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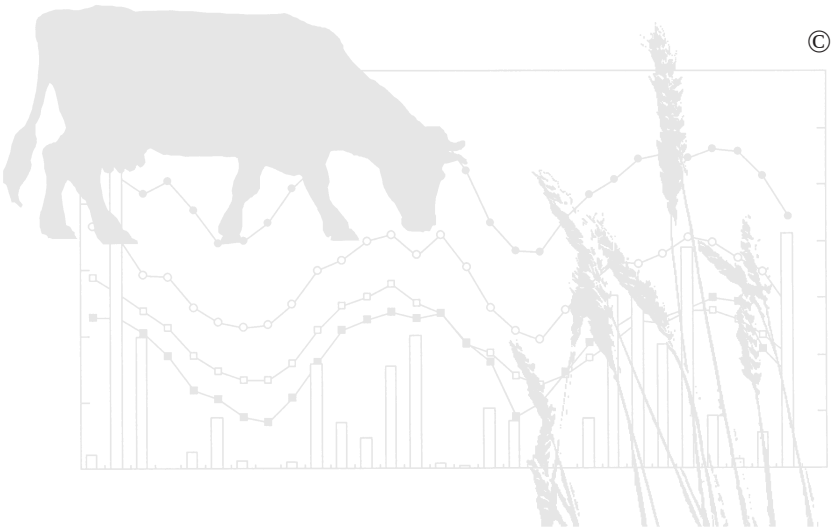
Australian Journal of Experimental Agriculture

Volume 39, 1999



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Review

Cutflower characteristics of terminal flowering tropical *Grevillea*: a brief review

D. C. Joyce[A] *and P. R. Beal*[BC]

[A] Silsoe College, Cranfield University, Silsoe, Bedford MK45 4DT, UK.
[B] Queensland Horticulture Institute, Department of Primary Industries, PO Box 327, Cleveland, Qld 4163, Australia.
[C] Author for correspondence; e-mail: Bealp@dpi.qld.gov.au

Summary. The large and colourful cut inflorescences of the terminal flowering tropical *Grevillea* species and hybrids are considered by enthusiasts to have potential as a cutflower crop. Developing understanding of the characteristics of grevillea inflorescences is collated in this review article. Botany, quality, cultivars, production and marketing, physiology and biochemistry, growth and development, flowering regulation, senescence, postharvest losses, pests and diseases, loss reduction measures, and use of floral preservatives for cut inflorescences are discussed. This overview of current knowledge provides a platform for future research and development on this novel native Australian flower.

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Introduction

Grevillea is a genus within the Proteaceae family (Wrigley and Fagg 1991). Grevilleas are related to more established cutflower crops that originated in South Africa. These South African species include *Protea*, *Leucadendron* and *Leucospermum*. Grevilleas, however, are native to Australia and some neighbouring island nations (Table 1). Common ancestry, in an evolutionary context, is thought to be attributable to origin of the Proteaceae in Gondwanaland (Wrigley and Fagg 1991). According to plate tectonics theory, this 'supercontinent' subsequently split in the Cretaceous period (135–65 million years ago). As a result, the present day continents of Africa, Antarctica, Australia and South

Table 1. Numbers of *Grevillea* species and taxa (species, subspecies and varieties) and endemic taxa in Australia and neighbouring island nations (after Olde and Marriott 1994)

Nation	Species	Taxa	Endemic taxa
Australia	338	402	400
Indonesia	2	3	1
New Caledonia	3	6	6
Papua New Guinea	3	3	1
Total	346	—	—

America, the subcontinent of India, and various islands, including those of Indonesia, New Guinea and New Zealand, were formed. Thus, temporal evolutionary diversification of various subfamilies and tribes of the Proteaceae continued in spatial isolation. Genera of native Australian Proteaceae which are used as cutflowers include *Banksia*, *Conospermum*, *Dryandra*, *Stirlingia* and *Telopea* (waratah). Others which are significant as cut foliage lines include *Adenanthos* and *Persoonia*. Some of these, and other genera such as *Buckinghamia*, *Alloxylon* (syn. *Oreocallis*) and *Stenocarpus*, can also be used as garden or landscape plants. One genus, *Macadamia*, produces edible nuts.

Between 250 and 340 *Grevillea* species are indigenous to Australia and neighbouring nations (Wrigley and Fagg 1991; Olde and Marriott 1994; Table 1). In terms of their morphological habit, grevilleas range in form from large trees [e.g. *G. robusta* (Silky Oak), Olde and Marriott 1995*b*] to small prostrate plants [e.g. *G. aquifolium* (Holly Grevillea), Olde and Marriott 1995*a*]. However, most of the tropical grevilleas are shrubs to small trees [e.g. *G. banksii* (Banks Grevillea), Olde and Marriott 1995*a*; *G. pteridifolia* (Golden Tree), Olde and Marriott 1995*b*]. In addition to speciation, hybridisation between species has occurred in the wild. Also, chance hybrids between *G. banksii* and related tropical species have been common in garden situations. Further, recent artificial hybridisation, at the hands of grevillea enthusiasts, has occurred within this group (Costin and Costin 1988; Olde and Marriott 1994). Marked and

Figure 1. Vase arrangement of inflorescences of a range of *Grevillea* hybrids.

stable variation can be seen within some species. For instance, a prostrate form of *G. banksii*, and cream- or white-flowered form (*G. banksii* forma *albiflora*) of the red-flowered *G. banksii.*

Cut grevillea flowers (inflorescences; Fig. 1) particularly of the tropical species are popular with householders and florists alike. The inflorescences of many of these *Grevillea* species and hybrids are large (e.g. 10–25 cm long), terminal, colourful and on long stems. Grevillea flowers occur in a huge range of colours; including white, pink, red, yellow, orange and green (Olde and Marriott 1994, 1995*a*, 1999*b*). Additionally, a large variety of colour combinations within individual inflorescences can be seen [e.g. red and white (*G. magnifica* subsp. *remota*), yellow and green (*G. formosa*)]. For instance, for individual flowers, the perianth tube may be red and the prominent style may be white; or, developing immature flowers may be green and developed mature flowers may be yellow. In addition to their flowers, the showy foliage of many species (e.g. *G. longifolia*) is suitable for use as cut foliage.

The potential economic value of grevilleas as cutflowers is yet to be realised. In Australia, few commercial growers produce grevilleas, and then only in limited quantities. Most of the blooms are marketed on local or regional markets. Similarly, production of cutflower grevilleas overseas is very restricted. One producer in Israel produces grevilleas for export to Europe.

Botany

Inflorescences

Individual grevillea flowers (florets) are typically borne in unit pairs (uniflorescences) on a floral rachis (inflorescence or conflorescence; Olde and Marriott 1994; Fig. 2). Flower pairs may be either arranged around the central rachis (cylindrical inflorescence) or orientated in only 1 direction (‘toothbrush’ or secund

Figure 2. Mature (harvest maturity stage 3, ‘late looping’; Beal *et al.* 1995) *Grevillea* ‘Sylvia’ inflorescence.

Figure 3. Harvest maturity stages for *Grevillea* ‘Honey Gem’ (Beal *et al*. 1995).

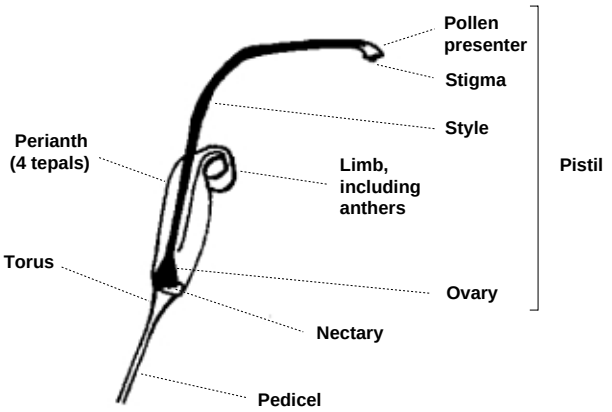

Figure 4. A *Grevillea* flower and its parts.

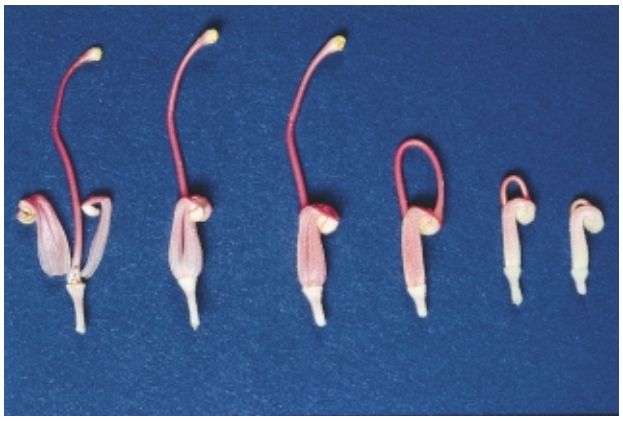

Figure 5. *Grevillea* 'Sylvia' flowers showing developmental stages (left to right): y**oung**, perianth split (loops <0.25 length of floret); **immature**, early looping (loops 0.25–0.50 length of floret); **mature**, fully looped (loops about equal to length of floret); **open (style released)**, style released and gently curved; **senescent perianth**, tepals (4 in total) beginning to separate one from the other; **perianth abscised**, tepals separating and abscising from the torus.

inflorescence). The floral rachis is supported by a peduncle. In some species, inflorescences are borne in paniculate arrangements on primary and secondary peduncles. Bracts commonly subtend the various structures (e.g. flowers). Beal *et al.* (1995) more simply distinguished individual grevillea flowers from the commercial cutflower or inflorescence by terming them florets in their illustrated leaflet for commercial cutflower growers.

Five maturity stages for *Grevillea* inflorescences were defined for the cultivars 'Sylvia' and 'Honey Gem' (Fig. 3 and Beal *et al.* 1995). Maturity was specified by the percentage of florets splitting, of styles looped and extended, and of styles released, as follows: stage 0, immature (<10% florets split); stage 1, perianth splitting (70–100% florets split, 0–10% styles looped, loops <0.25 length of floret is a split); stage 2, early looping (about 100% florets split, 10–50% styles looped, loops 0.25–0.50 length of floret); stage 3, late looping (50–100% styles looped, loops >0.5 and up to length of floret); stage 4, fully looped (100% styles looped, loops about equal to length of floret, <10% styles released); and stage 5, overmature (>10% styles released). Different experiments described in this review use slightly different sets of developmental stages.

Flowers

Grevillea flowers are comprised of a pedicel with a distal torus (Olde and Marriott 1994; Fig. 4). The torus supports the pistil (centre), the nectary, and the perianth tube on its outer rim. The pistil is comprised of the ovary (proximal), the style, and the pollen presenter (distal) bearing the stigma. In grevillea, the pistil is a visually prominent organ. The perianth tube is comprised of 4 tepals which are fused at their margins to one another. Anthers are fused to each tepal towards their distal margins within the limb.

Typically in *G.* 'Sylvia', *G.* 'Honey Gem' and *G. banksii* (the parental species common to both hybrids) florets develop as follows: splitting exposing the style which extends becoming looplike, becomes free after anthesis and more gently curved, and finally the tepals separate and abscise from the torus (Fig. 5).

Production and marketing

Grevillea production for cutflower use is classed as a new and emerging (infant) industry in Australia. Accordingly, few flower farms have significant areas planted to grevilleas. Nonetheless, the cutflower potential of grevilleas has been recognised by industry. To this end, Australian research organisations and rural industry funding agencies have committed resources to assisting commercial enterprises with the development of production and postharvest protocols. Beal and Joyce (1996*a*) have summarised the available, sometimes largely anecdotal, information on cutflower grevillea production. In relative contrast to production of grevilleas by the cutflower industry, production of grevillea plants for home garden and landscape use represents a significant portion of native species

produced by the Australian nursery plant industry. With respect to marketing, the nursery industry practises differentiation of grevilleas on the basis of cultivar characteristics, including floral features such as colour.

Commercial cultivars

A number of *Grevillea* hybrids, including *G.* 'Honey Gem' (orange-gold), *G.* 'Majestic' (red and cream), *G.* 'Moonlight' (white), *G.* 'Sandra Gordon' (yellow) and *G.* 'Sylvia' (pink), are marketed as cutflowers in Australia. The cultivar produced in Israel for marketing as a novelty flower in The Netherlands is 'Spiderman' (cream), which is thought to be a selection of *G. whiteana*.

There are many interspecific hybrids, mainly of F_1 and F_2 generation. They commonly include *G. banksii* and related species as parents (Joyce *et al.* 1996). The hybrids were originally selected for home garden and landscape use (Costin and Costin 1988; Olde and Marriott 1994). The continuing interest in their commercial cutflower potential is due to their wide range of flower colours and their attractive large terminal inflorescences.

Growth and development

The *Grevillea* species and hybrids used for cutflower production typically grow rapidly to 2–3 m height in 12–18 months in south-east Queensland. These woody perennials, which are largely of subtropical and tropical origin, normally flower in their first year of growth. Because of their vigour, pruning of field-grown plants is necessary to maintain them in a manageable state and to achieve marketable cutflower stems. Marketable blooms can be obtained by pruning and disbudding to reduce numbers of competing main and lateral inflorescences.

Regulation of flowering

Most *Grevillea* species and hybrids are floriferous. Control of their flowering has not, however, been studied. Observation suggests that different species and hybrids can vary markedly in their flowering time. The flowering habits of grevilleas vary from a single peak in production (e.g. *G. robusta*) to continual flowering (e.g. *G.* 'Robyn Gordon') through the year. Hybrid *Grevillea* selected for landscape and home garden use are generally long flowering. Flowering time data were collected in 1992–93 by P. Sinclair (pers. comm.) for 6 hybrid cultivars grown in subtropical south-east Queensland. All 6 cultivars flowered throughout the year. Data pooled across the 6 hybrids revealed a pronounced peak in 'useable' (marketable) blooms in June–September (late winter, early spring). A similarly prominent peak, but in 'unusable' blooms, was recorded during November –December (early summer). The hybrid cultivars 'Misty Pink', 'Moonlight', 'Pink Parfait' and 'Sylvia' produced marketable inflorescences throughout the year, whereas yields of marketable 'Majestic' and 'Pink Surprise' blooms tended to be confined to late winter–early spring.

Pests and diseases

Olde and Marriott (1994) extensively describe pests and diseases of grevillea. Fungal diseases of leaf and stem, and collar and root rots have been routinely associated with grevillea in unpublished records of Plant Pathology Herbarium, Queensland Department of Primary Industries. Phytophthora root rot is a very serious soil-borne disease of grevillea reducing plant survival and productivity. However, pests and diseases of grevillea blooms have not been well catalogued. Old and Marriott (1994) mention pests of flowers such as macadamia flower caterpiller (*Homoeosoma vagella*), grevillea psyllids and also fasciation. In the field, nectar-seeking parrots, such as the rainbow lorikeet (*Trichoglossus haematodus*), can cause extensive damage (Beal and Joyce 1996*a*). Insect pests include beetles and phytophagous larvae (Vuthapanich *et al.* 1993). For example, pre- and/or postharvest infestation by the sorghum head caterpillar (*Spodoptera* spp.) can

Table 2. Examples of grevilleas, within six colour groupings, having vase lives either equivalent to or longer than a reference cultivar, *Grevillea* 'Majestic' (range 5.3–6.0 days; after Beal and Joyce 1996*b* and Joyce *et al.* 1996)

Colour grouping	Genotypes with equivalent vase life	Genotypes with longer vase life
Cream/white	—	*G. whiteana*, *G. sessilis*, *G.* 'Moonlight'
Yellow	*G.* 'Golden Yul Lo'	*G.* 'Sandra Gordon'
Light pink	*G.* 'Kay Williams'	*G.* 'Caloundra Gem'
Red	*G.* 'Misty Pink', *G.* 'Pink Surprise', *G.* 'Jessie Morgan'	*G.* 'Sylvia', *G.* 'Pink Champagne'
Other	*G.* 'Honey Wonder'	*G.* 'Honey Gem', *G. pteridifolia*

severely damage grevillea inflorescences (J. Ligawa, D. Joyce and S. Hetherington unpublished data). *Alternaria*, *Stemphylium* and *Trichoderma* spp. fungi have been isolated from surface infections on wet-stored stems (i.e. those standing in solution; S. Meara, D. Joyce and S. Hetherington unpublished data).

Maintenance of productivity and quality

Cultural practices

Because grevillea is an infant cutflower crop, virtually no research and development effort has been put into developing cultural practices (e.g. irrigation, drainage, nutrition, pest and disease control, and pruning) appropriate for commercial flower production (Beal and Joyce 1996*a*). Choice of species or cultivar may be important in terms of vase life maximisation, since the vase life of most commonly available genotypes is relatively short (Table 2; Joyce *et al*. 1996). Additionally, there is likely to be a commercially significant interaction between growing region and bloom vase life and/or quality. With regard to the harvested unit *per se*, it is clear that pruning (e.g. disbudding) is necessary to consistently achieve long-stemmed determinant inflorescences.

Control of pests and diseases

Soil-borne diseases must be controlled or prevented to ensure acceptable plant survival and productivity. Appropriate measures include cultural precautions (e.g. use of mounds to improve drainage), sourcing plant stock from accredited nurseries, choice of resistant species, chemical treatments and use of protective rootstocks (Olde and Marriott 1994). Bird scaring devices or protection (e.g. netting) may be required for the commercial production of grevillea inflorescences in areas habituated by large nectar-seeking avians, such as parrots. Regular preventative applications of broad spectrum insecticides will also facilitate production of sound blooms. Also, postharvest application of an insecticide, and of a fungicide, is required. Precautionary measures may, for example, need to be taken to control grey mould disease caused by *Botrytis cinerea*; which commonly infects cutflowers (Reid 1992).

Breeding and selection

In the past, development of the many interspecific hybrids has commonly been unplanned and uncontrolled with selections only being identified for garden and landscape use. Plant improvement has largely involved natural (or chance) hybrids, simple (and subjective) selection procedures, lack of information on genetics and little progress in breeding beyond the F_2 generation (Beal and Joyce 1996*a*). The prospects for developing new grevillea cutflower varieties with extended vase life seem sound if controlled and focussed breeding and selection programs are conducted.

Harvesting, grading and packaging

The time of year (season) during which grevillea inflorescences are harvested may influence vase life and quality. Vuthapanich *et al*. (1993) reported that vase lives of *G*. 'Majestic' inflorescences harvested in winter were generally longer than those of summer-harvested blooms. In the case of *G*. 'Sylvia', maximum vase life (about 10 days) was recorded for inflorescences harvested during autumn–winter (J. Ligawa, D. Joyce and S. Hetherington unpublished data). Vase life was lowest (about 6 days) for spring–summer-harvested inflorescences. Inflorescences harvested in autumn–winter also tended to have stronger colour and higher endogenous soluble sugar concentrations (J. Ligawa, D. Joyce and S. Hetherington unpublished data).

Harvest maturities or development stages have been pictorially described for *G*. 'Sylvia' and *G*. 'Honey Gem' (Fig. 3; Beal *et al*. 1995). These hybrids have conical and cylindrical shaped inflorescences, respectively. Their optimum harvest maturity stages, based upon both vase life and floral display, were determined to be 'late looping' and 'early looping', respectively (Table 3; Beal *et al*. 1995). Vuthapanich *et al*. (1993) investigated harvest maturity stages for *G*. 'Majestic'. Longest vase lives were recorded for the least mature inflorescences ('split perianth' and 'few looped styles' stages). Vase life of *G*. 'Sandra Gordon' was also generally longer for less developed or less mature inflorescences (Lacey 1982).

Table 3. Harvest maturity stages and associated vase lives for *Grevillea* 'Sylvia' and *Grevillea* 'Honey Gem' (after Beal *et al*. 1995; D. Joyce, P. Beal and A. Shorter unpublished data)

Values followed by the same letter are not significantly different at $P = 0.05$

Values in parentheses show relative vase lives as compared with the longest recorded in this study (%)

Stage number, description	Vase life (days) 'Sylvia'	'Honey Gem'
0, 'immature'	7.5a (97)	9.2a (100)
1, 'split perianth'	7.4a (96)	8.1b (88)
2, 'early looping'	7.5a (97)	7.2c (78)
3, 'late looping'	7.7a (100)	6.6c (72)
4, 'fully looped'	5.9b (77)	5.7d (62)
5, 'overmature'	4.7c (61)	4.1e (45)

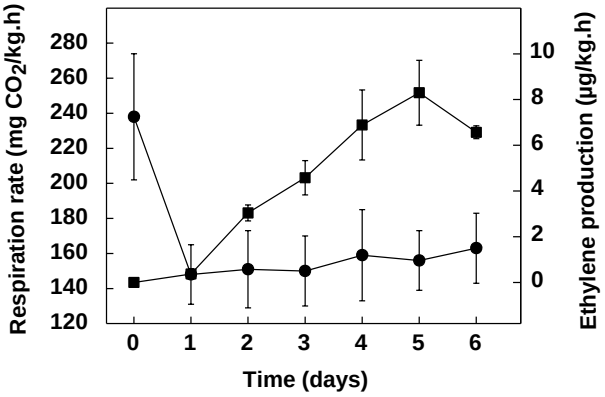

Figure 6. Respiration (●) and ethylene production (■) rates of harvested *Grevillea* 'Sylvia' inflorescences (Joyce *et al*. 1995). Vertical bars show standard errors of the means (n = 5 for respiration and n = 10 for ethylene).

In the course of packaging grevilleas, precautions must be taken to avoid interlocking of flowers on adjacent inflorescences. Sleeving, top-to-toe placement and cell-pack strategies merit consideration.

Storage

Low temperature storage of grevilleas has only been investigated for *G*. 'Sylvia' inflorescences (S. Meara, D. Joyce and S. Hetherington unpublished data). Vase life after dry storage (wrapped in moistened newsprint and sleeved in plastic) for 3, 6, 9 and 12 days was consistently longest for 0°C, as compared with storage at either 5 or 10°C. Vase life following 12 days at 0°C was 65% of the unstored control treatment vase life of 6.9 days. Vase life of *G*. 'Sylvia' was slightly but consistently, over 6, 12 and 18 days at 0°C, better maintained by dry (e.g. average of 6 days) than by wet (sleeved and stood in dilute chlorine solution; e.g. 5 days) storage.

Temperature quotients (Q_{10}; Wills *et al*. 1998) for respiration (metabolism) of *G*. 'Sylvia' over the temperature intervals of 0–10 and 10–20°C were estimated to be about 2.8 and 4.3, respectively (S. Meara, D. Joyce and S. Hetherington unpublished data).

Postharvest quality

The cutflower potential of grevillea inflorescences is to some extent limited by their typically short vase life of <10 days (Joyce *et al.* 1993; Olde and Marriott 1994). However, the vase life of some major cutflower lines (e.g. Dutch iris, tulip) is similarly short. Thus, this factor is more a nuisance than a major impediment. The factors which detract most from the visual appeal of grevillea inflorescences are flower, perianth, and perianth segment (tepal) abscission; and the generally untidy appearance of 'open' flowers.

Physiology and biochemistry of cutflowers

Respiration

Respiration rates have been measured during senescence both for harvested intact grevillea inflorescences and for individual flowers detached at various stages of development. Respiration rates of harvested *G*. 'Majestic' (Vuthapanich *et al*. 1993) and 'Sylvia' (Joyce *et al*. 1995) inflorescences declined markedly over the first day. Thereafter, lower relatively constant or slowly falling rates were sustained until the end of vase life (Fig. 6). Likewise, respiration rates of individual flowers detached at each of 6 sequential development stages ['young', 'immature', 'mature', 'open (style reflexed)', 'senescent perianth', 'perianth abscised'; Fig. 5] fell markedly within 24 h of harvest (Joyce *et al.* 1995).

Rates of respiration recorded at ambient temperature for *G*. 'Majestic' inflorescences fell from 400 to 100 mg CO_2/kg.h (Vuthapanich *et al*. 1993). Similarly, rates reported for *G*. 'Sylvia' flowers or inflorescences fell from 589 to 98 mg/kg.h (Fig. 6; Joyce *et al*. 1995). Thus, according to Kader (1992), grevilleas can be classified as having 'extremely high' respiration rates.

Ethylene production

Ethylene production by harvested *G*. 'Majestic' (Vuthapanich *et al*. 1993) and 'Sylvia' (Joyce *et al*. 1995) inflorescences tended to increase during senescence over time (e.g. Fig. 6). Similarly, ethylene production by individual flowers detached at the 'open', 'senescent perianth' and 'perianth abscised' development stages (Fig. 5) increased in time (Joyce *et al*. 1995).

Ethylene production rates measured at ambient temperature (20°C constant) for *G*. 'Majestic' inflorescences rose from 0 to 2.5 g C_2H_4/kg.h (Vuthapanich *et al*. 1993). Production of ethylene by *G*. 'Sylvia' flowers or inflorescences increased from 0 to 10 g C_2H_4/kg.h (Fig. 6; Joyce *et al*. 1995). By these measures, grevillea can be classified as being 'very low' up to 'moderate' ethylene producers (Kader 1992).

Since trends in respiration generally oppose trends recorded for ethylene production, it may be concluded

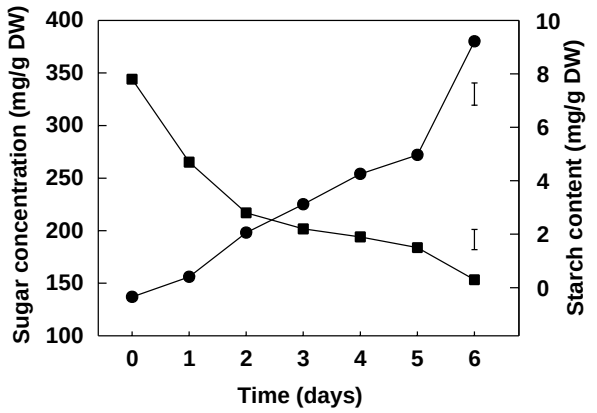

Figure 7. Total soluble sugar (●) and starch (■) concentrations in *Grevillea* 'Sylvia' flowers sampled from inflorescences harvested at 7 sequential development or harvest maturity stages; namely 'immature', 'perianth splitting', 'early looping', 'late looping' (Fig. 2), 'fully looped', 'overmature', and 'fully reflexed'. Vertical bars show l.s.d. (P = 0.05) values for sugar (upper bar) and starch (lower bar).

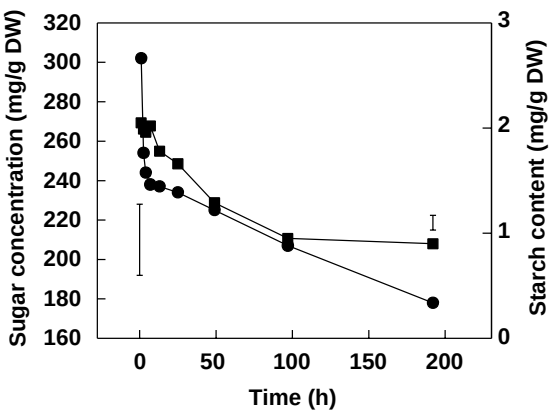

Figure 8. Changes in the total soluble sugar (●) and starch (■) concentrations of *Grevillea* 'Sylvia' flowers sampled from inflorescences harvested at the 'early to late looping' development or harvest maturity stages and held in vases for 8 days (192 h). Vertical bars show l.s.d. (P = 0.05) values for sugar (left bar) and starch (right bar).

that grevillea flowers are not 'climacteric' in nature (Wills *et al*. 1998). Thus, ethylene produced during senescence may be associated with processes such as abscission, 'non-climacteric' senescence, pollination and/or ovary development (Reid 1995).

Transient (≤24 h duration) small peaks (e.g. to 4 g/kg.h) in ethylene production upon detachment of individual flowers from their inflorescences have been recorded for fully developed flowers (namely 'styles reflexed', 'perianth segments splitting', and 'perianth abscised' stages, Fig. 5; Setyadjit, D. Joyce, D. Simons and V. Vithanage unpublished data). Less developed (namely 'style visible', 'small stylar loop', 'style looped to the length of the perianth tube', Fig. 5) did not show wound ethylene production.

ACC content

The ACC (1-aminocyclopropane-1-carboxylic acid) concentration in *G*. 'Sylvia' inflorescences rises during development and senescence in the course of vase life (Setyadjit, D. Joyce, D. Simons and V. Vithanage unpublished data). In concert with increasing ethylene production, ACC levels rose from about 0.5 to about 2 nmol/g fresh weight.

Pollination of *G*. 'Sylvia' flowers neither increased their endogenous ACC concentration nor enhanced their ethylene production rate (Setyadjit, D. Joyce, V. Vithanage and D. Simons unpublished data). Thus, their concomitant elevation in *G*. 'Sylvia' flowers aging during vase life appears to be a function of 'non-climacteric' tissue senescence *per se*; and not a function of pollination or pollination-induced ovary development.

Sugars

Sugars and starch levels have been quantified in flowers detached from *G*. 'Sylvia' inflorescences harvested at 7 sequential floral development stages (J. Ligawa, D. Joyce and S. Hetherington unpublished data). These maturity stages ranged through 'immature', 'perianth splitting', 'early looping', 'late looping', 'fully looped', and 'overmature' previously described by (Beal *et al*. 1995) to 'fully reflexed' (or 'all styles released'), a more advanced maturity. Total soluble sugar concentrations tended to increase throughout development from about 150 to about 350 mg sucrose equivalents/g dry weight (Fig. 7). Conversely, starch concentrations fell from 8 mg/g dry weight to about 0 mg/g dry weight. The major sugar was sucrose (about 50%), with glucose, fructose and mannose, in roughly equal proportions, comprising the rest of the identified soluble sugars. One further unidentified soluble carbohydrate was detected in high performance liquid chromatography analysis.

Carbohydrate concentrations have also been monitored during the vase life of *G*. 'Sylvia' inflorescences harvested at the early to late looping maturity stages (J. Ligawa, D. Joyce and S. Hetherington unpublished data). Total soluble sugar concentrations fell

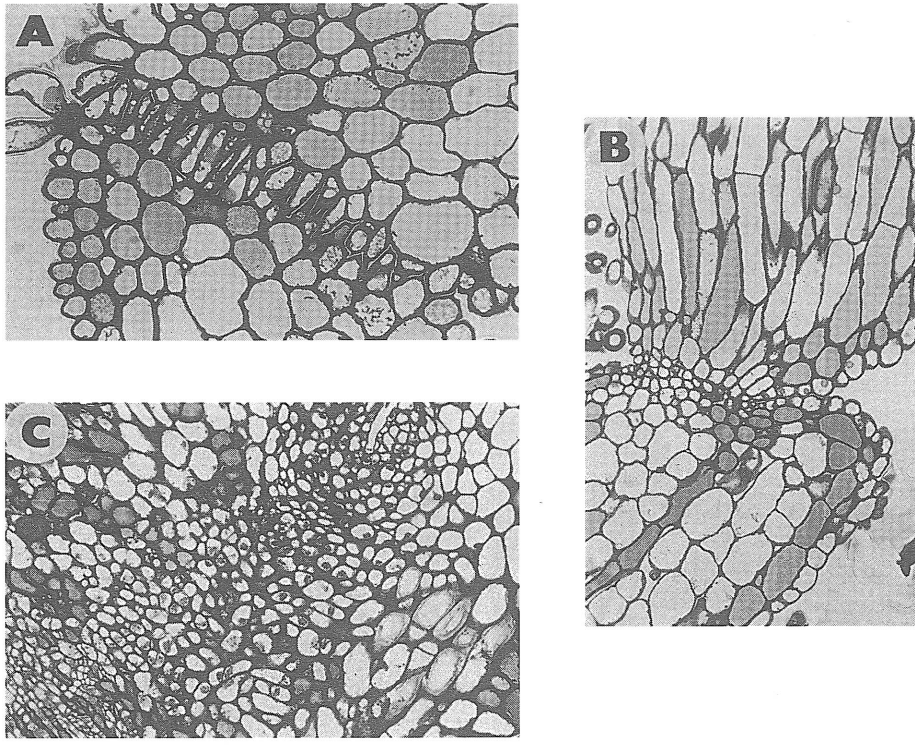

Figure 9. Photomicrographs of abscission zones: (*a*) Z1 (tepal to tepal), (*b*) Z2 (perianth onto torus), and (*c*) Z3 (pedicel onto rachis) of *Grevillea* 'Sylvia' flowers at the abscission layer.

from about 300 to about 180 mg/g dry weight over 8 days, and, correspondingly, starch concentrations fell from about 2 to about 1 mg/g dry weight (Fig. 8). The relative proportions of sucrose, glucose, fructose and mannose, as described above for different development stages or harvest maturities, were approximately constant throughout vase life.

Senescence of cutflowers

Abscission

The most obvious manifestation of senescence of grevillea inflorescences is abscission of perianth segments, perianth tubes and/or flowers. For ease of referral, the related abscission zones have been called Z1 (tepal to tepal), Z2 (perianth onto torus), and Z3 (pedicel onto rachis), respectively. Abscission zones of *G.* 'Sylvia' have been studied at the cellular level by light microscopy (D. C. Joyce unpublished data). In terms of definition at this level, Z1 appears to be simply comprised of 2 sets of adjacent inter-locking cells (Fig. 9*a*), Z2 has a separation layer clearly evident as files of small cells (Fig. 9*b*), and, Z3 is rather poorly defined anatomically (Fig. 9*c*). More generally, Olde and Marriott (1994) stated, with respect to Z1, that grevillea flower tepals 'adhere along their margins by means of hairs or papillae, by tooth-like cells, or by a slight concavity or flange ... of the longitudinal axis of the tepal margin'.

In the case of *G.* 'Sylvia', it was of interest to determine if separation of the tepals was achieved simply by their parting under physical forces (e.g. reflexion of the style, dehydration of the tepals) or whether biochemical processes (e.g. activity of cell wall hydrolyases) might be involved. Indirect evidence for latter process was obtained by examination of tepal separation surfaces (Z1) with a scanning electron microscope (D. C. Joyce unpublished data). Separation layer cells exposed by force had rough surfaces, and the cells were sometimes torn open; exposing symplastic materials therein (Fig. 10*a* and *b*). In contrast, separation layer cells exposed by natural processes had smooth surfaces (Fig. 10*c* and *d*). Nonetheless, further lines of evidence are needed to help confirm the proposition that tepal separation in *G.* 'Sylvia' involves biochemical activity.

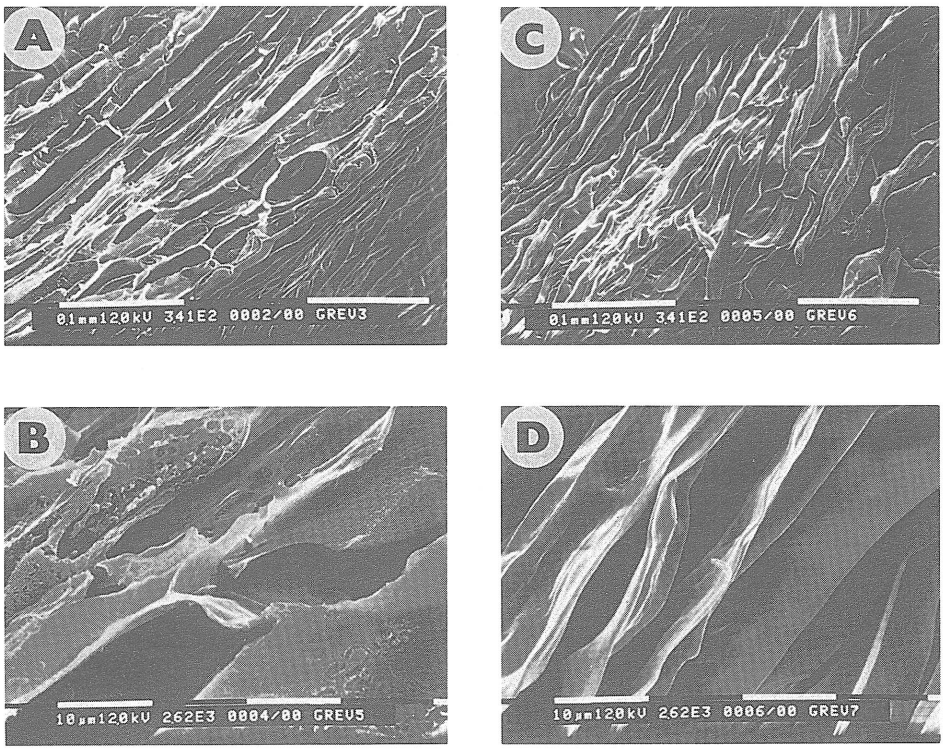

Figure 10. Scanning electron micrographs with plan views of abscission face of Z1 (tepal/tepal) separation layers of forcibly parted tepals (*a*, *b* with damaged cell layers) and naturally parted tepals (*c*, *d* with undamaged cell layers) of *Grevillea* 'Sylvia' flowers.

Fading

Grevillea 'Sylvia' flowers on inflorescences fade during development and senescence in the vase from comparatively bright to relatively dull pink. This fading is evident both for tepals, which may be shed quickly, and for the style, which is retained until the end of vase life; when the whole flower remnant often abscises. Likewise, flowers of other-coloured species or hybrids fade or discolour (Joyce *et al.* 1996). In some cases, however, discolouration is characterised by a deepening of colour (e.g. blueing of red flowers). Flower discolouration has been associated with vacuolar pH changes brought about by increased symplastic concentrations of ammonia resulting from proteolysis (Mayak and Halevy 1980).

Postharvest losses

Nature of losses

Harvested grevillea inflorescences are very susceptible to mechanical damage. Individual flowers are 'hook like'. Thus, adjacent inflorescences can interlock, and flowers are easily detached in attempts to separate them. Grevillea inflorescences also wilt readily, and are prone to attack by insects (in particular, caterpillars). The single most dramatic type of loss, however, is flower abscission from the inflorescence upon exposure of blooms to ethylene.

Loss of the visual display quality of grevilleas during vase life is characterised by: (i) abscission of flowers, perianth tubes and/or tepals, (ii) colour fading (androecium and gynoecium), (iii) flower opening (reflexing of the previously hooked style), and/or (iv) wilting of the inflorescence (Joyce *et al.* 1996). Symptoms (i)–(iii) tend to confer an untidy appearance upon the inflorescence. A condition known as 'slippers' is associated with abscission of the perianth tube from the torus and its subsequent adherence to the tip of the reflexing or extended style (Joyce *et al.* 1996).

Causes of postharvest losses

Postharvest losses of grevillea, as with many harvested floriculture crops (Nowak and Rudnicki 1990;

Table 4. Effect of various vase solution ingredients on the vase life of *Grevillea* 'Sandra Gordon' inflorescences (after Lacey 1982)

Values in parentheses show relative vase lives averaged across maturities as compared with the longest recorded in this study (%)

Treatment	'Perianth splitting'	'Early looping'	'Over-mature'	Mean
Control (deionised water)	3.6	4.0	3.4	3.7 (39)
Biocide, acidifier	8.0	7.5	6.4	7.3 (77)
Biocide, acidifier, 2% carbohydrate	9.5	9.0	6.5	8.3 (87)
Biocide, acidifier, 4% carbohydrate	10.3	10.0	8.1	9.5 (100)
Mean	7.9	7.6	6.1	

Table 5. Effect of increasing vase solution sugar concentrations on the vase life of cut *Grevillea* 'Sylvia' and *Grevillea* 'Honey Gem' inflorescences harvested at the 'early looping' stage (D. Joyce, P. Beal and A. Shorter unpublished data)

Values followed by the same letter are not significantly different at $P = 0.05$

Values in parentheses show relative vase lives as compared with the longest recorded for each cultivar in this study (%)

Solution	'Sylvia'	'Honey Gem'
Deionised water	7.3c (78)	7.9ab (93)
DICA (10 mg avail. Cl/L)	7.5c (80)	7.9ab (93)
1% (w/v) sucrose + DICA	7.7c (82)	7.2b (85)
2% (w/v) sucrose + DICA	8.3b (88)	8.0ab (94)
4% (w/v) sucrose + DICA	8.7b (93)	8.4ab (99)
6% (w/v) sucrose + DICA	9.4a (100)	8.5b (100)

Reid 1992), are largely associated with poor packaging (e.g. failure to prevent physical injury and/or water loss) and handling (e.g. rough handling, transport and handling delays, failure to maintain the cool chain) and exposure of blooms to ethylene gas. Harvesting at the correct maturity and control of pests and diseases are also important issues (see below).

Major postharvest losses of grevillea blooms can be associated with harvesting overmature or over-developed inflorescences (reduced longevity), interlocking of harvested inflorescences (mechanical damage), elevated handling and transport temperatures (shortened longevity), exposure to exogenous ethylene (flower abscission), excessive water loss (inflorescence wilting), and attack by phytophagous larvae.

Use of floral preservatives

Preservative (vase) solution ingredients

One of the earliest accounts of a vase solution study on grevilleas is that by Lacey (1982), who worked with *G*. 'Sandra Gordon'. She determined that use of an ammonium-based biocide (200 L Physan/L) and an acidifier (320 mg citric acid/L) enhanced vase life of inflorescences at each of 3 successive stages of harvest maturity/development (Table 4). Addition of carbohydrate (2 or 4% w/v sucrose) resulted in further vase life extension.

Vuthapanich *et al*. (1993) determined that chlorine biocide (NaOCl) provided alone in the vase water was phytotoxic to *G*. 'Majestic' at concentrations exceeding 50 mg/L. Dichloroisocyanurate (DICA, sodium salt; stabilised chlorine) was toxic at ≥50 mg/L. Provision of citric acid acidifer alone in the vase water did not enhance the vase life of *G*. 'Majestic' inflorescences (Vuthapanich *et al*. 1993).

Vase life of *G*. 'Majestic' inflorescences was increased by provision of between 0.5 and 4% (w/v) sucrose (+50 mg NaOCl/L) as the vase solution, with maximum vase life being achieved at 4% (w/v) sucrose (Vuthapanich *et al*. 1993). Nectar secretion was, however, recorded as a concern associated with provision of sucrose at ≥2% (w/v). Ligawa *et al.* (1997) found that 3% (w/v) sucrose (+10 mg available Cl as DICA) was a suitable vase solution for *G*. 'Sylvia' inflorescences. Vase life extensions for both *G*. 'Sylvia' and *G*. 'Honey Gem' have, nonetheless, been recorded for up to 6% (w/v) sucrose (Table 5). Provision of exogenous sugar to *G*. 'Sylvia' inflorescences via the vase solution has been shown to sustain relatively elevated rates of respiration (Joyce *et al*. 1995) and to maintain tissue total soluble solid (sucrose equivalents) concentrations (J. Ligawa, D. Joyce and S. Hetherington unpublished data).

The overall conclusion that may be drawn from consideration of the findings described above is that provision of exogenous sucrose is important if maximum vase life of grevilleas is to be realised. Joyce (1994) suggested that 2–3% (w/v) sucrose plus 20–50 mg available Cl/L might be a generally useful vase solution recommendation for native Australian flowers, including grevilleas. It was further suggested that, should symptoms of phytotoxicty become evident, 0.5–1.0% (w/v) sucrose plus 25 mg Cl/L may be more appropriate.

Pulsing with 30 or 40% (w/v) sucrose (+50 mg NaOCl/L) for 24 h at 20°C resulted in subsequent vase life extensions for *G*. 'Majestic' inflorescences (Vuthapanich *et al*. 1993). Similarly, sucrose pulsing (e.g. 10% w/v, 6–24 h, 22°C) was shown to extend the

Table 6. Effect of pretreatment with STS or NAA (see text for details) on flower abscission, gauged as relative loss in weight (% initial fresh weight), visual quality (1, excellent–9, very poor) and vase life, from *Grevillea* 'Honey Gem' inflorescences following their exposure to ethylene (6 L/L, 24 h, 20°C) (after Joyce and Haynes 1989)

Data are means ± s.d. (n = 5)
Values in parentheses show relative vase lives as compared with the longest recorded in this study (%)

Pretreatment (%)	Relative fresh wt (1–9 scale)	Visual quality (days)	Vase life
Untreated (control)	55 ± 29	7.4 ± 3.6	2.6 ± 3.6 (57)
4 mmol/L STS pulse	76 ± 38	4.2 ± 4.4	3.4 ± 2.5 (74)
0.5 mmol/L STS pulse	58 ± 26	7.0 ± 3.5	2.4 ± 3.1 (52)
0.22 mmol/L NAA dip	99 ± 10	1.8 ± 1.8	4.6 ± 2.3 (100)

vase life of *G*. 'Sylvia' inflorescences (Ligawa *et al*. 1997). However, as beneficial effects were not maintained through subsequent simulation of export handling, the practise was not recommended.

Anti-ethylene treatments

The anti-ethylene treatment most commonly used on ornamental plant material in recent times has been STS (silver thiosulfate) applied as a dip, spray or pulse (Reid 1992). Joyce and Haynes (1989) demonstrated that ethylene-induced flower abscission from *G*. 'Honey Gem' could be reduced by either a STS pulse treatment (4 mmol Ag^+/L, 15 min, 21°C; 0.5 mmol/L 18 h, 2°C) or a naphthaleneacetic acid dip [0.22 mmol NAA/L (40 mg/L)]. The NAA treatment was comparatively more effective (Table 6). In a more extensive study, Vuthapanich *et al*. (1993) investigated the ability of STS pulse treatments to prevent ethylene (ethephon)-induced and natural flower abscission from *G*. 'Majestic' inflorescences. Although responses to different pulse treatments were variable, 4 mmol/L Ag^+ (as STS) for 15 min at 27.5°C or for 60 min at 20°C were highly effective. The novel anti-ethylene gas 1-methylcyclopropene (1-MCP; Sisler and Serek 1997) is, however, likely to prove a more reliable treatment for preventing flower abscission from grevillea blooms (Fig. 11). In an experiment to determine the relative efficacy of an indoleacetic acid (IAA) dip versus gassing with 1-MCP, ethylene-induced flower abscission from *G*. 'Sylvia' inflorescences was unexpectedly (compared with Table 6) not inhibited by pretreatment with auxin (50 mg IAA/L), but was completely prevented by 1-MCP (50 nL 1-MCP/L, 24 h, 20°C; Table 7; S. Aiyar, D. Joyce and A. Shorter unpublished data).

Figure 11. Untreated control (left) and 1-MCP pretreated (right) *Grevillea* 'Sandra Gordon' inflorescences following their exposure to ethylene (10 L/L, 24 h, 20°C).

Table 7. Effect of pretreatment with 1-MCP or IAA (see text for details) on flower abscission, gauged as vase life, from *Grevillea* 'Sylvia' inflorescences following their exposure to ethylene (10 L/L, 24 h, 20°C) (S. Aiyar, D. Joyce and A. Shorter unpublished data)

Values followed by the same letter are not significantly different at P = 0.05

Pretreatment	– Ethylene	+ Ethylene
Untreated (control)	5.9b	2.0d
1-MCP	6.1ab	6.4a
IAA	5.0c	2.0d

Conclusions

The tropical group of species, forms and hybrids of *Grevillea* is large and diverse, with important differences in flower colour, vase life and flowering season. Further opportunities for identification of superior types and for

controlled and focussed breeding in enhancing cutflower quality remain to be investigated. These Grevilleas grow rapidly and flower in the first year in warmer situations. Their potential as a cutflower crop remains limited by lack of information on appropriate agronomy (e.g. pruning), pest and disease control and expected productivity. Field trials would be useful to better understand the yield potential and flower quality achievable in commercial plantings.

Grevillea cutflowers have a short vase life, are non-climacteric in nature and are ethylene sensitive. The optimum harvest maturity to maximise vase life has been identified in some cultivars. Vase life may be further enhanced by the production environment as well as with sugar pulses. 1-MCP can be used to provide protection against exposure to ethylene. Cut stems have been found to store well at low temperatures. However, care is required to avoid wilting and tangling of stems.

Tropical terminal flowering *Grevillea* have a unique appearance and attractive flowering stems that are in demand on cutflower markets. However, the full potential economic value of this crop has yet to be realised. Possible gains from use of superior varieties, and of improved production, harvest and handling protocols have been identified in this review. Wider commercial development of *Grevillea* for cutflowers seems likely with increasing interest from Australian and overseas flower markets and with further research.

Acknowledgments

The collaborative support and effort of our research students and colleagues in research and industry is acknowledged. In particular, we are grateful for interaction with Sreenath Aiyar, Edward Bunker and family members, Jean Howell, Yvonne Haynes, Suzan Hetherington, Priya Joyce, Jane Ligawa, Andrew Macnish, James McGeogh, Sarah Meara, Setyadjit, Anthony Shorter, David Simons, Penelope Sinclair and Vasanthe Vithanage. Financial and organisational support of the Rural Industries Research and Development Corporation, CSIRO Division of Horticulture, Department of Primary Industries Queensland and The University of Queensland is also recognised.

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Received 18 December 1998, accepted 21 June 1999