (*Yin *et al*., 2015). All these case studies prove genetic engineering as potential future tool for enhancing post-harvest life of cut flowers.

CONCLUSION

There is further need to work on floral preservative and packaging material, to find newer and better ones and establishing cold-chain after harvesting. Flower senescence a necessary evil cannot be completely checked but can be delayed or partially controlled by using anti-ethylene compounds and several package and practices. Genetic modifications in plants reduce ethylene perception or biosynthesis therefore, improvement of the crops at the gene level or developing ephemerals flowers as models can give an economical alternative.

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