

Advances In The Breeding And Cultivation Of Carnation- A Review

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Abstract - Carnation (*Dianthus caryophyllus* L.) is a prominent commercial flower, valued for its versatility in floral arrangements and ornamental uses. However, its cultivation faces numerous challenges due to biotic and abiotic stresses that adversely affect plant growth, flower quality and yield. This paper reviews carnation and cultivation advancements, focusing on various breeding strategies to enhance flower traits such as colour, fragrance, vase life and disease resistance. Key highlights include the introduction of novel colour varieties through genetic engineering, such as the MOON series, which incorporates genes from other species to produce unique hues. Additionally, the research discusses the development of cultivars with extended vase life through selective breeding, achieving significant improvements over traditional varieties. The exploration of fragrance through interspecific hybrids reveals potential for enhancing scent profiles. At the same time, studies on disease resistance indicate promising strategies for managing common pathogens like Fusarium wilt and root-knot nematodes. Overall, integrating advanced breeding techniques and genetic insights presents a pathway for improving carnation cultivation, ensuring better quality and resilience in the face of environmental challenges. This work underscores the importance of ongoing research in floriculture to meet market demands and enhance the sustainability of carnation production.

Index Terms – Carnation, breeding, floriculture, fusarium wilt, horticulture, flowers, flower crops, technology, agriculture.

1) Introduction

Carnation (*Dianthus caryophyllus* L.) is a leading commercial crop in the floriculture enterprise. It is an important cut flower excellently used in bedding, pots, borders, edging, rock gardens, bouquets and decorations. However, this flower crop is adversely affected by several biotic and abiotic stresses which affect the plant growth leading to poor flower quality and reduced yield. To cope with these problems many breeding approaches were used to improve carnation. Breeding is the alternative way for varietal development and improvement of flower fragrance, shape, colour, biotic and abiotic stress resistance by incorporating the desirable novel traits (Onozaki and Yagi, 2020).

2) Botany of carnation

Species within the Caryophyllaceae family are primarily annual, biennial or perennial herbs. Their stems are characterized by swollen nodes where the leaves attach. Leaf arrangement is typically opposite, though some species may have alternate or whorled leaves. Flowers can be solitary or grouped in various types of branched inflorescences. They generally possess both pollen-bearing and ovule-bearing parts, exhibit radial symmetry (actinomorphic) and are usually composed of 4 or 5 parts. The sepals may be either separate or fused at the base, while the petals are typically 4 or 5 in number, often notched at the tip or divided nearly to the base. In these flowers, the sepals and petals are attached below the ovary, which is superior. The stamens usually number 5 or 10 and there are typically 2 to 5 styles. The fruit is generally a dry capsule that releases its seeds through an opening at the tip.

3) Floral biology of carnation

Carnations are protandrous, meaning that their male gametes mature and are released before the female gametes are ready. This temporal separation between anther dehiscence and pistil receptivity typically leads to outcrossing. The stigma remains unreceptive to pollen for at least a week after the anthers have shed their pollen. In floriculture, carnations often require hand pollination to set seed due to their dense petal arrangement, which prevents access by natural pollinators and because they are usually grown in greenhouses or polytunnels that

exclude pollinators (Bird, 1994). Technicians manually remove petals to reveal the reproductive parts and then transfer pollen from other flowers onto the stigma (Sparnaaij and Berger, 1973).

The ideal temperature for pollen production in glasshouse conditions is around 23°C. Temperatures below 17°C can completely inhibit stamen development (Kho and Baer, 1973). Traditionally, removing lateral shoots and buds from flowering stems was used to encourage the development of the central flower, but this practice led to reduced fruit setting and fewer seeds per fruit (Sparnaaij and Berger, 1973).

Carnation fruits mature approximately six weeks after pollination (Sparnaaij and Beeger, 1973). Each fruit can contain up to 100 seeds, with an average of about 40 seeds per fruit (Sparnaaij and Beeger, 1973). The seeds are encased in a tubular capsule with a single compartment that opens from the top. Wind aids in seed dispersal by causing the capsule to move back and forth along the tip of a long flowering stalk (Bird, 1994). Carnation seeds can remain viable for several years when stored in a cool, dry place (Sparnaaij and Beeger, 1973).

4) Varieties introduced in India

Various carnation varieties are introduced in India from different countries. From Australia, the varieties include Chaubad Giant Mixed, F1 Hybrid Dwarf Mixed Colonis, Genes of France, *Dianthus plumarius*, *D. patraeus* and Perpetual Giant Mixed. Cyprus contributed Yellow Dusty, William Sim, Lena, White Sim and Arther Sim. France introduced Picotee Mixed, Grenddin, King of Blacks, Sunflod, Triompha Vauk, Grenadin Roi Des Roses, Vauie Selection Clause and Grenddin Range. From Germany, varieties such as Laddie Sim, Pink Manic, Red Sim, Arthur Sim, Dusty Sim and Scania were introduced. Japan provided *D. chinensis* var. *laciniatus*, *D. chinensis* var. *heddewigii*, and Regal. The UK contributed an extensive range including Chaubad Allwoods, *D. spiculifolius*, *D. armeria*, *D. balbissii*, *D. deltoids*, *D. pinifolius* var. *lilacinus*, *D. pulmarius*, *D. superbus*, *D. praecox*, *D. stembergii* and *D. fragrans*. Finally, the USA introduced Red Wonder, Scarlet Wonder, Pixie Delight and Scarlet Luminette.

5) Breeding objectives

- a) Breeding of carnation for novel colour
 - i) MOON Series

Carnations cannot naturally produce delphinidin-based anthocyanin pigments, which are responsible for blue or purple petals. In 1996, Florigene introduced the first genetically engineered blue-mauve carnation, named Moondust, by incorporating genes from petunias and snapdragons. The modification involved inserting a Flavonoid 3',5'-hydroxylase (F3'5'H) gene and a Dihydroflavanol reductase (DFR) gene from petunias into a white carnation that lacked DFR. These genes facilitate the production of delphinidin pigments, resulting in the blue-mauve colouration. This innovation led to the creation of various transgenic carnations with distinctive colour traits.

Moon series and their colours:

Moon Shade, introduced in 2001, is a purple carnation derived from the white variety Cream Cindrella. Moon Lite, also from 2001, is a lavender carnation, while Moon Vista, another 2001 variety, features a dark purple hue. Moon Aqua, introduced in the same year, presents a mauve colour, also developed from Cream Cindrella. In 2010, Moon Pearl emerged as a lavender carnation, developed from Cerise West Pearl, a pink variety. Moonique, another 2010 variety, is purple and was created from Kortina Chanel (pink). That year also saw the introduction of Moon Berry, a light purple carnation from Cerise West Pearl and Moon Velvet, a dark purple variety also derived from Cerise West Pearl. Moon Burst, a bicolour lavender variety developed from Moon Vista, was introduced in 2017, alongside Moon Strike, a purple carnation created from Moon Shade. Lastly, Moon Tea, a dark purple carnation developed from Cinderella (pink), was introduced in 2014.

- ii) Breeding for dusky glittering carnations by an efficient mutagenesis

The study investigates advancements in breeding glittering carnations (*Dianthus caryophyllus*) through an innovative mutagenesis system utilizing ion-beam irradiation. A systematic approach was developed to create novel mutants by selecting appropriate genotypes based on genomic information and inducing anthocyanin vacuolar inclusions (AVIs) through ion-beam treatment. The research successfully produced highly novel carnations with vibrant glittering colours, which had not been achieved through conventional breeding methods.

Twelve carnation cultivars with increasing sales were first selected and then their flowers in numerous greenhouses were extensively examined by visual observation to determine if the flowers could change into flowers with AVIs. One cultivar named 'La Vie en Rose' or 'LAV', was discovered that shows dusky grey sectors in some flowers. Cultivar 'LAV' has superior characteristics in general. We further examined more than 10,000 'LAV' individuals in greenhouses and selected one individual that has some AVIs sectors. We named the individual 'LAVS'. In vitro, LAVA nodes were irradiated with the 320 MeV carbon ion beams. Flower colour mutants such as white, light pink and dark salmon owners with a bit of glittering traits were obtained, whereas eleven solid glittering mutants of new colours have been created; one glittering red, two glittering salmon, one glittering purple, and one glittering deep purple individuals. Typical individuals of the colours glittering purple, glittering red and glittering salmon have been selected as 'LAVA Purple', 'LAVA Red' and 'LAVA Salmon', respectively. We microscopically examined the petal cells of these mutants and found that the degree of pigment inclusion or condensation, differs between the mutants.

The use of ion-beam mutagenesis represents a significant advancement in carnation breeding, enabling the creation of unique and commercially viable flower colours that enhance the floriculture market. Okamura *et al.*, 2012 suggested that this method can effectively produce desirable traits while retaining the overall quality of the original cultivars, paving the way for future innovations in ornamental plant breeding.

b) Breeding carnations for long vase life

i) Effects of crossing and selection for seven generations based on flower vase life in carnations

To enhance the vase life of carnation flowers, a breeding program was initiated in 1992 using conventional cross-breeding methods. They conducted repeated crosses and selected offspring with extended vase life over seven generations, from 1992 to 2008. By 2005, two cultivars developed, 'Miracle Rouge' and 'Miracle Symphony', which exhibited genetically determined vase lives ranging from 17.7 to 20.7 days- 3.2 to 3.6 times longer than 'White Sim' under standard conditions (23°C, 70% RH, 12-hour photoperiod).

Line 532-6 demonstrated an exceptional vase life, averaging 27.8 to 32.7 days, which is 4.6 to 5.4 times longer than 'White Sim'. They evaluated changes in ethylene sensitivity during flower senescence using a time-lapse video recorder. In 2010, line 806-46b was selected, which combined an ultra-long vase life (27.1 days, 4.4 times that of 'White Sim') with ethylene resistance. Analysis of six cultivars and 123 selected lines from the 1st to the 7th generations revealed a strong correlation between long vase life and reduced ethylene production (Onazaki, 2018).

c) Breeding carnations for fragrance

• An interspecific hybrid of carnation and *D. hungaricus*

In the carnation 'Miracle Symphony', methyl benzoate was the primary volatile compound, comprising 97% of the total volatiles. On the other hand, *Dianthus hungaricus* emitted a variety of benzenoids, with methyl salicylate being a significant odour-active compound (Kishimoto *et al.*, 2011). 'Miracle Symphony' and *D. hungaricus* each had distinct scents- weak fruity and minty or medicinal, respectively- driven by their dominant volatiles, methyl benzoate and methyl salicylate.

To investigate the scent profile of their interspecific hybrids, they crossed 'Miracle Symphony' with *D. hungaricus* multiple times and obtained several seeds. One seed successfully reached the flowering stage and confirmed its hybridity, designating it as OB44. The total volatile emission of OB44 was comparable to that of 'Miracle Symphony' but about 7% of that of *D. hungaricus*. In OB44, methyl benzoate remained the dominant volatile, present at similar levels to those in 'Miracle Symphony'.

• Interspecific hybrids of carnation and *D. superbis* var. *longicalycinus*

Carnation 229-1 emitted mostly methyl benzoate (89%) with no terpenoids, while *Dianthus superbis* var. *longicalycinus* had high levels of β -ocimene and β -caryophyllene, making up 67% of its volatiles. The total volatile emission from *D. superbis* var. *longicalycinus* was about 103 times higher than that of 229-1. Both had weak fruity and woody scents from their dominant volatiles.

Interspecific hybrids between 229-1 and *D. superbis* var. *longicalycinus* emitted terpenoids and benzenoids, with total volatiles 2–15 times higher than 229-1 but 2–15% of *D. superbis* var. *longicalycinus*. All detected volatiles from the parents were present in the hybrids, with β -ocimene and β -caryophyllene being principal in hybrid lines 4K38-2, -11 and -15. Despite being less than 20% of *D. superbis* var. *longicalycinus*

levels, these terpenoids contributed a noticeable woody scent, indicating that *D. superbus var. longicalycinus* is a promising hybridization partner.

Other hybrid lines featured various benzenoids or 1-octen-3-ol as main volatiles. Significant compounds included methyl salicylate in 4K38-3, benzyl benzoate and elemicin in 4K38-5, 1-octen-3-ol and eugenol in 4K38-6 and methyl benzoate and eugenol in 4K38-10 and -14. These hybrids often had higher levels of benzenoids compared to their parent lines, with some showing a similar or slightly altered scent profile compared to the parent carnations.

- **Interspecific hybrids of various carnation cultivars and unidentified *Dianthus* species**

In the varieties 'Ai Pink', 'Nagisa' and 'Shikibu', methyl benzoate was the predominant volatile compound, comprising 75–85% of the total volatiles. Limonene was the second most common volatile in 'Ai Pink', accounting for 15%. In contrast, wild *Dianthus* species exhibited a different volatile profile, with various benzenoids present. These wild carnations emitted a subtle fruity aroma primarily from methyl benzoate.

In *Dianthus* sp. 4, isoeugenol was the most prevalent volatile, making up 16% of the total, followed by methyl isoeugenol at 11%. *Dianthus* sp. 5 had benzyl alcohol as the most abundant volatile (32%), with methyl salicylate and limonene at 18% and 9%, respectively. *Dianthus* sp. 6 was characterized by high levels of methyl o-anisate (30%) and methyl benzoate (21%).

The total volatile emissions from these wild *Dianthus* species were 23 to 38 times greater than those from the carnations. *Dianthus* sp. 4 had a spicy aroma due to eugenol and its derivatives, while *Dianthus* sp. 5 and 6 each had distinctive scents likely influenced by their principal benzenoids. We explored whether the fragrant properties of these wild species could be transferred to interspecific hybrids.

d) Breeding carnations for disease resistance

The following is a summary of various carnation varieties with their respective characteristics:

1. Jasujung (2009): This variety, a cross between Francesco and Saturn, is ideal for cultivation in temperatures above 8°C at night and below 25°C during the day. It is highly recommended for cut flowers due to its pleasant fragrance, long stems and strong resistance to *Fusarium* wilt.

2. Lyra (2010): Developed from Ballantyne and Chateau, this spray carnation produces bright pink flowers. It thrives in conditions above 8°C at night and below 25°C during the day. Known for its early flowering, multi-branching habit, and fragrance, Lyra has medium resistance to *Fusarium* wilt, making it suitable for cut flowers.

3. Lepus (2012): A spray-type carnation resulting from the cross of Diamond and 99257-7 Line, Lepus features white flowers with red peaks. It has strong flower stalks and produces numerous blooms, making it excellent for floral arrangements. It offers medium resistance to *Fusarium* wilt.

4. Karen Rough (2012): This standard-type carnation, bred from Miracle Rouge and 4AZ31-5, boasts deep yellowish-red flowers. It is well-suited for cut flowers and is noted for its high resistance to bacterial wilt caused by *Burkholderia caryophylli*.

i) Effectiveness of some resistance inducers for controlling carnation fusarium wilt

This study investigated by Mora *et al.*, 2021, includes the impact of four resistance inducers on vascular wilt disease in carnations, caused by the pathogen *Fusarium oxysporum* (Fod). The data demonstrated that applying a 1mM thiamine solution *via.*, foliar spraying effectively reduced both the incidence and severity of the disease to levels that were statistically comparable to those seen in non-inoculated control plants.

In addition to mitigating disease symptoms, the thiamine treatment led to an increase in the concentrations of flavonoids and phenolic compounds within the plants. These biochemical compounds are known to play a role in plant defence mechanisms and are often associated with enhanced disease resistance.

These results indicate that thiamine could serve as a promising strategy for controlling vascular wilt in carnations. However, for practical application in commercial settings, it is recommended that this approach be incorporated into a broader integrated disease management program.

To fully understand the effectiveness of thiamine and optimize its use, additional studies are needed. Future research should focus on exploring the molecular interactions between thiamine, the plant and the pathogen to gain deeper insights into how this resistance inducer influences the disease resistance mechanisms at the molecular level.

ii) Response of some carnation varieties to *Meloidogyne incognita*, *Meloidogyne javanica* and *Meloidogyne arenaria*

Production of quality carnation against RKNs is quite important for commercial flower growers. In this study, the response of four carnation varieties grown widely in Turkey was investigated to isolates of *M. incognita*, *M. javanica* and *M. arenaria*. Reactions of Turbo and Betsy, which are cultivars of standard type, were found to be significantly different to *M. incognita*, *M. javanica* and *M. arenaria*. Turbo was resistant to three root-knot nematodes, but the Betsy cultivar was susceptible to these species.

Therefore, the Turbo cultivar may provide a positive contribution to the management and can be used for infected fields with three *Meloidogyne* species. The reaction of *M. incognita* on the Betsy cultivar was statistically different than *M. javanica* and *M. arenaria*. *M. incognita* and *M. javanica* developed slightly on Nirvana cultivar but *M. arenaria* did not develop on this variety and did not produce egg mass or gall on Nirvana. These results indicated that the *M. incognita* and *M. javanica* penetrated the roots of the plant but few individuals completed their life cycle. Glacier cultivar was susceptible to *M. incognita*, *M. javanica* and *M. arenaria*. Glacier cultivar was more susceptible than the Betsy cultivar to root-knot nematodes tested.

The result showed the prevalence of nematodes in various carnation varieties and treatments. For *Meloidogyne javanica*, the Standard variety had no nematode presence, while Turbo and Betsy had minimal levels (2.70 and 0.20, respectively) and Nirvana and Glacier had higher levels (5.12).

Similarly, *Meloidogyne incognita* was absent in the Standard variety but present in higher amounts in Turbo and Betsy (5.70 and 0.40, respectively), with Nirvana and Glacier showing similar high levels (6.00). For *Meloidogyne arenaria*, the Standard variety again showed no nematodes, while Turbo and Betsy had low levels (2.66 and 0.00, respectively), and Nirvana and Glacier had higher levels (5.44). Overall, the data highlights the variability in nematode resistance across different carnation varieties, with the Standard variety generally showing the least presence of nematodes (Celik *et al.*, 2022).

6) Research and development centres of carnation

In the development and cultivation of high-quality carnation varieties, several prominent national and international institutions and companies play a vital role. Among the key research institutes in India are the Indian Institute of Horticulture Research (IIHR) in Bangalore, the Directorate of Floriculture Research (DFR) in Pune and Tamil Nadu Agriculture University (TNAU) in Tamil Nadu. These institutions have been instrumental in advancing breeding techniques and optimizing cultivation practices suitable for Indian climates. Internationally, organizations like Breier Cross in Israel, Dumm Orange in Holland, Hilverda Florist in the Netherlands, Selecta One in Germany and Florigene in Australia are leaders in the global floriculture industry, producing innovative carnation varieties with enhanced traits such as unique colours, fragrance and disease resistance.

In the Indian floriculture sector, several multinational companies have established a strong presence. Some of the notable companies include KF Bioplants (Pune), Florence Flora, Kimya Biotech, Rise and Shine Biotech, SPA Flora Pvt Ltd, Zygo Flower Limited, Bhuvani Exim Pvt Ltd and Nilgiris Flower Company. These companies are involved in large-scale production, research and export of carnation flowers and other floriculture products, contributing significantly to both the domestic and international markets. Their efforts in collaborating with global breeders and implementing advanced horticultural practices have helped position India as a competitive player in the floriculture industry.

7) Advances in the cultivation of carnation

i) Effects of Substrate and Exogenous Auxin on the Adventitious Rooting of *Dianthus caryophyllus* L.

In this study, *Dianthus caryophyllus* L. (carnation) was used to explore how different rooting substrates and concentrations of external auxin affect the formation of roots in stem cuttings. The results showed that the properties of the substrates had a significant impact on root development. The substrate formulations used in the treatments were as follows: B1 consisted of cocopeat and perlite in a 1:1 ratio (by volume), B2 had a cocopeat to perlite ratio of 1:2 and B3 had a cocopeat to perlite ratio of 1:3.

Additionally, varying concentrations of Indole-3-butyric acid (IBA) and 1-naphthalene acetic acid (NAA) influenced the rooting percentage and seedling growth. The auxin treatments included the following concentrations: A1 consisted of NAA and IBA at 500 mg/kg and 50 mg/kg, respectively; A2 consisted

of NAA and IBA at 1000 mg/kg and 100 mg/kg and A3 consisted of NAA and IBA at 1500 mg/kg and 150 mg/kg.

The rooting percentage and seedling rate for each treatment were as follows: For A1 (500 mg/kg NAA + 50 mg/kg IBA), the rooting percentage was 99.3% and the seedling rate was 98.5%. For A2 (1000 mg/kg NAA + 100 mg/kg IBA), the rooting percentage was 99.8% and the seedling rate was 99.7%. For A3 (1500 mg/kg NAA + 150 mg/kg IBA), both the rooting percentage and seedling rate were 99.8% and 98.9%, respectively.

The rooting percentage and seedling rate for each substrate formulation were as follows: For B1 (cocopeat: perlite in a 1:1 ratio), the rooting percentage was 98.8% and the seedling rate was 98.2%. For B2 (cocopeat: perlite in a 1:2 ratio), the rooting percentage was 98% and the seedling rate was 97.2%. For B3 (cocopeat: perlite in a 1:3 ratio), the rooting percentage was 97.4% and the seedling rate was 95.5%.

From the findings of Zheng *et al.*, 2020, it was concluded that using an appropriate rooting substrate is crucial for successful root formation in carnation cuttings.

The best rooting occurred when the substrate had a cocopeat-to-perlite ratio of 1:1 (by volume). The combination of NAA at 1000 mg/kg and IBA at 100 mg/kg produced the highest rooting percentage and sped up the breeding process. Increasing the concentration of auxins beyond this level did not further enhance rooting and seedling growth. Moreover, the best rooting results were achieved with IBA and NAA at 100 mg/kg and 1000 mg/kg respectively, while higher auxin concentrations hindered rooting.

ii) Response of different varieties of carnations to different types of pinching

The experiment, conducted by Rai and Fatmi in 2020, involved 15 treatment combinations aimed at evaluating the effects of different pinching techniques on five carnation varieties: White Liberty (V1), Marvellous (V2), Purple Sky (V3), Vanity (V4) and Baltico (V5). The study explored three types of pinching methods: single pinch (P1), pinch and a half (P2) and double pinch (P3). The single pinch technique is used to promote early flower production, while the pinch-and-a-half method extends the flowering period and ensures a steady supply of flowers without significant peak periods. On the other hand, double pinching is employed to delay the flowering time.

In practice, single pinching was performed when the plants developed six nodes, approximately 30 days after planting. The pinching was done at the 6th node, leading to the growth of 5-6 lateral shoots. About 55 to 60 days later, a “pinch and a half” was applied, in which 2-3 of the lateral shoots were pinched off again. For the double pinch treatment, all lateral shoots were pinched off, effectively delaying the flowering period.

In the case of combination of variety and type of pinching the V5P1 treatment performed best overall, with the highest flower diameter (8.03 cm) and the longest vase life (10.67 days). V1P1 also showed strong performance with a relatively high plant height and vase life. In contrast, V1P3 exhibited the lowest values for plant height and vase life, indicating less favourable performance.

V4P1 achieved the tallest plant height but had a slightly shorter vase life compared to V5P1. V2 and V3 treatments generally showed lower values for plant height and vase life, with V2P1 and V3P1 providing relatively better results within their groups.

Overall, treatments that produced larger flowers and longer vase life tended to be more desirable, with V5P1 standing out as the most effective treatment in terms of both flower size and vase life.

iii) Effect of plant growth retardants on carnation

The study was conducted by James *et al.*, 2020 using a Randomized Block Design with 16 different treatments, each replicated three times. The experiment used the Orange Viana variety and tested three retardants- Cycocel (CCC), Ethrel and Maleic Hydrazide (MH)- at various concentrations (500 ppm, 750 ppm, 1000 ppm, 1250 ppm, 1500 ppm).

The lowest plant height after spraying was achieved with CCC at 1500 ppm (57.7 cm), followed by CCC at 1250 ppm (59.00 cm). The tallest plants were observed in the control group (water), with a height of 78.53 cm. CCC at 1000 ppm resulted in the highest number of shoots per plant (7.6), closely followed by MH at 1500 ppm and CCC at 1500 ppm (both 7.5). The least number of shoots was recorded with CCC at 500 ppm (3.6).

The maximum number of leaves was observed with CCC at 1500 ppm (135.07), followed by CCC at 1250 ppm (132.27), while the minimum was recorded with Ethrel at 750 ppm (111.33). The control group also showed the shortest time to flower bud appearance (87.56 days), whereas CCC at 1500 ppm took the longest (111.11 days), followed by MH at 1500 ppm (109.16 days).

The highest number of stalks was harvested from CCC at 1000 ppm (6.6), followed by MH at 1000 ppm (6.5) and CCC at 1250 ppm (6.2). The fewest cut flowers were obtained from Ethrel at 1250 ppm (4.43). CCC at 1000 ppm also achieved the highest Cost-Benefit Ratio (1:5.31), with MH at 1000 ppm following closely (1:4.95).

In conclusion, CCC at 1000 ppm proved to be the most effective retardant, resulting in the highest number of shoots per plant, maximum stalks harvested and the best Cost-Benefit Ratio (1:5.31). The control (water) produced the tallest plants and fastest bud appearance. CCC at 1500 ppm had the lowest plant height but the most leaves and the longest time to flower bud initiation. Ethrel treatments generally performed the worst. Overall, CCC at 1000 ppm provided the best balance of growth control and economic benefit.

iv) Insecticidal property of carnation

The results indicate that higher concentrations of both cold and hot water extracts increase the mortality rate across all three larval stages of the domestic fly. At a 0% concentration, there was no observed mortality for either type of extract. At a 2% concentration, cold water extract caused higher mortality (44.91% to 30.78%) compared to hot water extract (38.85% to 28.77%). At a 4% concentration, cold water extract continued to show greater mortality rates (68.85% to 47%) than hot water extract (52.77% to 43%). The highest mortality was recorded at a 6% concentration, with cold water extract resulting in the highest rates (77.70% to 57%) compared to hot water extract (66.14% to 46.92%).

Specifically, for the first, second, and third larval stages, the mortality rates with cold water extract at 6% concentration were 77.70%, 68.85% and 57%, respectively. In comparison, hot water extract at the same concentration resulted in mortality rates of 66.14%, 50.85%, and 46.92%, respectively. The increased effectiveness of cold water extract over hot water extract suggests that the heating process may alter the toxic compounds in the extract, reducing their effectiveness. The study also demonstrates a direct correlation between the concentration of the extract and the mortality rate; as the concentration increases, so does the death rate among the larvae.

Furthermore, the first larval stage exhibited the highest sensitivity to both types of extracts, with this stage showing the highest mortality rates across all concentrations. This suggests that the early larval stage is more vulnerable to the effects of the extracts compared to later stages (Al-Aaraji, 2020).

v) Comparison of petal senescence between cut and intact carnation flowers using potted plants

Ethylene, a key phytohormone, is known to drive petal senescence in cut carnation flowers. While much research has focused on cut flowers, less is known about petal senescence in intact flowers. This study compared changes in sugar levels, ethylene production and the expression of senescence-associated genes during petal senescence in both cut and intact carnations (*Dianthus caryophyllus* L. cv California Mahalo).

Kondo *et al.*, 2020 found that cut flowers had a significantly shorter lifespan compared to intact flowers. Both types of flowers exhibited inward rolling of petals and increased ethylene production towards the end of their floral life. However, in cut flowers, the rise in ethylene production occurred earlier. In cut flowers, glucose and fructose levels in the petals dropped rapidly after full opening, while these sugars remained relatively high in intact flowers.

The accelerated increase in the genes for 1-aminocyclopropane-1-carboxylate (ACC) synthase (DcACS1) and ACC oxidase (DcACO1) in cut flowers matched the increased ethylene production. Additionally, the transcript level of DcEIL1/2, a homolog of EIN3 and a key component of ethylene signalling, declined rapidly in senescing petals of cut flowers but remained relatively high in intact flowers.

The study also identified a homolog of the autophagy-related gene 8 (DcATG8a), crucial for autophagy and a gene for hexokinase (DcHKK1), a glucose sensor, in carnation flowers. The increasing transcript levels of DcATG8a during petal senescence were associated with ethylene production in both cut and intact flowers. Meanwhile, the transcript levels of DcHKK1 gradually decreased in both types of flowers, with a lesser decline in intact flowers. These findings indicate that petal senescence in cut flowers is accelerated by increased ethylene production, which is likely driven by a rapid decline in sugar content. The role of hexokinase suggests that sugar sensing may also play a part in regulating petal senescence.

Conclusion

Genetic diversity within carnations is relatively limited, which constrains breeding efforts. To overcome these limitations and achieve improvements such as extended vase life, novel colours, enhanced fragrance and better control of diseases and pests, breeders can employ various techniques including mutation, interspecific hybridization and selection. Additionally, advanced cultivation practices, such as using growth retardants, experimenting with new chemical combinations and optimizing nutrient and fertilizer applications, can further enhance the quality and performance of carnations.

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