



Australian Government

Department of Health and Ageing
Office of the Gene Technology Regulator

**The Biology and Ecology of
Dianthus caryophyllus L. (Carnation)**

August 2005

TABLE OF CONTENTS

PREAMBLE	1
SECTION 1 TAXONOMY.....	1
SECTION 2 ORIGIN AND CULTIVATION	1
2.1 Centres of diversity	1
2.2 Domestication and use	2
2.3 Cultivation in Australia.....	3
2.4 Plant improvement.....	3
2.4.1 Breeding	3
2.4.2 Genetically modified carnation	4
2.5 Commercial propagation.....	4
SECTION 3 MORPHOLOGY.....	4
3.1 Plant morphology.....	4
3.2 Reproductive morphology.....	5
SECTION 4 REPRODUCTION.....	5
4.1 Reproductive development	5
4.2 Pollination and pollen dispersal	6
4.3 Seed development, dispersal and dormancy	7
SECTION 5 PHYSIOLOGY AND BIOCHEMISTRY	7
5.1 Germination, growth and development.....	7
5.2 Biochemistry of carnation flower colour and scent.....	8
SECTION 6 BIOTIC INTERACTIONS	8
6.1 Weeds.....	9
6.2 Pests	9
6.3 Pathogens and diseases	10
SECTION 7 TOXICITY AND ALLERGENICITY OF CARNATION.....	12
SECTION 8 WEEDINESS OF CARNATION	13
SECTION 9 POTENTIAL FOR VERTICAL GENE TRANSFER	14
SECTION 10 REFERENCES	14

PREAMBLE

This document addresses the biology and ecology of *Dianthus caryophyllus* (carnation), with particular reference to the Australian environment, production and use. Information included relates to the taxonomy and origins of cultivated carnation, general descriptions of its morphology, reproductive biology, physiology, biochemistry, biotic interactions, toxicity, allergenicity and weediness. This document also addresses the potential for gene transfer to occur to closely related species. The purpose of this document is to inform risk assessments of genetically modified carnation that may be released into the Australian environment.

SECTION 1 TAXONOMY

Carnations and pinks are common or garden names for various species of the genus *Dianthus*, which belongs to the Caryophyllaceae family (Order: *Caryophyllales*). Members of the Caryophyllaceae are dicotyledonous. The family consists of 80 genera and 2000 species which are either annual or perennial and most of these herbs occur in the northern hemisphere. Over 300 *Dianthus* species have been identified (Galbally & Galbally 1997; Jurgens et al. 2003a).

There are four types of pinks: cottage, rockery, annual and cluster-head. Species commonly grown as pinks include *D. plumarius*, *D. alpinus*, *D. sylvestris*, *D. chinensis*, *D. deltoides*, *D. gratianopolitanus*, *D. carthusianorum*, *D. superbus* and *D. armeria*. Having been developed from *D. barbatus*, Sweet Williams is also classified as pinks, but is easily distinguishable by its sword-shaped leaves and ‘bunch’ or cluster of flowers.

Of the several kinds of carnations, the three most common are annual carnations, border carnations and perpetual-flowering carnations. *D. caryophyllus*, which is also known as the wild carnation or clove pink, is the ancestor of the border carnations. *D. caryophyllus* has been used extensively by breeders for centuries and as a result many cultivated varieties and hybrids exist, each with a name that usually describes its features (Galbally & Galbally 1997). In this document, carnation is used to refer to *D. caryophyllus* and its cultivars and to hybrids of *D. caryophyllus* with other species of *Dianthus*, which are commonly referred to in trade, botanical and horticultural literature as carnations.

Carnations are generally diploid ($2n = 30$) plants. Tetraploid forms ($4n = 60$) have also been identified. Triploid carnations were produced for commercial purposes, but the resulting plants were mostly aneuploid (Brooks, 1960). The majority of available cultivars in Australia and Europe are diploid (Galbally & Galbally 1997).

SECTION 2 ORIGIN AND CULTIVATION

2.1 Centres of diversity

Members of the *Dianthus* genus are fairly diverse, as their origins range from southern Russia to Alpine Greece and the Auvergne mountains of France. The *Dianthus* species are adapted to the cooler Alpine regions of Europe and Asia, and are also found in Mediterranean coastal regions. Table 1 summarises the origins of popular, commercially grown *Dianthus* species.

Table 1. Commercially popular members of *Dianthus* spp.

Botanical name	Common name	Origins
<i>D. alpinus</i> L. ^a		Austrian Alps.
<i>D. arenarius</i> L. ^{ab}		Northern and eastern mountains of Europe.
<i>D. armeria</i> L. ^b	'Deptford pink'	
<i>D. arvensis</i> ^a	'Finnish Pink'	Auvergne mountains of France.
<i>D. barbatus</i> L. ^{ab}	'Sweet William'	Grown in Britain as early as 1573.
<i>D. carthusianorum</i> L. ^b	'Cluster-head pink'	
<i>D. caryophyllus</i> L. ^{ab}	'Carnation'	Mediterranean
<i>D. chinensis</i> L. ^{ab}	'Indian Pink' or 'Rainbow Pink'	Hills of eastern Asia.
<i>D. deltoides</i> L. ^{ab}	'Maiden Pink'	Europe and Asia and was reported in Britain in 1581.
<i>D. erinaceus</i> Boiss. ^a		Dwarf, alpine form, mountains of the Middle East.
<i>D. fragrans</i> M.F. Adams ^b	'Fragrant Pink'	
<i>D. freynii</i> Vandas ^a		Native of Hungary and Bosnia.
<i>D. gratianopolitanus</i> Vill. ^{ab}		Southwestern France, introduced to Britain in 1792.
<i>D. haematocalyx</i> Boiss. & Heldr. ^a		Greece.
<i>D. knappii</i> Asch. & Kanitz ^a		Hungary.
<i>D. microlepis</i> Boiss. ^a		Mountains of Bulgaria.
<i>D. myrtinervius</i> Grisch ^a		Alpine meadows of Macedonia
<i>D. neglectus</i> Loisel. ^{abc}		Swiss and Italian Alps.
<i>D. nitidus</i> Waldst. & Kit. ^{ab}		Mountains of Macedonia.
<i>D. plumarius</i> L. ^{ab}	'Feathered pink'	Southern Russia.
<i>D. repens</i> Willd. ^b		Eastern European grasslands. ^d
<i>D. seguieri</i> Vill. ^b		Temperate regions of the eastern Mediterranean. ^d
<i>D. squarrosus</i> M. Bieb ^a		Southern Russia.
<i>D. superbus</i> L. ^{ab}		Central Europe
<i>D. sylvestris</i> Wulfen ^{ab}	'Woodland pink'	Alpine plant of southern Europe.

^a from Galbally and Galbally (1997).

^b Listed in Global biodiversity information data portal (GBIF): www.gbif.net. The relevant authority is identified as Catalogue of life partnerships: Integrated taxonomic Information System.

^c *D. neglectus* is identified by Galbally and Galbally (1997) and its alternative name *D. pavonius* is also mentioned. The GBIF portal lists it as *D. pavonius*.

^d Source: Rock garden plant database: (www.kadel.cz 2004)

D. caryophyllus is not seen in the wild except in some Mediterranean countries. This is consistent with Floras records (databases describing the plants of a region or regions) indicating that the natural distribution of carnations is restricted to the Mediterranean regions of Greece, Italy, Sicily, and Sardinia (Tutin et al. 1993).

2.2 Domestication and use

The genus *Dianthus* contains several species that have been cultivated for hundreds of years for ornamental purposes (Ingwerson 1949). Carnation (clove pink) was grown in the Middle Ages for its clove-like perfume. Carnations are used as ornamental plants in gardens and in the cut-flower industry. Modern cut-flower varieties of carnation have been selected for flower size, petal number, stem length and disease resistance. In the 19th century, commercial growing was extensive in France and included both field production and glasshouse production. After germplasm was transferred to the USA, carnation breeding and growing for the cut-flower market became very popular in the USA. Increased market demand in Europe and the USA in the early part of the twentieth century provided the impetus to ensure that carnations remained popular in the cut-flower industry.

As mentioned above, *D. caryophyllus* has been used extensively by breeders for centuries and many cultivated varieties and hybrids exist (Galbally & Galbally 1997). Carnations are among the most extensively grown cut-flowers worldwide. Cut-flower carnations, roses and chrysanthemums make up close to 50% of the world cut-flower trade. In 1995, carnation trade contributed to 15% of the world cut-flower market. (<http://www.ilo.org>, 2004).

2.3 Cultivation in Australia

Carnations are exotic to Australia but have been grown commercially as a flower crop since 1954. At present, the industry produces approximately 140 million cut-flowers per annum across a total of 100 ha in Victoria, South Australia, Western Australia, and New South Wales. Victoria is the largest production centre.

Carnation seeds are commercially available in Australia for cultivation in gardens. Commercial information does not specify particular regions within Australia to cultivate carnations. However, because border carnations are hardy and can survive in cold areas (minimum temperatures as low as -28 °C) (Galbally & Galbally 1997), they are expected to be able to grow in open gardens throughout Australia.

2.4 Plant improvement

2.4.1 Breeding

Carnation breeding is directed to outcomes such as:

- a qualitatively better product;
- improved productivity, more rapid flowering, better yield distribution; and
- new varieties to increase diversity and sustain market demand.

The breeding procedure typically consists of hybridisation, self-pollination and selection (Holley & Baker 1992). If the desired trait is recessive, it may not be expressed in the F₁ progeny. By self-pollinating the F₁ and growing a large population of F₂, selection of one or more individuals with desirable traits will be possible. The process of inbreeding (self-pollination) may, however, hinder the breeding objectives by generating recessive homozygotes expressing undesirable traits.

A variation of the above breeding method has been described as pedigree breeding which entails selecting F₂ individuals by continual soft-cut propagation (Galbally & Galbally 1997).

While inbred parental lines are necessary to breed homogeneous F₁ hybrid varieties, inbreeding detrimentally affects the inbred plants (Galbally & Galbally 1997). Inbreeding depression appears in the third selfed generation (S₃) and therefore, it is almost impossible to produce S₄ seeds (Sato et al. 2000).

Hybrids between carnation and other *Dianthus* species can provide useful sources of genetic traits to achieve the above objectives (Segers 1987). For instance, interspecific hybrids have been obtained through crossing *D. caryophyllus* and *D. capitatus*. These hybrids are highly resistant to bacterial wilt caused by *Pseudomonas caryophylli*. However, the flower quality is adversely affected and further improvement through backcrossing is necessary before commercial production (Onozaki et al. 1998).

Interestingly, traditional techniques for carnation breeding were developed before the discovery of inheritance by Mendel. As a result, these traditional techniques do not include a self-pollination step. In the absence of self-pollination, continuous hybridisation has inadvertently resulted in highly heterozygous carnation varieties. The high level of heterozygosity promotes recombination mutations resulting in further new varieties (Holley & Baker 1992).

Mutation breeding has been also employed to create new colour mutants. More recently, the development of doubled haploidy techniques has also permitted breeders to accelerate breeding and selection (Holley & Baker 1992).

Dwarf carnations, which have been commercialised as alternatives to potted chrysanthemums, have also been generated by breeding programs (Holley & Baker 1992).

Post-harvest flower longevity is a major trait of interest in carnation breeding. De Benedetti and colleagues (2003) used randomly amplified polymorphic DNA (RAPD) analysis on two cultivars, their F₁ progeny and subsequent backcross progeny to identify molecular markers associated with flower vase life. The cultivars used, each with different flower longevity, were 'Roland' and 'Milady'. Flower vase life in carnations appears to be a complex quantitative trait involving multiple genes with additive effects.

2.4.2 Genetically modified carnation

Carnations have been genetically modified for prolonged vase life or to produce violet, mauve, or purple coloured flowers. These have been commercially released in Europe. Several GM carnations with modified vase life, flower colour or resistance to fungal pathogens have also been approved for limited and controlled release in Australia. In 1995, a GM carnation with improved vase life and another GM carnation with modified flower colour were approved for commercial release in Australia under the former voluntary system for regulation of gene technology overseen by Genetic Manipulation Advisory Committee. The GM carnation with modified flower colour was subsequently re-licensed by the Gene Technology Regulator, under the current regulatory system, in 2003.

2.5 Commercial propagation

Most commercially important carnation varieties are sterile and are therefore vegetatively propagated (Zuker et al. 2002). Furthermore, since most cultivars are highly heterozygous, vegetative propagation is used to maintain the selected characteristics. Efficient direct plant regeneration via adventitious shoot initiation has been obtained from petals, receptacles, stems, hypocotyl callus tissues, calyxes, nodes, internodes and leaves (Frey & Janick 1991; Nugent et al. 1991). Regeneration from stems is apparently preferred, as plants grow faster, look healthier, and do not flower prematurely.

SECTION 3 MORPHOLOGY

3.1 Plant morphology

Border carnations, which are the cultivars and derivatives of *D. caryophyllus*, are perennial. They normally grow up to 60 cm in the open garden and may grow a further 15 cm when cultivated in pots. Their side-shoots cluster together around the base of the plant, usually about 10 – 15 in number. Young outdoor plants send up between one to five stems that can each produce up to six flowers (Galbally & Galbally 1997).

Carnation stems are woody at the base but have herbaceous branches. The carnation leaves are narrow and stalkless and their colour varies from green to grey-blue or purple. The flowering stems have swollen nodes (Bird 1994).

Carnations do not retire below ground during the winter and unlike shrubs do not have dormant buds which expand in spring (Bird 1994).

3.2 Reproductive morphology

The single flowers of *D. caryophyllus* have 5 petals and vary from white to pink to purple in colour (Galbally & Galbally 1997). In contrast, border carnation cultivars may have double flowers with as many as 40 petals (Bird 1994). When grown in gardens, flowers grow to between 6 and 8.5 cm in diameter. Some greenhouse-grown plants, disbudded for exhibition, have flowers up to 10 cm in diameter (Galbally & Galbally 1997). Petals are generally clawed or serrated. The flower is bisexual as it has both male (stamens) and female (gynoecium) reproductive organs. Flowers bloom simply or in a branched or forked cluster. The stamens can occur in one or two whorls, in equal number or twice the number of the petals. The fruit is in form of a capsule and contains many small seeds. Some floral characteristics of *Dianthus* spp. are given in Figure 1.

As a result of increased number of petals in cultivars, the reproductive tissues of the flower have become enclosed by petals restricting the access for insect pollinators, especially those without a long proboscis.

There are many flower varieties of carnation. These are divided into groups based on plant form, flower size, and flower type: standards (sims), sprays (minis or miniatures), and midis (chinensii). Standards or sims flowers have a single large flower per stem, whereas sprays have a larger number of smaller flowers. The flowers of midis are smaller and the stem is shorter than the standard type, and there are twice as many flowers (per plant per annum) as standards. Midis can produce either a single flower per stem, or have multiple side branches with flowers.

SECTION 4 REPRODUCTION

4.1 Reproductive development

Carnation is a facultative long day plant, and the effect of temperature on growth and development may be modified by the day length. The shoots are most sensitive to day length when 5 – 7 leaf pairs are visible. In long days, 8 – 10 leaf pairs and in short days 16 – 18 leaf pairs may be initiated prior to flower differentiation.

Day length has no effect on the rate of development from visible flower buds to anthesis (opening of flowers), but more calyx splitting has been detected in long days than in short days (Beisland & Kristoffersen 1969).

Temperature, light intensity and day length affect carnation growth in the greenhouse (Beisland & Kristoffersen 1969). Low temperature stimulates the initiation of flowers whereas increased temperature results in rapid vegetative growth, more leaf pairs initiated prior to flower initiation, shorter internodes, weaker stems, reduced flower size, reduced cut flower life, and reduced branching (Hanzel et al. 1955).

Calyx splitting is a problem in carnation production. The split calyx is unsightly and devalues the cut-flowers. It is caused by the formation of a large number of petals or by lateral buds inside the calyx at low temperatures (Holley & Baker 1992). The flower bud is most sensitive to calyx splitting at low temperatures when it is 3 – 6 mm in diameter (Kohl 1961).

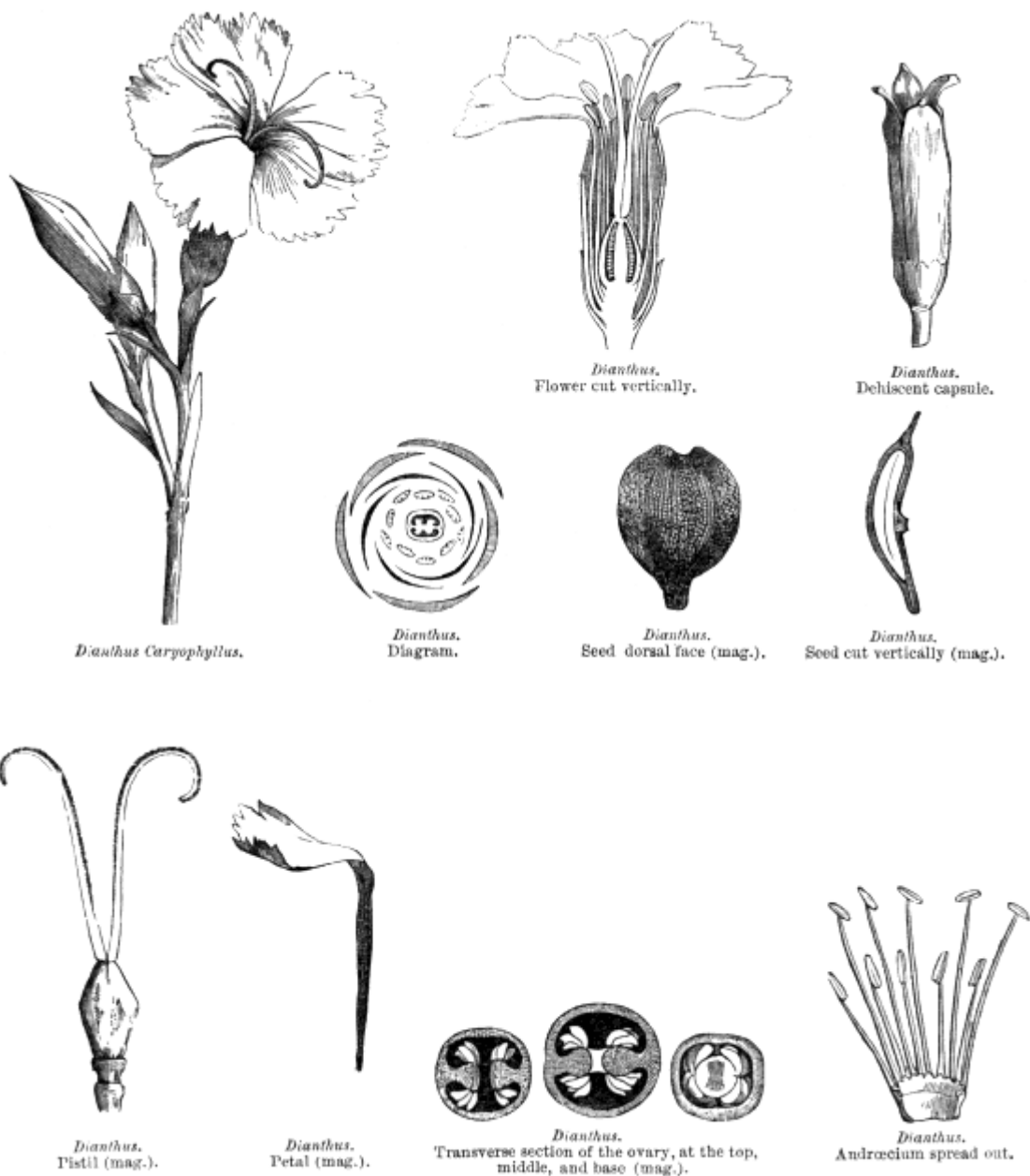


Figure 1. Floral characteristics of *Dianthus* spp. (single flower) (Watson & Dallwitz 2000).

4.2 Pollination and pollen dispersal

The majority of *Dianthus* species are self-sterile because the stigma is not receptive to pollen until one week or more after anthers have shed them. The cultivated carnations require pollination by hand to set seed (Bird 1994).

As a result of the long history of use of vegetative propagation and selection for flower characteristics, the carnation does not produce much pollen, and consequently seed set is low or absent (Galbally & Galbally 1997). The quantity and quality of pollen varies according to the cultivar (Kho & Baer 1973; Galbally & Galbally 1997). Carnation pollen is heavy and sticky and has low viability (percentage germination for some lines is less than 10%). Wind plays little role in pollen dispersal.

The optimal temperature for pollen production in glasshouse plants is approximately 23°C. This temperature, however, results in smaller flowers when compared to those produced by plants incubated at 10°C (Kho & Baer 1973).

In the wild, cross-pollination of carnation relies on insect pollinators. There are no known reports of insect pollinators of *D. caryophyllus*, in particular. However, pollination is likely to be effected by lepidopteran pollinators. Lepidopteran species of the genera *Macroglossum*, *Plusia*, *Pieris*, *Hesperia*, *Aphantopus*, *Aporia*, *Cyaniris*, *Ochlodes*, *Mesoacidalia*, *Polyommatus* and *Thymelicus* are documented pollinators of other *Dianthus* species. Only *Macroglossum*, *Plusia* and *Pieris* occur in Australia.

Pieris rapae (family Pierinae) is an introduced lepidopteran and occurs in the south-east and south-west of mainland Australia and in Tasmania. The larvae damage cruciferous plants (e.g. mustard, radish, turnip etc). *Plusia argentifera* and *P. chalcites* are pests of dicotyledonous plants. Moths of the genus *Macroglossum* pollinate a number of different *Dianthus* species, including *D. barbatus* (Britton et al. 1979). Lepidopteran pollinators, however, have not been reported by commercial carnation growers.

4.3 Seed development, dispersal and dormancy

Under horticultural conditions, erratic and inadequate seed production has been a chronic problem for carnation breeders, requiring hand fertilisation.

The carnation fruit ripens within five weeks of pollination. Up to 100 seeds can develop in each fruit. However, fruits contain on average 40 seeds each (Sparnaaij & Beeger 1973). Once the seed has matured, it is contained within a tubular capsule with a single compartment, which opens from the top. The wind facilitates seed dispersal by causing a back and forth movement of the capsule which is located on the tip of a long flowering stalk (Bird 1994).

If carnation seeds are stored in a cool and dry place, they will remain viable for several years (Sparnaaij & Beeger 1973).

SECTION 5 PHYSIOLOGY AND BIOCHEMISTRY

5.1 Germination, growth and development

The carnation is an annual, dicotyledonous plant. However, plant breeders have selected perennial forms. Cut-flower varieties can be grown for 1-3 years.

Dianthus species in general may be propagated by seed in spring and by cuttings in late summer (Galbally & Galbally 1997). In the glasshouse environment, propagation may be conducted throughout the year. Carnation seeds germinate better in the dark, and exposure to frost and snow accelerates their germination (Ingwerson 1949). Seeds normally germinate in seven to ten days at 21°C. The cotyledons are broad and rounded. Transplantation to pots must be done after the first true leaves appear.

Due to its highly heterozygous nature, the carnation does not come true to its parent when grown from seed. Consequently, under horticultural conditions this method of propagation is only used for selection of new varieties (Galbally & Galbally 1997).

Carnations do not grow efficiently in acidic soil. Addition of lime to soil at a rate of 60 – 120 g/m² is sufficient to allow healthy growth (Bird 1994).

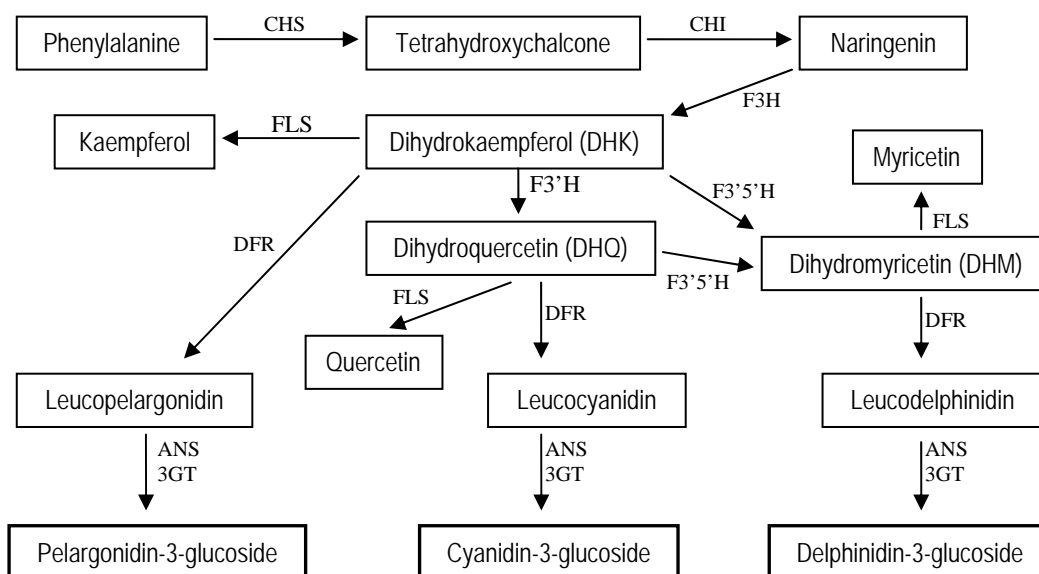
5.2 Biochemistry of carnation flower colour and scent

Flower colour in carnations is attributed to the presence of two pigment types: carotenoids and flavonoids. The carotenoids are responsible for colours ranging from yellow to orange. However, many carnation plants do not contain carotenoid pigments. Flavonoids are water-soluble pigments such as anthocyanins which accumulate in the vacuoles. There are three major types of anthocyanins that contribute to flower colour (Zuker et al. 2002):

- delphinidins that produce blue or purple flower colour;
- cyanidins that produce red or magenta flower colour; and
- pelargonidins that produce orange, pink or brick red flower colour.

Synthesis of all anthocyanins follows a similar pathway until the colourless naringenin is converted to dihydrokaempferol (DHK) (Figure 2). In cultivated carnations, DHK is either converted to the colourless leucopelargonidin by the enzyme dihydroflavonol 4-reductase (DFR) or to dihydroquercetin (DHQ) by flavonoid 3'-hydroxylase. Pelargonidin or cyanidin is produced depending on whether DHK is first converted to leucopelargonidin or DHQ, respectively. Delphinidin synthesis requires the conversion of DHK or DHQ to dihydromyricetin (DHM) by flavonoid 3', 5' hydroxylase (F3'5'H).

Carnations do not naturally have blue or mauve flowers because they lack that part of the anthocyanin biosynthetic pathway that produces delphinidins or blue pigments.



Key to enzymes:

3GT: Flavonoid 3-glucosyltransferase

CHS: chalcone synthase

F3'H: flavonoid 3' hydroxylase

ANS: anthocyanidin synthase

DFR: dihydroflavonol 4-reductase

F3'5'H: flavonoid 3',5' hydroxylase

CHI: chalcone isomerase

F3H: flavanone 3-hydroxylase

FLS: flavonol synthase

Figure 2. Anthocyanin biosynthetic pathway (Holton & Cornish 1995)

The carnation flower fragrance is predominantly due to eugenol, *B*-caryophyllene and benzoic acid derivatives. Observations in the cultivar 'Eliat', show that the level of these compounds increases during flower development and coincides with an increase in flower fragrance (Zuker et al. 2002).

There are significant differences in the chemical composition of scents in carnations. One study on five perpetual-flowering carnations and one malmaison carnation showed that the proportion of eugenol (trace – 84%) and methyl salicylate (0.1 – 1.4%) caused differences in scent (Clery et al. 1999).

Another study on seven non-carnation *Dianthus* species and *Saponaria officinalis* (all members of the Caryophyllaceae) suggests that similarities in floral scent composition may be explained by adaptation to different pollinator groups (Jurgens et al. 2003b). Diurnal or day-active *Dianthus* spp. (*D. armeria*, *D. barbatus*, *D. sylvestris*, *D. deltoides*) were pollinated by day-active butterflies. Their flowers were brightly coloured and contained higher amounts of fatty acid-derived hydrocarbons than the night active (night opening), white-coloured species (*D. superbus*, *D. arenarius*, *S. officinalis*).

SECTION 6 BIOTIC INTERACTIONS

6.1 Weeds

Because carnations are generally short, they can be rapidly swamped by weeds which compete with the plants and can cause production problems.

Commercial production of carnations is for cut-flowers. Commercial growers cultivate carnations in greenhouses using sterile soil. This greatly improves weed and disease management (Galbally & Galbally 1997).

Amateur growers generally plant carnations in their gardens. They are advised to monitor and physically remove common weeds. Grass can also grow among carnations and its early growth can go unnoticed as its leaves resemble those of young carnations (Bird 1994).

6.2 Pests

Thrips including Western Flower thrips (*Frankliniella occidentalis*) are serious pests of carnations. White markings on the petals, particularly in red varieties, indicate the presence of thrips. Thrips can reinfest a crop from nearby vegetation. Peak infestation periods occur in spring when grass and bush dry out in surrounding areas. Thrips can be chemically controlled by registered products. Agricultural chemicals are regulated in Australia by the Australian Pesticides and Veterinary Medicine Authority (APVMA). The APVMA registers products and approves use patterns.

Aphids are seldom seen in well-managed crops. Chemicals used to control thrips should also control aphids.

Mites can establish themselves in pockets, relatively unnoticed, in protected crops. The first symptom of mite infection of the plant is a silvery appearance of leaves. Yellow flowering varieties are particularly attractive to mites. Early infestations may be found underneath curled leaves. Mites can be controlled with chemical treatment.

Helicoverpa caterpillars can cause severe damage to unopened flower buds particularly during the late spring and summer period.

Depending on the country, other arthropod pests including ants, earwigs and wireworm (*Agriotes lineatus*) may also damage carnations (Galbally & Galbally 1997).

Slugs (*Arion distinctus*) have also been reported as pests causing problems in garden carnations (Bird 1994).

6.3 Pathogens and diseases

Table 2. Common pathogens and diseases of carnation[†]

Type of organism	Taxonomic name	Disease	Symptoms
Bacterium			
	<i>Pseudomonas andropogonis</i> <i>P. woodsii</i> <i>P. caryophylli</i>	Bacterial Leaf Spot Bacterial wilt	Leaves develop spots similar to those caused by fungal infections. Spots, however, are translucent. Sudden wilting of tops or individual branches. Basal stem cracks. Roots may be rotted. Vascular discoloration in stems is yellowish to brown. The outer layer (epidermis) separates easily from the stem, which is sticky to the touch.
	<i>Erwinia chrysanthemi</i>	Bacterial slow wilt	Wilting, twisting, curling, and stunting of lower leaves and side shoots followed by death of lower leaves. Wilted plants may recover only to wilt again. Stunted plants have narrow, yellow-green leaves. Symptoms require several weeks to develop. If plant wounds are infected, the wounded area becomes soft and slimy.
	<i>Agrobacterium tumefaciens</i>	Crown gall	Tumour-like swellings (galls) that occur at the crown of the plant, just above soil level. Although it reduces the marketability, it usually does not cause serious damage to older plants.
	<i>Corynebacterium fascians</i>	Fasciation	Clusters of short, spindly or swollen, fleshy shoots develop at a node on the main stem. These shoots are dwarfed, with misshapen leaves and may be at, below, or near the soil line. The main stem of an affected plant sometimes appears to grow normally, but may be stunted. Blossoming is reduced. The roots on a diseased plant are sometimes short with swollen areas.
Fungus			
	<i>Alternaria dianthicola</i>	Alternaria leaf spot	Gray-brown leaf or petal spots with purple margins. Black spore masses form in spots. Branch rot starts at nodes and girdles stem.
	<i>Uromyces dianthi</i> Niessl	Rust	Small blisters containing rust-red spores form on leaves.
	<i>Ustilago violacea</i>	Anther smut	The fungus completely takes over the anthers of the host, which burst open to release the purple, powdery spores instead of pollen.
	<i>Stemphylium botryosum</i>	Calyx rot	Rot starts at tip of calyx and progresses towards base.
	<i>Macrophomina phaseolina</i>	Charcoal rot	Microsclerotia, small black structures, develop under the cortical tissue of roots or on the surface of stem lesions which enable the fungus to survive in the soil. If lesions continue to develop, usually only under very moist conditions, plants may die. Fruit may also become infected, resulting in a firm, dark-coloured decay.
	<i>Peronospora dianthicola</i>	Downy mildew	Downy mildew appears as white to purplish-gray "down" on leaf undersides when the fungus sporulates.
	<i>Cladosporium echinulatum</i>	Fairy-ring leaf spot	Conspicuous tan spots with concentric rings. Margin of spot may be red. Dark spores form in spots.
	<i>Fusarium tricinctum</i>	Fusarium bud rot	Outwardly normal buds are brown and decayed inside. Fungus spores are carried to the buds by grass mites. Petals inside bud decay first.
	<i>Fusarium graminearum</i>	Fusarium stem rot	Stem rotted at soil line and high up on plant. Roots and base of stem rotted. Tops wilt and die. Pink cushions of spores may form at base of plant on decayed tissues. Common as a cutting rot.
	<i>Fusarium oxysporum</i>	Fusarium wilt	Yellow, wilted branches frequently occur on one side at first. Vascular discoloration is dark brown. Root system usually remains intact. In late stages, stem develops a dry, shredded rot. Infected parts die.
	<i>Botrytis cinerea</i>	Grey mold (<i>Botrytis</i> blight)	Woolly grey fungal spores form on soft, brown, decayed blossoms and can move into plant parts wherever blossoms touch them.
	<i>Zygothia jamaicensis</i> <i>Schizothyrium pomi</i>	Greasy blotch	Greasy-appearing spots on leaves with radiating weblike margins. Pimpling of infected areas. Leaves yellow and die.

Type of organism	Taxonomic name	Disease	Symptoms
	<i>Phialophora cinerescens</i>	Phialophora wilt	Gradual wilting of plants; leaves become straw coloured. Not one-sided like in Fusarium wilt. Brown discoloration of vascular system. Little or no tissue rotting in late stages. Uncommon.
	<i>Rhizoctonia solani</i> <i>Thanatephorus cucumeris</i>	Rhizoctonia stem rot	Stems at the soil level have a lesion with a brown border. Rot progresses from the outside. Stems have dry, shredded appearance. Entire plant wilts and dies. Dark fungal strands and sclerotia may be visible.
	<i>Sclerotinia sclerotiorum</i>	Sclerotinia flower rot	A cottony, white, dense mat of mycelial growth on the surface of the host and on the adjacent soil surface. Within this white mass, dense white bodies of fungus form which become black and hard (sclerotia) as they mature.
	<i>Septoria dianthi</i>	Septoria leaf spot	Yellowish brown, withered spots surrounded by a purplish margin on leaves. As the disease progresses, entire leaves and stems become necrotic.
	<i>Sclerotium rolfsii</i>	Southern blight	Lower leaves yellow and wilt first. Leaves will also die back from the tips and stems will fall over. The fungus typically attacks the plant just under or at the soil line. Sometimes a dark brown lesion can be seen on the stem before other symptoms are visible.
Oomycete			
	<i>Phytophthora parasitica</i>	Phytophthora stem rot	Stem rotted at soil line. May be mistaken for Rhizoctonia stem rot.
	<i>Pythium</i> spp.	Pythium root rot	Plants are stunted, particularly in lower, poorly drained areas. Rootlets rotted.
Nematode			
	<i>Heterodera trifolii</i>	Cyst	Multiple infections may kill root tips of the plant.
	<i>Hoplolaimus</i> spp.	Lance	Lance nematodes feed externally along root surfaces but may also feed with at least part of the body embedded in the root. Roots damaged by lance nematodes may be darkened and restricted in their development. Above-ground symptoms include yellowing, stunting, and sometimes death of plants.
	<i>Pratylenchus</i> spp.	Lesion	Above-ground symptoms caused by high populations of root lesion nematodes are sometimes falsely attributed to lack of water or nutrients.
	<i>Paratylenchus hamatus</i>	Pin	Pin nematodes do not cause any particular symptoms but can slow down the growth and reduce crop production.
	<i>Mesocriconema</i> spp.	Ring	At high population densities, ring nematodes can cause extensive root pruning which stresses the plant and reduces yields.
	<i>Meloidogyne</i> spp.	Root-knot	Above-ground symptoms of root-knot nematode damage may be mistaken for nutrient deficiency or water stress. Roots usually develop galls or knots, and tubers can be invaded when root-knot nematode populations are high.
Virus			
<i>Cauliovirus</i>	<i>Carnation etched ring virus</i> (CERV)	Carnation etched ring	Infection by CERV is sometimes mixed with infection by CarMV. CERV causes more severe symptoms such as leaf yellowing, brown spots and rings on leaves, and streaking and flecking of the stems. Plants flower at a later date and the flower quality is reduced. CERV is spread from plant to plant by aphids. Symptoms may be slight in young cuttings. No obvious effect on plant vigour.
<i>Carlavirus</i>	<i>Carnation latent virus</i> (CLV)	Carnation latent	No distinct symptoms on carnation plants; however, it can affect crop production and has been demonstrated to impair flower quality. It is transmitted from plant to plant by aphids.

Type of organism	Taxonomic name	Disease	Symptoms
<i>Carmovirus</i>	<i>Carnation mottle virus</i> (CarMV)	Carnation mottle	The most common and widespread virus disease of carnations. Usually there are no symptoms. However, when the symptom is expressed, the infected plant may have a yellow mottle on the leaves. Flower quality and yield are reduced. Virus free plants have broader leaves and more vigorous growth. CarMV is highly infectious and is rapidly spread from plant to plant by foliage contact or during handling.
<i>Closterovirus</i>	<i>Carnation necrotic fleck virus</i> (CNFV)	Carnation necrotic fleck Carnation streak	Yellow or brown flecks and streaks on the leaves, sometimes followed by reddening and necrosis. Flower quality and yield are affected. Symptoms are masked at low temperatures.
<i>Dianthovirus</i>	<i>Carnation ringspot virus</i> (CRSV)	Carnation ring spot	Small (1 - 2 cm) rings, sometimes concentric, appear on leaves. Chlorosis, mottling, and distortion of young leaves. Plants stunt.
<i>Potyvirus</i>	<i>Carnation vein mottle virus</i> (CVMV)	Carnation vein mottle	Yellow spotting and mottle patterns on the leaves. Young leaves tend to exhibit spots and flecks of a darker green colour on the veins. Infected plants have depressed yields and the incidence of "colour breaks" and calyx splitting are greater. Symptoms tend to disappear on old leaves. CVMV is spread from plant to plant by aphids and is found wherever carnations are grown.

† references:

www.agriculture.gov.au 1994)

www.ppath.cas.psu.edu 2005)

www.umass.edu 2005)

www.qnb.ca 2005)

ucipm.ucdavis.edu 2005)

SECTION 7 TOXICITY AND ALLERGENICITY OF CARNATION

Despite a long history of floriculture, there are few reports of occupational respiratory allergy within the floral industry and no reports of toxicity. Allergic disorders induced by ornamental flower exposure are usually manifested as dermatological symptoms (eczema, urticaria and contact dermatitis) that may or may not be associated with respiratory manifestations.

However, respiratory symptoms are sometimes observed exclusively (Sanchez-Guerrero et al. 1999).

Reports of allergic reactions to carnations include the following:

- Twelve cases of occupational allergic contact dermatitis were diagnosed over a 14-year period among workers involved with decorative plants. The plant families and plants causing occupational contact dermatitis were Caryophyllaceae (two patients- carnation, cauzeflower), Compositae (five patients- chrysanthemum, elecampane, gerbera, feverfew), Alstroemeriaceae (five patients- Alstroemeria), Liliaceae (four patients- tulip, hyacinth) and Amaryllidaceae (two patients- narcissus). The patients were middle-aged, and their average exposure time was 13 years (Lamminpaa et al. 1996).
- A commercial flower seller/distributor developed severe dermatitis and rhino conjunctivitis from dermal and pulmonary exposure to *D. caryophyllus*, *Gypsophila paniculata* and *Lilium longiflorum* after eight years working with these flowers. The patient showed positive skin prick responses to all three species, and serum specific IgE for *D. caryophyllus* and *G. paniculata* (Vidal & Polo 1998).
- The relationship between the allergic symptoms induced by carnations and IgE-mediated reactions was investigated in carnation cultivation workers exhibiting exposure related rhinitis and asthma. Skin prick test responses with carnation extract were positive in 15 of 16 patients, and negative in all control subjects. Nasal provocation response to carnation extract was positive in 13 of 16 patients.

Immunoblotting of sera from 13 patients showed 2 major IgE-binding fractions in most of the patients, which could constitute the major allergens. This study suggests the involvement of carnations in occupational allergy, mediated by an IgE-dependent mechanism (Sanchez-Guerrero et al. 1999).

SECTION 8 WEEDINESS OF CARNATION

Weeds are plants that spread and persist outside their natural geographic range or intended growing areas such as farms or gardens. Weediness in Australia is often correlated with weediness of the plant, or a close relative, elsewhere in the world (Panetta 1993; Pheloung et al. 1999). The likelihood of weediness is increased by repeated intentional introductions of plants outside their natural geographic range that increase the opportunity for plants to establish and spread into new environments (e.g. escapes of commonly used garden plants) (Groves et al. 2005).

Although *D. caryophyllus* and its cultivars are widely cultivated as ornamental plants, there are few records of them being found as naturalised plants even in Mediterranean countries, and there are no records of naturalised *D. caryophyllus* in Australia. However, three other species of *Dianthus* are naturalised in Australia; *D. armeria*, *D. barbatus* and *D. plumarius*, which are restricted to south-eastern mainland Australia and to Tasmania.

Carnations are grown in many countries including Australia, European countries, Israel, Japan and South American countries. They have not been reported as weeds, invasive species or pest species in any of these countries.

Cultivated carnation shares few life history strategies with plants that are classed as weeds or invasive species. It does not reproduce rapidly, is not dispersed widely by abiotic means, and is not a nitrogen-fixer, climber, or clonal. In addition, cultivated carnations generally do not produce much pollen and consequently seed set is low or absent (Galbally & Galbally 1997). Although cultivation of carnation is via vegetative reproduction, carnation does not naturally reproduce asexually.

Weediness has been studied and reported for other *Dianthus* species and for other members of Caryophyllaceae. The CSIRO Handbook of Australian Weeds (Lazarides et al. 1997) describes *D. barbatus* and *D. armeria* as weeds. Deptford Pink (*D. armeria*) became a weed through garden escape and is currently identified as a weed in New South Wales (NSW), Victoria and Tasmania. Its habit is either biennial or annual. *D. barbatus*, another garden escapee, is described as a perennial weed in NSW.

The Co-operative Research Centre for Weed Management systems reviewed recent incursions of weeds between 1971 and 1995 and identified four members of the Caryophyllaceae (Groves 1998). These included:

- *D. plumarius* ssp. *vulgare*: recorded as naturalised in northern Tasmania in 1991;
- *Silene dioica*: recorded as naturalised in NSW in 1982, originally from Mediterranean Europe;
- *Silene tridentata*: recorded as naturalised in NSW in 1986, originally a native of Algeria; and
- *Euonymus* sp.: Spindle Tree which is thought to be a native of Japan, recorded as naturalised in Victoria in 1988.

Southern Weed Science Society, USA has described *D. armeria* as an invasive weed which has spread across North America. Other members of the Caryophyllaceae that are identified as wildflowers of south-eastern USA are species of *Silene*, *Stellaria*, *Saponaria* and *Minuartia* (www.2bnthewild.com 2004).

SECTION 9 POTENTIAL FOR VERTICAL GENE TRANSFER

Vertical gene transfer is the transfer of genetic material from parent to offspring by reproduction. This type of gene transfer can occur by sexual or asexual reproduction. This section deals with gene transfer from *D. caryophyllus* to other plants of the same species or closely related species by sexual reproduction.

Successful gene transfer requires that three criteria are satisfied. The plant populations must:

- overlap spatially;
- overlap temporally (including flowering duration within a year and flowering time within a day); and
- be biological relatives close enough to result in fertile hybrids and facilitate introgression into a new population (den Nijs et al. 2004).

Carnation has been cultivated for over 2000 years and new varieties have been developed mainly by the selection of desirable individuals from inter- and intra-specific crosses. A large number of *Dianthus* species and cultivars are sexually compatible. Many *Dianthus* species are obligate outcrossers because they are protandrous (i.e. the anthers and pollen mature before the pistils) thereby preventing self-pollination.

Insect pollinators can contribute to gene transfer as they help outcrossing between individual plants. These pollinators are described in section 4.2.

In a horticultural setting, pollination between carnation and other *Dianthus* species rarely occurs without human intervention. This is because with continual breeding of carnation many cultivars have lost their ability for natural fertilisation. In addition, hand pollination can contribute in selecting desirable varieties. Selection within *D. caryophyllus* and propagation by soft cuttings has typified the breeding and commercialisation process.

Carnations generally produce only small quantities of pollen. The quantity and quality of pollen varies according to cultivar and species (Kho & Baer 1973; Galbally & Galbally 1997). The pollen of carnation is heavy and sticky, is not wind-dispersed, and has low viability (percentage germination for some lines is less than 10%).

In Australia, gene transfer from carnations to any other plant species, even the most closely related naturalised *Dianthus* species, is unlikely due to the very low fertility of carnations.

SECTION 10 REFERENCES

Beisland, A., Kristoffersen, T. (1969). Some effects of temperature on growth and flowering in the carnation cultivar 'William Sim'. Stromme, E. ISHS Acta Hort.[14], 97-107.

Bird, R. (1994). *Border Pinks*. Timber Press, Portland. pp 1-174.

Britton, E.B., Brown, W.L., Calaby, J.H. (1979). *The Insects of Australia*. Melbourne University Press., Melbourne.

Clery, R., Owen, N.E., Chambers, F.S. (1999). An investigation into the scent of carnations. *Journal of Essential Oil Research* **11**: 359.

den Nijs, H.C.M., Bartsch, D., Sweet, J. (2004). *Introgression from genetically modified plants into wild relatives*. CAB International, UK. pp 1-403.

Frey, L., Janick, J. (1991). Organogenesis in carnation. *Journal of the American Society for Horticultural Science* **116**: 1108-1112.

- Galbally, J., Galbally, E. (1997). *Carnations and pinks for garden and greenhouse*. Timber Press, Portland, Oregon, USA. pp 1-310.
- Groves, R.H. (1998). Recent incursions of weeds to Australia 1971-1995. Co-operative Research Centre for Weed Management Systems (Australia).
- Groves, R.H., Boden, R., and Lonsdale, W.M. (2005). Jumping the garden fence: Invasive garden plants in Australia and their environmental and agricultural impacts. Report No. CSIRO Report prepared for WWF Australia, WWF-Australia,
- Hanzel, J., Nelson, K.S., Kiplinger, D.C. (1955). Floral initiation and development in the carnation var. Northland. *Proc Am Soc Hort Sci* **65**: 455-462.
- Holley, W.D., Baker, R. (1992). Breeding for better varieties. Chapter 3. In: WD Holley, R Baker, eds. *Carnation Production II*. Colorado state University, pp 21-30.
- Holton, T.A., Cornish, E.C. (1995). Genetics and biochemistry of anthocyanin biosynthesis. *Plant Cell* **7**: 1071-1083.
- Ingwerson, W. (1949). *The Dianthus*. Collins, pp 1-128.
- Jurgens, A., Witt, T., Gottsberger, G. (2003a). Flower scent composition in *Dianthus* and *Saponaria* species. *Biochemical Systematics and Ecology* **31**: 345-357.
- Jurgens, A., Witt, T., Gottsberger, G. (2003b). Pollen grain numbers, ovule numbers and pollen-ovule ratios in Caryophylloideae; correlation with breeding system, pollination, life form, style number and sexual system. *Sexual plant reproduction* **14**: 279-289.
- Kho, Y.O., Baer, J. (1973). The effect of temperature on pollen production in carnations. *Euphytica* **22**: 467-470.
- Kohl, H.C. (1961). Period during development of a carnation shoot when temperature has greatest effect on flower size. *Proc Am Soc Hort Sci* **77**: 540-543.
- Lamminpaa, A., Estlander, R., Jolanki, R., Kanerva, L. (1996). Occupational allergic contact dermatitis caused by decorative plants. *Contact Dermatitis* **34**: 330-335.
- Lazarides, M., Cowley, K., Hohnen, P. (1997). *CSIRO Handbook of Australian Weeds*. CSIRO, Canberra, ACT. pp 1-264.
- Nugent, G., Wardley-Richardson, T., Lu, C.Y. (1991). Plant regeneration from stem and petal of carnation (*Dianthus caryophyllus* L.). *Plant Cell Reports* **10**: 477-480.
- Onozaki, T., Ikeda, H., Yamaguchi, T., and Himeno, M. (1998). introduction of Bacterial Wilt (*pseudomonas caryophylli*) resistance in *Dianthus* wild species to carnation. In "*ISHS Acta Horticulturae III: New Floricultural Crops*", Considine, J. eds, Acta Horticulturae, Perth, Western Australia. pp. 127-132.
- Panetta, F.D. (1993). A system of assessing proposed plant introductions for weed potential. *Plant Protection Quarterly* **8**: 10-14.
- Pheloung, P.C., Williams, P.A., Halloy, S.R. (1999). A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management* **57**: 239-251.

- Sanchez-Guerrero, I.M., Escudero, A.I., Bartolom, B., Palacios, R. (1999). Occupational allergy caused by carnation (*Dianthus caryophyllus*). *Journal of Allergy and Clinical Immunology* **104**: 181-185.
- Sato, S., Katoh, N., Yoshida, H., Iwai, S., Hagimori, M. (2000). Production of doubled haploid plants of carnation (*Dianthus caryophyllus* L.) by pseudofertilized ovule culture. *Scientia Horticulturae* **83**: 301-310.
- Segers, A. (1987). The development of interspecific carnation hybrids. *Acta Horticulturae* **216**: 373-375.
- Sparnaaij, L.D., Beeger, G.W. (1973). The improvement of seed production for breeding purposes in the glasshouse carnation (*Dianthus caryophyllus* L.). *Euphytica* **22**: 274-278.
- Tutin, T.G., Burges, N.A., Chater, A.O., Edmondson, J.R., Heywood, V.H., Moore, D.M., Valentine, D.H., Walters, S.M., Webb, D.A. (1993). *Flora Europaea*. Cambridge University Press, Cambridge. pp 227-246.
- ucipm.ucdavis.edu (2005). <http://ucipm.ucdavis.edu/PMG/r280110611.html>.
- Vidal, C., Polo, F. (1998). Occupational allergy caused by *Dianthus caryophyllus*, *Gypsophila paniculata*, and *Lilium longiflorum*. *Allergy* **53**: 995-998.
- Watson, L. and Dallwitz, M.J. (14-12-2000). The Families of Flowering Plants: Descriptions, Illustrations, Identification, and Information Retrieval. <http://biodiversity.uno.edu/delta/>. Accessed on 18 August 2005.
- www.2bnthewild.com (2004). <http://www.2bnthewild.com/>.
- www.agriculture.gov.au (1994). <http://www.agriculture.gov.au/product4.cfm?display2=Horticultural%20Crops&display3=Pests%20and%20diseases&display4=Fact%20sheets>.
- www.gnb.ca (2005). <http://www.gnb.ca/0029/00290020-e.asp>.
- www.kadel.cz (2004). <http://www.kadel.cz/flora/s/kvResult.asp?Rod=Dianthus>.
- www.ppath.cas.psu.edu (2005). http://www.ppath.cas.psu.edu/EXTENSION/PLANT_DISEASE/carnatio.html.
- www.umass.edu (2005). http://www.umass.edu/umext/floriculture/fact_sheets/pest_management/plantdis.html.
- Zuker, A., Tzfira, T., Ben-Meir, H., Ovadis, M., Shklarman, E., Itzhaki, H., Forkmann, G., Martens, S., Neta-Sharir, I., Weiss, D., Vainstein, A. (2002). Modification of flower color and fragrance by antisense suppression of the flavanone 3-hydroxylase gene. *Molecular Breeding* **9**: 33-41.