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VASE-LIFE AND POST-HARVEST QUALITY IN TULIP AND DAFFODIL

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I declare that this report represents a true and accurate record of the data available.

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Note

Flower preservatives and related materials are sometimes referred to by their trade names, for the sake of accurate reporting. No endorsement is intended of materials mentioned, nor criticism of those not mentioned. Before considering the use of any chemical, the relevant legislation and manufacturer's information should be consulted.

VASE-LIFE AND POST-HARVEST QUALITY IN TULIP AND DAFFODIL

INTRODUCTION

For many Britons, the daffodil is the quintessential spring flower, so it is satisfying that UK growers have achieved a world-leading position for the production of the bulbs and flowers. Demand for high-quality cut-flowers continues to be strong, under the influence both of the multiples in the home market, and the demands associated with the export trade to Europe and the USA. Efficient agricultural systems, the skills of growers, and R & D have all contributed to this success, taking advantage of the UK climate which allows the production of daffodils over an extended season. Currently, about 100 million daffodil bulbs are forced annually in England and Wales, and flowers cropped from the field, always a feature of the bulbs industry in south-west England, are increasingly important in eastern England, where it is estimated that in seven years out of ten flowers are picked from the second-year of the crop. The total daffodil flower yield (forced and field-grown) is now estimated at about 100 million bunches (10 stems each), of which some 25 per cent, with a value of about £3.5 million, are exported.

Although tulip bulb production in the UK has declined drastically, there is still a strong home market for the cut-flowers which are available in a wide range of exotic colours. Currently, some 50 million tulip bulbs are forced annually in England and Wales, while a rise in the area of field-grown tulips in 1993/94 was due to interest in outdoor flower production.

A major problem with cut-flowers of both daffodil and tulip is the relatively short vase-life. For example, a recent handbook quoted vase-lives of 4 to 8 days for daffodil and 5 to 6 days for tulip, compared with 12 to 16 days for carnation (with preservative), 7 to 14 days for chrysanthemum, and 6 to 16 days for rose (Sacalis and Seals, 1993). For daffodils, the demands for cost-efficient packaging and transportation for exports have led to picking at a much earlier stage than previously, and although early picking and the good keeping qualities of Golden Harvest have revolutionised marketing, it is easy for crops to be picked too early, resulting in poor quality in the vase. To ensure growth of export and home markets, it is important for producers to do all they can to produce daffodil and tulip flowers which bring satisfaction, not disappointment, to consumers. The farm-gate value of bulb flowers for England and Wales in 1992 amounted to £26 million, so that even a 5 per cent increase in the value of sales would bring in over £1 million.

The objective of the present review is to examine the scientific literature on factors which affect vase-life and post-harvest quality in cut daffodils and tulips. These factors have been divided into the following groupings: (1) varietal, (2) production, (3) harvesting, (4) storage and (5) chemical.

<u>Varietal effects</u> are self-explanatory, and a great deal of effort has gone into varietal selection. However, the quest for varieties with good post-harvest qualities has to be tempered by the need to favour those with high productivity and freedom from susceptibility to pests and diseases, and the slow rate of commercialisation of new cultivars.

Production effects can be divided between (1) the production of bulb stocks and (2) the immediate production of cut-flowers (either by forcing or using field-grown crops). It is not the purpose of the present report to review the routine aspects of standard bulb-growing and bulb-forcing practices, which have been dealt with in the regular advisory literature: a good standard of husbandry is assumed. There has been little research on the effects of previous bulb history on the post-harvest quality of bulbs subsequently forced, and not much more on the effects of the bulb forcing techniques themselves: nevertheless, some guidelines can be established.

Harvesting effects have been studied more fully, especially in relationship to stage of flower picking and immediate handling, and this seems to be an area where growers could tighten up procedures with useful benefits on quality: quality must, however, be balanced by the need for the whole production process to be cost-effective.

Storage effects have been the most extensively researched, and are complex as they cover a number of phases and many techniques. The phases of 'storage' include (1) temporary holding and treatment immediately after harvest, (2) long-term storage before despatch, (3) transportation, (4) further storage and holding during the wholesale and retail chain, and (5) ultimate 'storage' in the consumer's vase. Many experimental studies have not distinguished these various phases. The techniques used to preserve flower quality over this whole procedure include the manipulation of environmental conditions, notably temperature and humidity.

Chemical effects are properly included under storage effects, as the treatments could be applied at any of the storage phases from initial holding to the final vase. The chemical additives used to extend vase life include bactericides, nutrients, ethylene-inhibitors and growth regulators, often used in combination. While chemical treatments are not widely used with daffodils and tulips, many studies were found in the literature - perhaps because this approach is considered to offer 'easy' answers to extending vase-life.

For convenience, the main part of this review is completely split between daffodils and tulips. Most of the review concerns standard varieties most usually used for cut-flower production: under daffodils, however, reference is made to double and tazetta cultivars where appropriate. Guidelines are presented for growers on the best available practices for cut-flower production, and priorities for future R & D are proposed.

The literature review was completed in early-December 1994, primarily utilising CAB International and HRI databases.

DAFFODIL

Aspects of quality

Cut-flowers should have a long vase-life and other post-harvest attributes which enhance the perception of the flowers in the vase. As has been mentioned in the Introduction, the vase-life of daffodils does not compare favourably with those of some other cut-flowers, even under the best conditions: for example, recent US literature quoted a vase-life of 4 to 8 days (Sacalis and Seals, 1993). It is important, first, to ensure a vase-life at the top of this range, by varietal selection and optimising all aspects of production techniques, and, secondly, to develop the use of flower preservatives to extend vase-life towards a goal of two weeks, as has been done for carnations.

A number of other post-harvest characteristics is needed. Buds must open normally to present a well developed flower of good size. In poor daffodils, which may have been cropped too early or stored badly, flowers are often small, and goose-necking and flower opening may be inhibited. Other desirable characters are a strong stem and neck supporting the flower, and good leaf poise (in forced crops when foliage is cropped with the flower stem). Uniformity, and freedom from contamination with soil or other growing medium, are other important considerations.

Current recommendations

Recent practices for harvesting and marketing cut daffodils have been summarised in ADAS literature (ADAS, 1986a, b). These recommendations derive largely from trials at Rosewarne Experimental Horticulture Station (EHS) (see reviews of ADAS, 1970; Tompsett, 1982). The main points are as follows:

1. Cropping stage: for trumpet and large-cup varieties harvest at fat, upright green pencil for export, otherwise split sheath stage. For double varieties, crop with sheath split, opening and colouring. For tazettas, crop with one floret open; double tazetta varieties are often picked with half the florets open.

2. Initial treatment: remove field heat quickly by placing crates in open stacks at 1 to 2°C (or vacuum cool to 1°C).

3. Storage: carried out dry, holding stems vertically at 1 to 2°C and 90 per cent relative humidity, for not more than 5 to 7 days.

4. Packing: pack quickly (eg, into non-sealed polythene sleeves) after cooling and return to cool store.

5. Transportation: load cooled packs only and hold at 1 to 2°C throughout distribution.

6. Wholesale premises: continue storage at 1 to 2°C and 90 per cent relative humidity.

7. Retail premises: preferably continue holding at 1 to 2°C, for example, as dry, sleeved pre-packs in cool counter; for higher temperatures or if with other flowers, place in water and reduce holding period.

8. Customer treatment: trim 1 cm from base of stem, place in clean water (no chemical additive), and do not mix with other flowers. The optimum temperature for opening flowers is 10 to 16°C.

There are some difficulties in defining the limits of acceptability for a fat upright pencil stage (Tompsett, 1982). The bud should be vertical, and not, but nearly, splitting. An early pencil would have only a small empty space evident at the top of the spathe.

Recent US literature (eg, De Hertogh and Springer, 1977; De Hertogh, 1989; Armitage, 1993; Sacalis and Seals, 1993) says that daffodils are usually harvested at the goose-neck stage: flowers cropped when fully open have a longer vase-life, but are more difficult to transport. The illustration in the Holland Bulb Forcer's Guide (De Hertogh, 1989) shows a fully goose-necked flower with the bud swelling and the spathe split right back: cutting earlier is firmly advised against. Dutch advice (Buschman and Roozen, 1980) is to harvest as soon as the bud sheath has just burst. Although additives are not generally used, the following chemical treatments are mentioned (Sacalis and Seals, 1993): (1) silver nitrate (30 to 60 mg/litre) together with sucrose (3 to 7%), or a proprietary floral preservative, to counter ethylene effects and provide sugar and extend vase-life from 4 to 6 days; (2) 6-benzyladenine (BA), which can extend vase-life by about 1 day (not widely recommended); (3) sodium benzoate (1 mM) as a bactericide to increase vase-life by 1 day; (4) at the retailing and consumer stage, using a commercial floral preservative as recommended, or making up a solution of 8-hydroxyquinoline citrate (HQC) (200 mg/litre) plus sugar (2%). Storage for 1 to 2 weeks at 0 to 2°C and 90 per cent minimum relative humidity, with flowers dry and upright, is said to be acceptable.

Varietal effects

Vase-life data is given for a range of cultivars in some advisory literature, for example IFC (undated), where vase-life is classified in general terms ('normal', 'moderate', etc), and MAFF (1982) where the quoted vase-lives of 32 varieties range from 8 days (White Lion, Investment and Finland) to 13 days (Tibet), the major varieties Carlton and Golden Harvest having vase-lives of 10 and 12 days, respectively. Vase-life data for a much wider range of cultivars is given in the reports of varietal assessments carried out at Rosewarne EHS (Hanks, 1993) and HRI Kirton (Hanks, 1994). The vase-life of 20 cultivars, from different sources, are listed in Table 1, and show that although there is good agreement between some data, in some cases results are variable. Trials suggest that varietal differences in response to different storage conditions (eg, temperature and duration) are probably small (eg, Wallis, 1967, 1968).

The vase-life of narcissus cultivars was reviewed by Fry (1965, 1967a), following extensive variety assessment work at Rosewarne EHS. Picking flowers as the bud burst stage (or later for double varieties) and conducting vase-life tests at 16°C and 60 per cent relative humidity under fluorescent lighting (12 hours per day), the average vase-life was quoted as 7 to 8 days, but with extremes from 5 to 12 days. Vase-life was not related to the texture of the flower, some 'flimsy' flowers lasting 10 to 12 days (eg, Mrs Langtry, Lucifer) and some with thick perianth segments only about 6 days (eg, Dutch Master, Kingscourt). Varieties with very short vase-lives (5 to 6 days) included The First, Bambi, Boswin, Rose van Lima and Cragford; modern, long-lasting varieties include Laurens Koster and Red Rim, with quoted vase-lives of 12 days, and, among commercially important varieties, St Keverne and Cheerfulness had vase-lives of 10 days. Short vase-lives were, generally, found in trumpet varieties, while large-cups, doubles, triandrus and tazetta varieties had average vase-lives, and long vase-lives were found in small-cup, cyclamineus, jonquil and, especially, poeticus varieties. Some late-flowering varieties had good vase-lives when held at lower temperatures, while some early-flowering varieties lasted poorly at higher temperatures. Varieties may have other post-harvest characteristics which render them good subjects (such as attractive colour changes, eg in Trousseau or Mount Hood) or bad ones (such as early senescence of the corona edge as in Aflame or Scarlet Elegance). Excessive growth of the neck (ie, from the stem proper to the ovary) is a problem in some orange or red large-cup varieties, many small-cup varieties, and especially those derived from *Narcissus poeticus poetarum* (Fry, 1967b). Market varieties where this occurs include Carbineer, Helios, Hollywood, Scarlet Elegance, Sempre Avanti, Verger, Aflame and White Lion.

Because only a limited range of daffodil varieties is routinely forced in The Netherlands, varieties have been assessed in order to extend the range. Vase-life and post-harvest quality are important aspects of these assessments. Recent articles include Pasterkamp (1989, 1990) and Pasterkamp and Koot (1993).

Table 1 Vase-life (days) of some commercial narcissus varieties

Variety	Reference*			
	1	2	3	4
Actaea	9.2	9.1	8.4	-
Barrett Browning	8.6	8.3	8.2	good
California	11.1	10.2	10.2	-
Carlton	9.5	7.8	8.4	good
Cheerfulness	10.4	10.2	8.0	good
Dutch Master	8.6	7.6	7.6	good
Flower Drift	8.8	8.4	-	good
Fortune	11.2	8.3	7.8	normal
Geranium	9.2	8.4	6.0	good
Golden Ducat	11.0	9.2	9.2	-
Golden Harvest	11.7	9.4	9.0	good
Hollywood	10.0	9.5	7.6	-
Ice Follies	9.2	7.7	7.0	normal
Mount Hood	11.5	7.9	7.6	good
Quirinus	10.8	10.4	9.0	-
Rembrandt	9.9	9.3	-	-
Standard Value	8.9	7.4	7.0	-
Unsurpassable	9.6	7.7	-	good
Verger	10.0	9.6	9.6	-
White Lion	8.4	8.7	6.4	normal

*[1]MAFF (1982) [2]Hanks (1993) [3]Hanks (1994) [4]IFC (undated) (rated moderate, normal, good or excellent)

-, not tested

Production effects (1) bulb production phase

As stated in the Introduction, routine aspects of bulb-growing practices are not considered in this review, although, obviously, cultural techniques will certainly affect the overall yield and gross quality of blooms subsequently obtained, either in the field or in forcing. Advice can be found in standard textbooks (eg, ADAS, 1985b; de Zwet *et al.*, 1990).

More subtle effects of previous growing history on subsequent flower quality are likely to exist, although no appreciable research has yet been carried out. There are certainly, for example, differences in the number of weeks of cold treatment needed to produce a forced crop in a specified number of days in the glasshouses (Millar, 1980), and in the "critical bulb weight" for floral initiation (Rees, 1986), all of which implies delayed effects.

From the results of weed control trials at Kirton, it was concluded that higher standards of weed control may be needed when producing bulbs for forcing (Turquand, 1966). Weed competition and herbicide treatments may affect subsequent flower production and quality via effects on the number and size of bulbs and flower-containing units produced. Experiments at Kirton and Rosewarne on bulb orientation when planted, showed that bulbs from different treatments, when subsequently forced, showed persistent effects of earlier treatments (NAAS, 1961; Wallis, 1964). Previous horizontal or deeper planting resulted in later flowering.

Lifting date can affect flower quality and vase-life when bulbs are forced. In trials at Kirton, bulbs of Carlton, Fortune and Golden Harvest were lifted from late-June to mid-July (Turquand, 1971). Later lifting increased flower size in Carlton and Fortune (but not Golden Harvest), and increased vase-life by one day. Vase-life was not affected by giving warm-storage treatment after lifting, but this treatment gave flowers of better quality. In similar trials in The Netherlands, bulbs lifted in early-July gave longer stems and larger flowers of better quality than bulbs lifted in June (Anon., 1986).

Production effects (2) flower production phase

Procedures for forcing bulbs should also follow the standard advisory literature (eg, Buschman and Roozen, 1980; ADAS, 1985a; De Hertogh, 1989).

The vase-life of Actaea, Golden Harvest and Magnificence flowers taken early, middle, late and (as 'scrubs') very late from a crop were studied at Rosewarne (Wallis, 1967). Mid- and late-cropped flowers had slightly longer vase-lives than early flowers or scrubs.

The keeping quality of flowers of Actaea, Golden Harvest and Magnificence (picked at fat goose-neck stage) from early-, mid- and late-season forced crops was studied at Rosewarne (Nichols and Wallis, 1972). Vase-life was slightly better from crops at the middle and end of the season, than from earlier ones, but the differences were of very little practical significance. In similar studies in The Netherlands, flower samples were tested over the whole forcing season: flowers were smaller from November and December crops than from January to March forcing (Swart, 1988). Provided flowers were cropped at the correct stage of development, however, vase-life and quality of most cultivars were not reduced by early forcing (Swart and van der Wejden, 1986). It was found that flowers were more likely to be picked immature later in the forcing season, giving shorter vase-life and poorer quality. As a general rule, narcissus cropped near the natural time of flowering (eg, from field-grown crops) can be harvested relatively immature, whereas a more mature stage was found to be necessary for picking early-forced crops (Swart, 1992).

The vase-life of tazetta narcissus flowers (Soleil d'Or and Paperwhite) from advanced, natural-season and retarded crops on the Isles of Scilly has been studied (Tompsett, 1978). Vase-life was comparable throughout this extended season, from early-December to mid-February.

High temperatures (>18°C) during forcing should be avoided, as this can lead to loss of flower buds (De Hertogh, 1989). Glasshouse temperatures above 18°C lead to reduced quality in some varieties, such as excessive foliage in Helios, and poor trumpet colour in varieties like Fortune (Rees, 1972). Lower temperatures are preferable. However, in trials in the US, the vase-life of flowers of variety Bloemfontein grown at forcing temperatures of 15 or 20°C was found to be equal (Doss, 1986). Vase-life was also the same when grown under light intensities of 10 or 20 klux. In Golden Harvest flowers produced in a glasshouse (night temperature, 17°C) or under artificial light (night temperature, 21°C), the glasshouse crop had shorter stems and a longer vase-life (Almquist *et al.*, 1984). Dutch trials showed that stronger crops resulted from higher light levels and lowering the glasshouse temperature just before picking (de Greef and Gort, 1987).

Some recent Dutch articles have asked how the consumer's perception of daffodils might be improved by more attention to aspects of production and harvesting. Firm foliage that develops within a long, undamaged leaf sheath improves quality (van der Weijden, 1990a, b). Long sheaths were found to be encouraged by longer cold treatments, pre- and post-boxing temperatures not below 9°C, and later forcing. Sheath length was also a varietal characteristic. Deeper planting, or covering plants after housing, did not result in longer leaf sheaths. Shallow planting and upright planting (rather than broadcasting bulbs) lessened the risk of damage at cropping. Rouwhorst (1990) listed the following production points for improving quality: avoiding excessively early cropping, using flowers with firm foliage, close grading by bunch length and weight, and avoidance of contamination with substrate.

Harvesting effects

From early trials at Rosewarne, it was found the best vase-life occurred when standard varieties were picked just after bud burst (Wallis, 1965, 1966). Even at that date, this was considered too late for marketing reasons, and picking at tight to fat goose-neck stages was recommended, while accepting that vase-life and flower size and development would be inferior.

Vase-life of Carlton, Golden Harvest and Unsurpassable flowers cut at different stages (upright pencil to goose-necked and just opening) were investigated in Holland (H. Rattink, unpublished data quoted in de Pagter and de Winter, 1972). Vase-life was about a day longer with the earliest cropping stage, compared with the latest. Dutch literature has long advised cutting as the spathe was splitting, rather than as upright buds (eg, Anon., 1972c; Swart, 1978).

Data from Rosewarne on the effects of picking stage on varieties such as Golden Harvest, Carlton, Hollywood, Margaret Mitchell and Dulcimer have been summarised (Tompsett, 1982; ADAS, 1986a). Flowers of standard cultivars were cropped at (1) green pencil, (2) fat, unsplit pencil and (3) split sheath/early goose-neck stages, and stored for 3 days at 2°C before being subjected to a standard vase-life test. Cropping at stage (1) greatly reduced stem length in all varieties (by up to one-third) compared with cropping at early goose-neck stage, and this was not made up by later growth in the vase. Cropping stage did not generally affect flower size, although storage reduced diameter in some varieties (such as Golden Harvest). Generally there were few problems of flower opening associated with early cropping stages, but some Hollywood blooms cropped at pencil stage failed to open fully as the perianth tended to catch in the edge of the corona. The cropping stage did not affect total vase-life, but with cropping at stage (1), the period with open flowers was reduced by about one day (out of 7 days) for all varieties. Golden Harvest stood picking at fat pencil and storage, but a very early pencil stage was unacceptable due to short stems and reduced open vase-life.

Golden Harvest and Barrett Browning blooms were picked at pencil, goose-neck and fully open stages in trials in the US (Almquist *et al.*, 1984). Flowers picked fully open had shorter stems and longer open vase-life than those picked at the earlier stages.

When cropping flowers at an early stage, there is a danger of cropping too early. For Carlton, it is recognised that the spathe should be nearly filled with the swelling bud, to within 1 cm of the tip, before picking takes place (see illustration in Briggs, 1990). Cropping earlier than this results in small flowers with impaired opening. For the same variety, Goszczyńska *et al.* (1989) concluded that cropping at upright pencil stage reduced vase-life and flower size compared with cropping at early goose-neck or later stages. With variety Bloemfontein, however, it was reported from trials in the US that vase-life was about 10 days when picked at upright pencil or early goose-neck stage, but only 8½ days when picked when the flower was beginning to open (Doss, 1986).

Most trials relate to standard varieties, and other types like doubles are picked later (ADAS, 1986a). White Lion was investigated at Rosewarne, cropping at (1) fat, unsplit bud, (2) split sheath or (3) perianth opening. Earlier cropping stages reduced stem length and (when combined with storage) open vase-life, and occasional flowers failed to open, but flower diameter and total vase-life were again unaffected. In the double variety Dick Wilden, where the spathe opens well before the bud is fully grown, keeping quality was found to be reduced by premature picking in Dutch trials (Swart and van der Weijden, 1986). However, the optimum picking stage for doubles appeared to vary between cultivars (further details not available) (Swart, 1985).

Tazettas are picked with one floret open, and double poeticus varieties are picked fully open as they do not open from buds (Fry, 1965). In trials with Soleil d'Or at Rosewarne, flowers were picked at three stages: (1) split sheath, green buds protruding; (2) yellow fully formed buds loosened from the sheath, and (3) the usual, one floret open stage (ADAS, 1984). After 1 day of holding in water and 1 day in market boxes at ambient temperatures, vase-life was assessed. Flowers picked at all stages gave a similar number of open florets at their peak, but the dates of the peak and of senescence were earlier from the more mature stages. When picked at the usual stage, floret coloration was satisfactory, but it was poor when picked at the earlier stages.

The tazetta narcissus Ziva is usually cropped with all florets open, easily leading to damage. Dutch trials showed that it can be harvested with two to three florets open, without adverse effects on bud opening or keeping quality (Swart, 1989).

Daffodils may be cropped by pulling (producing greater length), breaking or cutting the stem. The only information available on any effect of cutting method on post-harvest quality is from trials on the Isles of Scilly with Soleil d'Or, where trimming pulled flowers or leaving un-trimmed had no effect on vase-life (ADAS, 1985c).

Trimming the base of the stem, although often advised, was, in German literature, said to be ineffective in prolonging vase-life (Anon., 1972c).

Storage effects (1) temperature and duration

Many investigations on flower storage were carried out in the US. Narcissus flowers can be stored dry at 0 to 1°C for 10 to 21 days (Post, 1951; Post and Fischer, 1952; Asen *et al.*, 1964; Lutz and Hardenburg, 1968; Staby *et al.*, 1982). The highest freezing point for narcissus flowers is -0.1°C (Whiteman, 1957). A storage temperature of -0.6°C was recommended for temperature flowers, including narcissus, by Post and Fischer (1952). Later trials with Carlton however, showed that storage at -0.6°C gave similar results compared with using 0.6°C (Nichols, 1969a).

Storage reduces vase-life and quality, and storage conditions have to be adjusted to minimise losses. In Polish experiments with Carlton (cut at pencil or goose-neck stages), for example, vase-life and flower size were reduced when stored for 6 days at 3 to 4°C, compared with using fresh (Goszczyńska *et al.*, 1989). Several studies have been reported on the interaction between storage temperature and duration, and a few examples from the US will be quoted. For King Alfred flowers cropped fully open and stored dry, storage life was 1 to 2 days at 27°C, 2 to 3 days at 21°C, 3 to 5 days at 16°C, 8 to 14 days at 4°C and 21 to 28 days at 0°C (Hardenburg *et al.*, 1967). When early goose-neck Bloemfontein flowers were stored in water or dry for 7 days at 1°C, their vase-life was about 8 days; storing for 21 days at 1°C or for 7 days at 5°C, vase-life fell to 5 days, and was drastically reduced by longer or warmer storage (Doss, 1986). The temperature of the initial holding period was also important: using 17°C rather than 12°C halved vase-life, to about 8 days (Doss, 1986).

In trials at Rosewarne, flowers of Carlton, Magnificence, Actaea, King Alfred and Fortune were cropped at fat goose-neck stage and (after an initial holding period) stored dry for 1 to 3 days at 7 or 16°C (Nichols and Wallis, 1972). Using the higher temperature reduced subsequent vase-life but not flower size. When storage at 1 to 2°C was extended to more than 14 days, a quarter of the vase-life was lost, some flowers failed to open when transferred to ambient conditions, and flower diameter and quality were reduced (Wallis, 1967, 1968). In trials at higher temperatures, a quarter of the vase-life was lost with more than about 8 days' storage at 4°C or about 6 days at 7 or 10°C.

In further Rosewarne trials, flowers of a range of varieties (picked at fat goose-neck stage) were stored at 0.6 to 10°C and their deterioration studied (Nichols and Wallis, 1972, 1976). The general pattern of loss of vase-life and quality was similar for all cultivars, although the rate of decline was cultivar-dependent. There was little practical difference between using 0.6 and 1.7°C, but higher temperatures were unsuitable unless very short-term. At 1.7°C, a storage duration of 2 to 4 days gave no detectable reduction in vase-life, while 12 to 15 days' storage reduced vase-life by 25 per cent. The rate of opening was dependent on temperature: at 1.7 to 4°C, buds of several varieties opened slowly and did not reach full size (Actaea was an exception); at 10 and 16°C, full size was reached in 4 to 8 and 1 to 2 days, respectively. After prolonged storage (ie, >16 days at 1.7°C or >20 days at 0.6°C), buds of all cultivars tested failed to open. These results confirmed the earlier reports for Carlton (Smith, 1965a). It was reported that some varieties coloured better and opened faster under light than in darkness (Wallis, 1963). This may, however, be partly a temperature effect, and no further details are available.

Some data from Rosewarne, showing the loss of vase-life with increasing storage temperature and duration, have been summarised (Tompsett, 1982; ADAS, 1986a). Considering a 20 per cent loss of vase-life to be acceptable, this occurred after 12 days' storage at 2°C, after 7 days' storage at 4°C, and after 2 days' storage at 10°C. A total cool-chain distribution period of 7 to 10 days should satisfy this requirement.

The effect of storage of Carlton flowers has been studied in The Netherlands. Flowers were stored dry or in water at 0 to 10°C for 1 to 9 days: the lower the temperature, the better the vase quality, especially if stored for more than 3 days (Boer, 1978; Boer and Harkema, 1979). When flowers were held at 0 to 1°C, bud development did not proceed beyond the slightly split sheath, early goose-neck stage with up to 10 days' storage, by which time buds stored at 9 to 10°C were half-open. Temperature during marketing and transport has also been studied (van Beek, 1984). Bunches held throughout in closed refrigerated containers at 4°C had the least advanced buds and the longest vase-life; bunches cooled during transport and storage were next best, and those given normal uncontrolled handling were less satisfactory.

Tazetta varieties may be stored in bud in water for up to a week at 2 to 4°C (ADAS, 1970). The loss of vase-life of Soleil d'Or following cold storage at 2°C in fibre-board boxes was comparable with that of large-flowered varieties in trials at Rosewarne (ADAS, 1984; Anon., 1984). Storage for 3 days produced an insignificant loss of vase-life, while 6 days' storage gave a vase-life of 6 days compared with 7 days in the non-stored control.

Tazetta varieties are traditionally picked with one floret open, then opened under cover at above-ambient temperatures. The effect of storage temperatures was studied at Rosewarne. Floret opening was negligible at 1°C, took 38 days at 4°C, but only 4 days at 16°C; at 16°C, however, the colour development of orange coronas was slight (Smith and Parker, 1966). Stems of Grand Soleil d'Or (picked at the one-floret-open stage) developed deeper coloured coronas when stored at 1°C for up to 15 days than when opened at higher temperatures, but even a few days' storage was useful (Smith, 1966; Wallis, 1967; Smith and Wallis, 1967). This effect was not dependent on the degree of opening of the florets. Tazetta cultivars therefore show additional benefits of cool-chain distribution. Cool storage of standard varieties with orange coronas (such as Fortune) did not significantly affect coloration as it does in Soleil d'Or (Nichols, 1969b; Nichols and Wallis, 1972).

Vacuum cooling has been investigated in both The Netherlands and the UK. Boer and Wiersma (1974) reported that narcissus flowers could be vacuum cooled after packing in crates, cooling to 4 to 5°C in 20 minutes, without detrimental effect. Vacuum cooling from ambient temperatures to 0 to 1°C in about 30 minutes was not detrimental, vase-life being unaffected (ADAS, 1986a, c, 1987). In an HDC levy-funded project no evidence was produced to show that vacuum cooling was harmful (Tompsett, 1987). It did not increase vase-life nor reduce stem bending. Pre-wetting the product slightly increased the cooling rate.

Trials in Holland of a technique for the long-term (3 month) storage of cut flowers at 0.5°C (no further details available) were not successful with narcissus, resulting in small flowers (Swart, 1984).

Storage effects (2) dry or in water

Trials at Rosewarne showed that, for standard varieties picked at fat goose-neck stage, there was little differences in vase-life when flowers were opened in water then packed, or packed dry then opened (Wallis, 1965, 1966). Dry packing gave a slight loss of weight (less than 10%), but no loss of quality. There was little effect of temperature used for opening flowers (7 to 18°C) on subsequent vase-life (of the open flower); opening took twice as long at 10°C than at 16°C.

Other UK trials with Carlton flowers stored at -0.6, 0.6 or 1.7°C showed there were no practical differences in storing wet or dry for 10 days on subsequent quality in the vase, vase-life being about 80 per cent of the fresh product (Nichols, 1966, 1969a). With storage for 17 days dry at 1.7°C, flowers subsequently failed to open, although those stored in water were satisfactory. Stored dry at 4.4°C, some buds failed to open after only 10 days' storage. Similar results were found for cultivar Flower Record.

Cropping flowers of Carlton, Magnificence, Actaea and Fortune at fat goose-neck stage, the effects of an initial holding period (about 19 hours) either in water or dry (in loose polythene sleeves) was studied at Rosewarne (Nichols and Wallis, 1972, 1976). Using a wet or dry holding period had little effect on subsequent vase-life or quality, following a range of storage treatments (up to 3 days at 7 or 16°C). In further trials, initial holding periods wet or dry at 1 to 10°C were investigated in several varieties (Nichols and Wallis, 1972). Using wet or dry storage had no effect on vase-life in King Alfred, Actaea, Fortune or Edward Buxton, whereas in Magnificence and Golden Harvest dry storage gave a better vase-life, although flowers were smaller.

Several Dutch studies have confirmed that dry storage or storage in water had little or no effect on vase-life under a range of storage conditions (eg, Boer and Harkema, 1979; van Beek, 1984).

In trials with Soleil d'Or on the Isles of Scilly, dry holding or holding in water for 24 hours before simulated transport had little effect on vase-life (ADAS, 1985c).

In trials at Rosewarne, daffodils were stored in water in different containers, but no differences in vase-life were found (Wallis, 1966). Storage was in glass, plastic, galvanised, painted sheet-metal or earthenware containers, either with 0.003 per cent silver nitrate changed weekly, or plain water changed daily.

Storage effects (3) boxes or loose

Storage in commercial fibre-board boxes was compared at Rosewarne with loose storage for up to 14 days at 1 to 2°C, using Fortune and Golden Harvest picked at the goose-neck stage (Tompsett, 1970, 1971; Nichols and Tompsett, 1972, 1976). Flowers stored in closed boxes lost 1 to 2 days of vase-life after 3 days' storage, rising to a loss of 4 days after 14 days' storage, compared with non-stored (fresh) flowers. Temperature measurements showed that it took over 30 hours for the produce to cool to the store temperature, the flowers being densely packed and the boxes insulating, although this would be advantageous when the material was taken from the cold store for transport. Comparisons of storage in closed (lidded) or open boxes, or loose (either dry or in water), showed that there were no practical differences in vase-life between the different treatments, even after storage for 14 days. In the case of Golden Harvest, storage of unboxed flowers gave slightly better results than box storage, and for short-term storage there was a slight benefit of open storage or storage in buckets.

In earlier Rosewarne trials with stacked market boxes of flowers in store, it was found that some reached a temperature of 20°C after 2 days in an 11°C store, indicating accumulating metabolic heat, while ethylene levels had built up to 0.03 to 0.04 ppm, potentially harmful levels which could affect vase-life (Wallis, 1963). Using market boxes insulated with expanded polystyrene increased the temperature of the flowers, once they had warmed up (Tompsett, 1979). Vase-life was reduced when storage was longer than 2 days in insulated boxes.

Storage effects (4) controlled or modified atmospheres

'Gas-packs' - where the cut flowers are placed in plastic sleeves which are then inflated with air or a mixture of carbon dioxide and air, and then sealed - were investigated for narcissus by Smith at Ditton (1965b). The presence of carbon dioxide increased vase-life to a slight extent, in spite of an accumulation of ethylene.

The storage of flowers in 97 to 100 per cent nitrogen at 0 to 27°C has been studied in the US, using fully open King Alfred flowers placed in water at the various temperatures or stored dry in the case of 0°C storage (Asen *et al.*, 1964; Hardenburg *et al.*, 1967; Parsons *et al.*, 1967). Storage in 100 per cent nitrogen increased display life compared with storage in air: for example, at 5°C a 3-week storage period in nitrogen gave a display life as long as that of freshly picked flowers, while even 2 weeks' storage in air reduced display life by 40 per cent. At 0°C, 3 weeks storage in air gave a display life of 4 days, and in nitrogen, 5 days. Storage in 97 or 99 per cent nitrogen was less effective than 100 per cent. When flowers at the split-sheath stage were used, storage in nitrogen was slightly less effective. While stored at 0°C, the respiration rate was low and nearly constant, but it increased dramatically on transfer to higher temperatures (eg, by 900% if transferred to 21°C).

In another US study, with flowers of cv Bloemfontein cropped at early goose-neck stage, it was found that storage in nitrogen (for 21 days at 1°C) gave a longer vase-life (by 1 to 2 days) than storage in a compressed air atmosphere (Doss, 1986). In these experiments, both nitrogen and compressed air were scrubbed for ethylene and were humidified. However, storage in nitrogen was not significantly better, from a practical viewpoint, than storage in open buckets in the cold store.

Storage effects (5) pollutants

In studies at Rosewarne, it was found that including sachets of an ethylene scrubber (Purafil ES) in the market boxes did not increase vase-life (Tompsett, 1979). Like some other important flower-bulbs, petal senescence of narcissus is not sensitive to ethylene (Reid, 1989). However, the effect of exposure of cut flowers to ethylene (3 ppm) for 23 hours at 21°C, simulating the exposures which might be found in a room with ripening vegetables or fruit, was studied in Holland by Woltering and Harkema (1981a, b). Carlton, Dutch Master and Golden Harvest flowers were included, and treated blooms had shorter vase-lives (by about 20%), smaller flowers (diameter 1 cm less) and the flowers remained upright, not 'goose-necking' properly, compared with control flowers.

Following tests in Holland with flowers of varieties Carlton, Unsurpassable and Jules Vernes, it was concluded that narcissus were not susceptible to damage by fluorine (Sytsema, 1972b).

Storage effects (6) stem bending

After cropping, stem growth of narcissus continues, an effect studied at Rosewarne. The stems bend geotropically if stored horizontally, although only slightly at 2°C compared with 9 or 16°C. Tazetta cultivars are very liable to curve, especially if pulled with etiolated bases (ADAS, 1981; Tompsett, 1982). The effect is enhanced if the stems are kept turgid by standing in water before packing, or if kept moist in the pack. Further trials under HDC levy funding (Tompsett, 1987) showed that stem bending could not be prevented by treatment with Ethrel or by trimming the cut ends; was sometimes reduced by silver thiosulphate treatment; was more marked in flowers picked early (upright green pencils) than in more mature ones; and was best prevented by vertical storage. More appealing packaging has been developed to overcome this problem, such as water-holding packs that keep the flowers upright for transport and point-of-sale display (Rouwhorst, 1990). Flowers which arrive with bent stems may be wrapped tightly in wet paper and placed in water under direct overhead lighting (Vaughan, quoted in Armitage, 1993).

Chemical effects

There have been many experiments with chemical additives on narcissus vase-life. Because many researchers have used a combination of chemicals, it has not been practical to divide this section by chemical types, and a roughly chronological narrative has been given.

The effects of dipping King Alfred flowers (for 5 seconds) in growth regulators with wetter were studied in Canada by Ballantyne (1963, 1965, 1966). Dipping flowers (cropping stage not recorded, but probably well developed) in solutions of 6-benzyladenine (BA), kinetin or naphthaleneacetic acid (NAA) after 2 weeks' storage at 0.5°C delayed floral senescence by up to one day. Dipping freshly-cut flowers in BA and 2,4-dichlorophenoxyacetic acid (2,4-D) at various concentrations, and then placing in plain water at room temperature (23°C), senescence was delayed by 2 days when BA (5×10^{-4}M) and 2,4-D (10^{-4}M) were used together, and by 1 day only using BA alone. BA treatments (at 100 ppm) were later evaluated on a range of cultivars in UK trials (Nichols, 1969b). There were no benefits and quality was adversely affected in some cultivars.

The effect of silver nitrate (30 mg/litre) on flower longevity of Golden Harvest, Magnificence and Actaea (picked at fat goose-neck stage) was studied in the UK by Nichols and Wallis (1972). Silver nitrate was ineffective, also a conclusion of several other trials (Smith, 1965a; Tompsett, 1982). Vase-life was also unaffected by silver thiosulphate (STS) (Nichols, 1979).

The response of narcissus to sucrose solution was shown to be poor, in contrast to the response of some other cut flowers (Freeland, 1974; Nichols, 1974, 1975). In Actaea, sucrose (4%) in the holding water led to growth of the ovary, but hardly delayed flower senescence, indicating there is no problem with water uptake but that the ovary is a strong sink for nutrients. Radiolabelled sucrose was diverted to the ovary as the petals aged. In Dutch trials, sugar (10 to 50 g/litre) had little effect on vase-life in a number of varieties, and a range of floral preservatives were without much effect in Carlton (de Pagter and de Winter, 1972).

Treatment of King Alfred, Fortune and Actaea flowers with cycloheximide (1 mg/litre for 24 hours) delayed senescence by 2 days, but higher concentrations prevented bud opening and caused stem yellowing (Nichols, 1978).

The effect of ethylene inhibitors on the vase-life of King Alfred and The First narcissus (cropped at the goose-neck stage) was examined in the US (Wang and Baker, 1979). The preservative solutions included sucrose (2%), 8-hydroxyquinoline citrate (HQC) (0.02%) and the test compounds, all in a buffered solution (pH 4.6). Flowers placed in the control preservative solution had a vase-life of 4 days and the addition of either the ethoxy or methoxy analog of rhizobitoxine, or of sodium benzoate, extended vase-life by 1 day.

Boer and Hilhorst (1979) reported no positive effects of commercial preservatives on Carlton, and, in other Dutch trials, Tulip Chrysal and Chrysal VB were found to be ineffective on narcissus (Sytsema and Barendse, 1975). Preservatives have been examined extensively in Poland. The effects of 12 different preservatives were examined on Golden Harvest flowers (Piskornik and Piskornik, 1980). Three locally made formulations, containing sucrose (30-70 g/litre) and silver salts (30-60 mg/litre), and a commercial preservative solution (Cornell), were successful in maintaining water uptake and extending vase-life by 50 per cent (from 4 to 6 days). Four locally developed preservatives were compared with four commercial products (Flovit, Proflovit, Chrysal and Cornell) in King Alfred stood in the various solutions (Piskornik, 1981). The generally most effective preservative, 'AR-9', extended vase-life by 36 per cent; this formulation contained sucrose (60 g/litre), 8-hydroxyquinoline sulphate (HQS) (250 mg/litre), chlormequat chloride (CCC) (70 mg/litre) and silver nitrate (50 mg/litre). In further studies, flowers of Golden Harvest were placed in solutions containing cobalt (in the ionic form or as a chelate with ethylene diamine tetraacetic acid) or silver (in the ionic form or as a sodium thiosulphate complex), along with sucrose or HQS (Piskornik, 1985). Individual materials were ineffective in increasing vase-life, but, with sucrose or HQS, cobalt chelate increased vase-life by 30 per cent and silver thiosulphate complex by 52 per cent. Water uptake was stimulated. Piskornik (1986) demonstrated a persistent rise in ethylene production in narcissus flowers following pollination, leading eventually to senescence, so ethylene inhibitors are likely to be important.

In later Polish studies, Carlton (cropped at early- to late-goose-neck stages) were placed in a range of preservative compounds (Goszczyńska *et al.*, 1989). HQC (200 mg/litre) or calcium (500 mg/litre) or silver nitrate (50 mg/litre), each plus sucrose (2%), increased vase-life by about 1 day (3 days for controls) without affecting flower size, being more effective with early goose-neck flowers. Using gibberellic acid (GA) (20 mg/litre) (especially with HQC or silver nitrate plus sucrose) increased vase-life by about 1½ days, while BA (10 mg/litre) had little effect. Applying GA as a 20 hour pulse treatment was as effective as a continuous treatment, but using silver nitrate (plus sucrose) as a continuous treatment led to stem deterioration and loss of vase-life.

In trials in the US, flowers of Golden Harvest and Barrett Browning (cut at pencil, goose-neck and fully open stages) were placed in tap water, deionised water, a solution of a commercial flower preservative (Oasis), 25 per cent 7-Up or HQC (200 ppm) plus sucrose (2%) (Almquist *et al.*, 1984). Using HQC plus sucrose extended vase-life, compared with controls, by 2 days (vase-life under the conditions used was 3 to 5 days) in pencil and goose-neck blooms. Other treatments were ineffective.

The effect of Alar (50 or 100 ppm), NAA (50 or 100 ppm), GA (50 or 100 ppm), Benlate (100 or 200 ppm) and sucrose (500 or 1000 ppm) on vase-life was studied in India, using flowers of Cheerfulness, Snow Princess and All Yellow cropped when half-open (Choudhary and Verma, 1986). Vase-life was increased by all chemicals tested. The mean vase-life for controls was 12 days: GA (100 ppm) had the greatest effect (22 days vase-life), but other treatments gave vase-lives of 17 to 21 days.

The vase-life responses of flowers of variety Bloemfontein (cropped at early goose-neck stage) to silver nitrate, sucrose and bactericide were studied in the US by Doss (1986). Harvesting flowers into silver nitrate (25 ppm) plus sucrose (1.5%) solution increased vase-life by a day, compared with using deionised water. The addition of a bactericide (Physan 20) reduced flower quality and longevity. These responses (to silver nitrate and sucrose) held with flowers picked at pencil, early goose-neck or loose bud stages, although vase-life was much less with the late stage. For longer-term storage under otherwise favourable conditions, using silver nitrate (25 ppm) plus sucrose (6%) increased vase-life by up to 4 days, the bactericide again having a detrimental effect.

In studies on cultivar Agathon, carried out in Russia, the best quality blooms were obtained following placing in citric acid (0.02%) and sucrose (4%), when stored for 21 days at 2 to 4°C and 85% relative humidity (Belynskaya and Kondrat'eva, 1990).

The effects of germicides on the longevity of various cut flowers was examined in Australia (Jones and Hill, 1993). In narcissus Fortune, sodium dichloroisocyanuric acid (50 mg/litre) (DICA) and HQC (250 mg/litre) each increased vase-life, although by only one day, while 1-bromo-3-chloro-5,5-dimethylhydantoin (12 mg available chlorine/litre) did not.

There have been relatively few trials on tazetta narcissus. The effect of STS on the vase-life of the tazetta narcissus Ziva was variable in Dutch trials (Swart, 1990). In one case a preliminary treatment for 19 hours gave a 2 day increase in vase-life.

TULIP

Aspects of quality

As cut-flowers, tulips have a vase-life at the lower end of acceptability (6 to 7 days), and better keeping quality is a prime objective of breeding work (van Eijk and Eikelboom, 1986). Swart (1992) quoted an average vase-life for 20 cultivars of 10 days at 15°C or 5 days at 20°C.

Other important aspects of cut-tulip quality include good flower size and an attractive shape which should be maintained during vase-life. Tulips - particularly Darwin hybrid cultivars such as Apeldoorn -are susceptible to a range of flower defects ranging from complete flower blasting through poorly coloured petals to white-tipped petals; other varieties are susceptible to topple, and these disorders can largely be avoided through correct culture. Disorders like tied-leaf can also down-grade the flowers, but are more sporadic and the causes are less well understood. Stems should be strong enough to hold the flower upright. In some cases there is excessive elongation of the upper internodes in the vase, which is usually considered unattractive.

Bunch weight is considered an important aspect of quality (eg, Dwarswaard, 1990). However, stem weight was found not to be a good indicator of quality, according to one survey in Holland (Koortekaas and de Vroomen, 1990). Quality decreased with increasing length but increased with increasing stem diameter.

Current recommendations

Recent UK advice for handling tulip cut-flowers (ADAS, 1986b) included the following points:

1. Production: attention to detail including avoiding undersized bulbs and controlling tulip fire.

2. Harvesting: when colour is just visible along the edge of the petal.

3. Immediate handling: cool quickly to remove field heat.

4. Packing: dry-pack in sleeves (not too tight) containing five blooms, pack sleeves tightly in boxes.

5. Storage: optimum temperature 2°C. Storage for up to 7 days at not more than 4°C can result in a loss of vase-life of 10 to 20 per cent (ADAS, 1983).

6. Flower conditioner: not usually used.

7. Retail: stand upright in water for 2 to 3 hours, not mixing with other flowers.

Dutch literature (eg, Buschman and Roozen, 1980) illustrates the recommended harvest stage. Darwin Hybrids should be cut "as soon as the bud has half coloured" (colour visible along the petal edges, mid-line of petals still green), and other varieties "after the entire bud has coloured" (across the whole petal surface of the bud). US literature (eg, De Hertogh and Springer, 1977; De Hertogh, 1989; Armitage, 1993; Sacalis and Seals, 1993) recommends that tulips are harvested when the bud is coloured but remains tight, although the optimum stage varies with variety. Darwin Hybrid varieties can be harvested somewhat earlier. Flowers should be cooled immediately to 0 to 2°C at at least 85 to 90 per cent relative humidity: storage should be either upright in water or dry in a horizontal position for short periods, at 2°C. For longer-term storage, wrap flowers tightly and store upright, dry, for up to 5 days; some varieties can be stored for 2 to 3 weeks if harvested in the green bud stage and held at 0°C. It is useful to store tulip flowers with the bulb still attached, as this slows drying out, removes a disease source from the glasshouse, and can add useful length to the stem when cut. Preservatives should be avoided as they cause stem elongation without much benefit on vase-life (some literature mentions preservatives such as Tulip-Chrysal, AAdural, Compo-Blumenfrish, Flora 2000 and Phylo 2000 which can be used; Nowak and Rudnicki, 1990). Avoid exposure to ethylene, which can reduce longevity. Use distilled or deionised water for storage, as quality can be affected by water quality. For the retailer and consumer, re-cutting the stem base, not using preservatives, and avoiding placing daffodils in the same vase, are emphasised.

It was shown in a Dutch survey that, to achieve post-harvest quality, storage temperature and duration were considered the most important factors, more so than humidity, ethylene, wet or dry storage, or effects due to bacteria or *Botrytis* (Hoogerwerf *et al.*, 1989).

Varietal effects

The vase-life of cut tulips is highly correlated with the longevity of attached flowers in the field, a useful selection criterion in tulip breeding (Eikelboom and van Eijk, 1978; van Eijk and Eikelboom, 1986). Vase-life is also positively correlated with time of forcing.

Vase-life data for a range of varieties is given in some advisory literature, for example Benschop and De Hertogh (1969), De Hertogh and Williams, 1969; IFC (undated) and ADAS (1983). The last quotes vase-lives between 5 to 6 days (for Apeldoorn) and 11 to 12 days (Merry Widow). In recent US literature, a vase-life of 5 to 6 days is quoted, but only 3 to 4 days for some cultivars (such as Apeldoorn, General Eisenhower, Godoshnik, London, Oxford and President Kennedy) (Sacalis and Seals, 1993). In trials in Switzerland, the performance of 51 cultivars was compared, including vase-life tests (Meylan and Tripod, 1979). Cultivars with long vase-life included Mirjoran, Jewel of Spring and La Marseillaise (14 days), those with short vase-lives included Beauty of Apeldoorn, Pink Trophy, Balalaïka, Garden Cinderella (7 days) and Elisabeth Arden (5 days). Further vase-life data for many cultivars can be found in the results of tulip variety trialling at Kirton (Turquand, 1970; Anon., 1970, 1972a, b; Briggs, 1973, 1974, 1976; Millar, 1976, 1977, 1979).

Varietal assessments, including post-harvest quality, are frequently reported in the Dutch literature for both box and border forcing. Some recent articles include Pasterkamp and Hof (1989, 1990a, b) and Pasterkamp and Buurmann (1991a, b, 1993).

Production effects (1) bulb production phase

Information does not appear to be available about the effect of previous growing conditions on the subsequent quality of cut-flower production. Cultural advice available in standard advisory literature (eg, ADAS, 1982) should be followed, to produce bulbs of good quality. Important considerations (for bulbs to be used for forcing) are the use of bulbs of adequate size and free of diseases such as *Botrytis tulipae* (tulip fire), which can disfigure blooms.

Production effects (2) flower production phase

All aspects of the pre-harvest phase could potentially affect the overall yield and quality of flowers, and routine advice on good bulb forcing practice should be followed (eg, Buschman and Roozen, 1980; ADAS, 1983; De Hertogh, 1989). Correct procedures and conditions are needed during the pre-cooling, post-planting cooling, and glasshouse phases of forcing, adhering to appropriate advice. Although one standard text states that there is "no consistent evidence to suggest lifting date, storage treatment or date of forcing has a significant effect on the keeping quality of the cut flower although slight seasonal variations may occur" (ADAS, 1983), such effects cannot be ruled out.

Tulips are susceptible to bud blasting (varying in extent from complete loss of the flower to slight white-tipping of the petals which could down-grade quality), which is related to a number of adverse growing conditions, but especially to ethylene exposure (de Munk and Kamerbeek, 1975). Although no experimental evidence is available, these authors suggest that exposure to ethylene during dry storage or in the glasshouse results in a decrease in keeping quality. Although it is not used as a practical treatment in Europe, gibberellic acid (GA) application can reduce losses due to bud blasting which occur under a variety of circumstances including short cold treatments, ancymidol treatments and exposure to *Fusarium*-affected bulbs (Hanks and Rees, 1977; Hanks, 1979). Tulip cultivars vary in their sensitivity to ethylene, which may result in stunted stems, reduced flower size and gummosis (De Hertogh *et al.*, 1980).

Warm-storage of bulbs after lifting, used to produce earlier flowers, also results in benefits such as heavier plants (Le Nard, 1980). There have been a few studies on the effect of growing temperatures on vase-life and quality. It is useful to use a low initial glasshouse temperature (13°C) to avoid weak stems and poor flowers, and lowering the temperature again at the first sign of colour will result in deeper flower colour (Rees, 1972). In experiments on cultivar William Pitt in Japan, bulbs were forced with growing (night) temperatures of 10, 17.5 or 25°C (Yokoi *et al.*, 1977). Growing at the lowest temperature resulted in the best cut-flower quality and longest vase-life. Trials in the US with tulip Preludium showed that vase-life was the same with growing at 15 or 20°C, and at light intensities of 10 or 20 klux (Doss, 1986). Experiments in France on Apeldoorn tulips suggested that the best lasting qualities were obtained using a root temperature during forcing below 18°C (Le Nard, 1980). Trials in Holland have been conducted to investigate the effects of raising glasshouse temperatures (to speed flowering) or lowering them (eg, to delay flowering over the weekend). Raising the temperature led to paler, weaker plants (even in varieties not susceptible to bud blasting), whereas lowering the temperature (for several days to 2 to 5°C) did not affect quality (de

Greef, 1986; de Greef and Gort, 1988). There was a correlation between low growing temperature and long neck (top internode) growth in the vase, although the effect was relatively small (Swart, 1984). Further trials showed that lower growing temperatures, and high temperature storage (23 or 25°C) until mid-September before cooling, produced heavier blooms, useful when small grades of bulb were being forced (Granneman, 1991).

Experiments in Holland showed that quality and vase-life of tulips were not improved by applying nitrogen after housing (Swart, 1981; de Greef and Mollers-Grimbergen, 1982), although fertiliser produced better leaves in Japanese trials with cultivar William Pitt (Yokoi, 1964). The effect of bulb spacing during forcing has been studied with various cultivars in experiments in Japan and Germany (Yokoi, 1964; Stoffert, 1965). Densely planted bulbs produced slightly taller flowers, but the effects were small and bulbs are usually planted as close as practical.

Long-day or night-break treatments produce tulips with longer stems, particularly at lower growing temperatures (Hanks and Rees, 1979, 1980). Treatments could possibly be developed for producing longer stems in glasshouse forcing. Short varieties of tulip can be shaded to encourage elongation (Rees, 1972).

The vase quality of Monte Carlo and Merry Widow flowers collected from auction in Holland in the January to early-April period was studied by Kortekaas and de Vroomen (1990) in relation to production factors. There were no differences in quality between bulbs boxed outside (on the standing ground) or in a controlled-temperature store (rooting room). Bulbs forced in the glasshouse soil had longer stems, and flowers of Merry Widow tended to be cropped when less mature, compared with box-forcing, and this could not be attributed solely to the fact that smaller bulbs and later forcing times were used for forcing in the glasshouse soil. The size of bulb used was related to the market value of the crop: larger bulbs resulted in larger stem diameters and larger flowers, with fewer weak stems, but there was no relationship between bulb size and stem or neck length, maturity when picked, or the number of non-opening blooms. Yields were poorer when stocks of unknown quality or from uncertified stocks were used. The direct bunching of flowers in the glasshouse led to more bruised stems, although this did not seem to detract from quality in the vase. Blooms produced later in the season had longer stems which detracted from vase quality, were harvested too immature to give good results, opened relatively quickly in the vase, and had a higher proportion with weak stems. The vase-life of very early forced tulips is usually short (Woltering, 1982).

In the US the growth retardant ancymidol is used to produce attractively dwarfed tulips as pot-plants (De Hertogh, 1989). Pre-harvest treatments with ancymidol were investigated in trials with varieties Hibernia and Paul Richter, to see if post-harvest stem extension (which detracts from quality in the vase) could be controlled by pre-harvest ancymidol treatments (Einert, 1975). Ancymidol (at 50 to 200 ppm) was applied as a spray to run-off, at various times from 72 hours before harvest (bud well enclosed within leaves) to 24 hours pre-harvest (colour showing on buds). Ancymidol sprays reduced post-harvest stem extension, producing a stronger, thicker stem with less bending. There were some differences in response according to rate and stage of application. Ancymidol treatments did not affect vase-life in either variety, but in Paul Richter treated flowers kept their cup shape longer and there were some changes in the colour of the ageing petals.

"Ice-tulips" are specially likely to produce poor quality blooms if optimum production regimes are not followed (de Jong *et al.*, 1990). The best schedule, applicable to most cultivars, was found to be: store at 23°C until mid-September, at 20°C until mid-October, at 17°C until November, cool for 4 weeks at 5 or 9°C, plant in boxes and then freeze at -2°C until housing in August to November the following year at 12 to 15°C. This temperature schedule resulted in compact plants (less neck growth in the vase) and fuller flowers. "Freezing-in" bulbs after planting gave longer, firmer, heavier plants, with less upper internode extension, than when bulbs were frozen packed in peat and planted afterwards. Cropping stage was also important using frozen tulips (Swart, 1992): when flowers were picked very early (no colour), colour was poor and flowers were smaller with one day's less vase-life. Samples of flowers showed that the keeping quality of ice tulips depended more on the forcer than on the cultivar, thus emphasising the importance of correct techniques (Swart, 1990).

Harvesting effects

There appears to be relatively little information in the recent literature on trials on stage of cropping for tulip. No doubt, however, the recommendations given in standard Dutch advisory literature (eg, Buschman and Roozen, 1980, see Current recommendations, above) were derived from substantial trialling. The principle of cropping once the bud has fully coloured (or partly coloured in the case of Darwin hybrid varieties) has been long established (eg, Swart, 1978).

In some US trials, Preludium flowers were harvested at (1) tight bud, no colour, (2) tight bud, some colour at tip, and (3) bud just beginning to unfold (Doss, 1986). Harvested into water, vase-life was about 14 days for the two earlier stages and only about ½ day less at the latest stage.

In their survey of Dutch flower quality, Kortekaas and de Vroomen (1990) found that differences in maturity of flowers visible at auction were not visible 6 days later in the vase; however, they recommended avoiding harvesting at an immature stage. More post-harvest stem extension occurs when tulips are picked at an early (green bud) stage, than when the bud has begun to colour (Pisulewski *et al.*, 1989a).

By harvesting tulips with the bulb intact, the flowers can be stored more easily with no loss of vase-life, for up to 12 days at 2 to 3°C (Anon., 1966).

Storage effects (1) temperature and duration

Storage of tulips was extensively investigated in the US. Cut tulips can be stored dry at -0.6 to 0°C for 4 to 8 weeks (Post and Fischer, 1952; von Oppenfeld *et al.*, 1955; Bünemann and Dewey, 1956; New, 1964; Lutz and Hardenburg, 1968; Staby *et al.*, 1982). Some of these trials were conducted using closed or sealed containers, and the tulips were not injured by the accumulation of carbon dioxide (see below). Flowers can also be stored with the stems in water, when tulips can be held in saleable condition for 35 days at 0°C (Whiteman *et al.*, 1934). Storage in these conditions could be extended to 4 months, but vase-life was then very short.

Some Dutch studies on cut tulip storage were summarised by Hekstra (1966). Flowers could be stored dry at 0 to 5°C for up to 5 days, without effect on vase-life, or for up to 2 weeks if protected against drying out. Storage at higher temperatures was harmful, and at 12°C there was a ½ day reduction in subsequent vase-life (at 17°C) for each day's storage. Averaged over a large selection of varieties, it was found that, over the range 10 to 20°C, a rise of 1°C reduced vase-life by about 1 day; provided the variation between day and night temperature was not more than 10°C, the effect of variable temperature was the same as the average temperature (Hekstra, 1966).

In UK trials, tulips were stored in water or dry at 2, 4 or 7°C for 4, 7 or 14 days (Nichols, 1971a). When stored at 2 to 4°C for 4 days, there was no loss of vase-life, and no effect of using wet or dry storage. Vase-life of tulip Golden Harvest (picked half-coloured) fell from 53 days at 4°C to 7 days at 21°C (Smith, 1965a). A 25 per cent reduction in vase-life was brought about by 9 days' storage at 2°C, falling to 2 days' storage at 21°C.

Vacuum cooling of tulips was evaluated in Dutch trials (Boer and Wiersma, 1974). Cooling blooms after packing into crates and before loading to 4 to 5°C, in 20 minutes, was not detrimental to quality.

Storage effects (2) dry or in water

From studies in Holland (using Apeldoorn and Merry Widow tulips) it was recommended that storage should be at below 6°C and preferably at 0 to 1°C, and that, if for more than 1 day, should be in water, otherwise quality was lost (Boer and Witmondt, 1975, 1976). For Apeldoorn, satisfactory results were obtained following up to 6 days wet storage at 0 to 1°C but only up to 1 day's dry storage; for Merry Widow the limits were 9 days (wet) or 3 days (dry). The effect of initial storage in water as a 1 hour post-harvest treatment, compared with holding dry, was investigated in Holland with the same varieties (Swart, 1986). Following this initial wet or dry treatment, blooms were wrapped and stored dry for 4 days at low temperature before vase-life testing. Initial wet storage did not improve vase-life, but Apeldoorn was more sensitive to dry storage, resulting in loss of size, flower shape and quality. Flowers cropped at an early stage (before distinct colour could be seen on the bud) were more damaged by dry storage, even in Merry Widow, and showed benefits of an immediate treatment in water.

In further studies with tulip Apeldoorn, flowers (1 hour post-harvest treatment in water as above) were stored at 2°C for 1 to 5 days either in water, dry but wrapped, or dry and non-wrapped (Swart, 1991). Wet-stored flowers continued to take up water, increasing in fresh weight over the 5 day period; dry-stored flowers showed small increases in fresh weight initially (for 3 days if wrapped and only for 1 day if non-wrapped). The loss of fresh weight was correlated with loss of quality when placed in a vase-life test, shown as abnormal flowers with off-colours and papery petals. Several other properties of the flowers were studied, but none were useful as indicators of water stress (eg, ion leakage, osmotic potential, ethylene production or concentration of 1-aminocyclopropane-1-carboxylic acid or abscisic acid).

Using tulip Preludium, dry storage was compared with storage in water at different temperatures in US trials (Doss, 1986). Dry storage gave vase-lives similar to that of storage in water at 1 or 4.5°C for up to 14 days, but was unsatisfactory for longer or warmer storage.

The post-harvest qualities of several cultivars, cut at tight bud, were compared in the US following conventional dry packing or bunching and storage in polythene bags (New, 1964). Wrapped, bunched tulips could be stored at -0.6 or 0.6°C for 7 weeks, and then withstood simulated "severe delivery conditions" and retail storage better than conventional dry packed blooms.

Cropping and storing flowers with the bulb intact is a useful way of preventing drying out of the flower, the bulb being removed later in the packing shed (Hekstra, 1966). In this case there can be difficulties in water uptake if the stem is removed at the base of the bulb (rather than above it).

In their study of the effects of commercial flower preservatives (see below), Staby *et al.* (1978) included treatments using tap, deionised and distilled water. Water quality had little effect on post-harvest quality, compared with the effects of preservatives.

In a survey of water in which flowers (including tulips) were held during handling and distribution in Holland, bacterial numbers (especially at the retail level) were high enough to reduce flower longevity (Hoogerwerf and Van Doorn, 1992). Where chlorine was used, bacterial numbers were low.

Pre-treatment of cut tulips with polyethylene glycol or polyvinyl pyrrolidone was evaluated in Holland, to see if the damage associated with dry storage could be reduced (Swart, 1983). No benefits were found in trials with several varieties.

Storage effects (3) controlled or modified atmospheres

Tulips can be dry-stored successfully sealed with plastic film at 0°C for 5 weeks, even though carbon dioxide concentrations rose to 15 per cent and oxygen was depleted to below 1 per cent in the packs (von Oppenfeld *et al.*, 1955). With longer storage, carbon dioxide concentrations above 7 per cent caused damage. Trials in Holland showed that carbon dioxide concentrations over 5 per cent, at storage temperatures of 1 to 10°C, led to geotropic bending of tulip stems (van Stuivenberg, 1946, 1949).

Dry-storage of William Copland tulips at -0.6 to 10°C in sealed containers, in moist air with controlled levels of carbon dioxide and oxygen, was studied in further trials in the US (Bünemann and Dewey, 1956). Flowers could be stored successfully for 8 weeks at -0.6°C, either dry and sealed with 11 per cent carbon dioxide and 10 per cent oxygen, or with stems in water in the open. Sealed storage in moist air with ambient carbon dioxide and oxygen concentrations at -0.6°C was limited to 2 weeks, as was using carbon dioxide concentrations of 16 per cent or more. Storage at 4 or 10°C for more than 2 weeks was also unsatisfactory.

In more recent trials with variety Preludium in the US, vase-life was not different when blooms were stored in nitrogen instead of using open storage (Doss, 1986).

Storage effects (4) humidity and light

It was reported in Holland that differences in relative humidity above 40 per cent had no effect on the vase-life of tulip, but rapid air circulation had a strong drying effect even at 70 per cent relative humidity (Hekstra, 1966). There was also said to be very little effect of light on tulip vase-life (Hekstra, 1966), although at <12°C vase-life was slightly longer in complete darkness than in normal daily light. Aarts (1957) reported that light at 300 uW/cm^2 shortened the vase-life of tulip variety van der Erden by 2 days, compared with carrying out vase-life tests in the dark.

Storage effects (5) pollutants

The effect of exposure of various cut flowers to ethylene (3 ppm) for 23 hours at 21°C, simulating the exposures which might be found in a room with ripening vegetables or fruit, was studied in Holland by Woltering and Harkema (1981a, b). In tulip, ethylene treatment led to shorter vase-life (by up to 30%), and poor flower development and coloration. Apeldoorn was more sensitive than the other cultivars tested (Gander and Merry Widow). However, petal senescence of tulip was not considered sensitive to ethylene, in common with the situation found in other important flower bulbs (Reid, 1989).

The effect of fluorine as a contaminant of water was studied in a range of cut flowers by Sytsema (1972a). In tulip, fluorine (at 1 mg/litre) resulted in withered, discoloured leaf tips, becoming more serious at higher concentrations. Flowers and their vase-life were not affected, however. Adding a preservative (Tulip Chrysal) reduced fluorine damage to leaves, but caused the ends of the stem to wither.

Chemical effects

It has not been practical to sub-divide this section by chemical types. A roughly chronological account is given, although some work on commercial preservatives and on growth retardants is described separately at the end.

Sugar in the vase water delays wilting in many cut flowers: for tulip Eclipse, the optimum concentration from Dutch trials was 4 to 6 per cent for sucrose or glucose (Aarts, 1957), although results with tulips were not always consistent (Sytsema, 1971).

In Dutch trials with tulips cytokinins gave variable results. A 2 to 4 hour treatment with 6-benzyladenine (BA) gave good results in one study (Systema, 1971) but using kinetin in the holding solution was detrimental in another (Staden, 1973).

Silver nitrate (30 ppm) had no consistent effect on vase-life in UK trials (Smith, 1965a). The effects of treatment with sucrose (2%) plus silver nitrate (33 ppm) with or without Ethrel (48 ppm a.i.) on four tulip varieties (Apeldoorn, Elmus, Golden Harvest and Rose Copland) were studied at Kirton (Briggs, 1973, 1974). Sucrose increased vase-life in most varieties, increased stem length in all four, and increased flower size in Golden Harvest only. Used as a continuous treatment, sucrose plus silver nitrate gave the following improvements in vase-life over plain water in some experiments: Apeldoorn (from 6 to 10 days), Elmus (from 7 to 15 days), Rose Copland (from 12 to 18 days) and Golden Harvest (from 15 to 16 days). Silver nitrate had no additional effect. Ethrel (either as an initial 24 hour pulse or continuous treatment) reduced stem length in all varieties, including the excessive length when sucrose was present. Ethrel also reduced vase-life, although this effect varied between varieties, and it caused adverse changes in the shape of flowers of Apeldoorn.

In other studies in the UK, it was found that Ethrel inhibited stem elongation and caused smaller flowers in tulip, while flower senescence was hardly affected (below 100 mg a.i./litre) (Nichols, 1971b). Stems of various cultivars were placed in silver thiosulphate (STS) solutions (0.01 to 2.0 mM silver for 10 minutes to 24 hours): the highest concentration caused leaf damage, but at lower levels there was no effect on petal longevity, and the inhibition of stem elongation caused by ethylene or Ethrel was completely reversed (Nichols and Kofranek, 1981, 1982). Silver nitrate was less effective than STS. Whereas immersion of lily bulbs in STS before planting led to better quality flowers, the treatment had no effect on quality in tulip bulbs (although immersion in plain water sometimes gave more simultaneous flowering) (Swart, 1979, 1982).

Foliar sprays of aluminium sulphate were found to reduce stomatal opening in some flowers, thereby improving water balance, but were ineffective in tulips (Schnabl, 1976). In Dutch trials, nickel added to the holding water had no effect on longevity of tulip (Staden, 1974).

Cycloheximide was investigated using Elmus and Apeldoorn flowers in UK trials (Nichols, 1978). It inhibited stem elongation, the effect persisting when flowers were subsequently transferred to sucrose solution. 0.2 mg/litre for 24 hours reduced stem extension by 30 per cent without loss of flower quality.

The effect of preservatives on the vase-life of Merry Widow tulips was studied in Poland by Nowak and Rudnicki (1975). A preservative Proflovit-72, containing 8-hydroxyquinoline sulphate (HQS) (0.3 g/litre), chlormequat chloride (CCC) (0.05 g/litre) and sucrose (50 g/litre), gave the best vase-life and quality, vase-life being 11 days compared with 6 days for untreated control flowers. The following three mixtures gave a vase-life of 9 days: silver nitrate (50 ppm), potassium permaganate (5 ppm) or HQS (200 ppm), all in combination with CCC (50 ppm) and sucrose (5%).

The use of sugar on early-forced tulips of several varieties (Apeldoorn, Bestseller, Golden Olga, Kees Nelis, Merry Widow and Prominence) was studied in Holland by Woltering (1982). Freshly cut blooms were held in water or sugar solutions as a pre-treatment. The best treatment was 12 hours in sugar (12%), but, even so, vase-life was extended by only half a day, which is not worthwhile. Higher sugar concentrations resulted in rapid bacterial contamination. However, similar treatments given later, as in the home when the flowers were opening, produced a useful increase in vase-life. The best response was in Merry Widow, with an increase of 7½ days in vase-life, compared with controls; there was virtually no gain in Apeldoorn or Kees Nelis, and a gain of about 2 days in the other varieties. A disadvantage of this treatment is that the stem continues to grow, bending over the vase.

In further trials in Poland, the effects of various preservatives were compared in varieties Christmas Surprise, Red Matador, All Bright and Polka (Pisulewski *et al.*, 1989a, b). In cultivar Christmas Surprise, 8-hydroxyquinoline citrate (HQC) (50 to 200 mg/litre) did not enhance vase-life over the control, but adding sucrose (2%) increased vase-life by 1 day; adding silver nitrate did not improve vase-life but resulted in tissue browning on the lower part of the stem. Increasing the sucrose concentration above 2 per cent both increased neck growth and caused lower stem injury. Gibberellic acid (GA) also increased stem growth and, added to HQC and sucrose, increased vase-life; adding Ethrel to this mixture (at 25 mg ai/litre) reduced stem elongation without affecting vase-life. In further experiments with cultivar All Bright, 20 hour pulse or continuous use of HQC plus sucrose did not increase vase-life, while adding GA was effective. Pulsing with a higher sucrose concentration (5%) increased the vase-life of All Bright and Polka, without injury. Ethrel inhibited the undesirable effects of stem extension in all four cultivars used.

In trials in Russia with tulip (variety Parade?), quality was better after dry storage following pulse treatment with sucrose (6%) for 24 hours (Belynskaya and Kondrat'eva, 1990). By this technique storage could be extended to 3 to 4 weeks.

The effects of the germicides sodium dichloroisocyanuric acid (DICA), 1-bromo-3-chloro-5,5-dimethylhydantoin and HQC were investigated using tulip Apeldoorn in trials in Australia (Jones and Hill, 1993). There were no benefits, but using DICA appeared phytotoxic, significantly reducing vase-life.

Chemical effects: some commercial preservatives

Some earlier Dutch work on preservatives was summarised by Hekstra (1966). Calcium nitrate, silver nitrate and Florasef did not affect vase-life, Chrysal had a small beneficial effect and sugar (sucrose or glucose) a stronger one. Sugar (3 to 4%) doubled vase-life in some cultivars but had little effect in others. Higher concentrations of sugar led to excessive stem growth and tipping. Alar reduced stem extension without effect on vase-life. Variable effects of Tulip Chrysal on Apeldoorn and Merry Widow were reported in other Dutch trials (de Winter, 1971). This preservative was useful especially with early-season forced Apeldoorn cropped half-coloured, giving good flower development and colour and slightly greener foliage. In both varieties vase-life was extended (by 2 to 3 days). In some cases the material produced shrinkage of the lower part of the stem, shrivelled leaf tips and colour changes in the flower. Pre-treatment (for 2 hours before despatch) was ineffective. Tulip Chrysal and Chrysal VB were reported to be effective flower preservatives by Sytsema and Barendse (1975). Another preservative consisting of benzalkonium chloride (10 ppm), sugar (2.5%) and calcium carbonate (10 ppm), was compared with Tulip Chrysal, and was reported to give better decorative value, with a vase-life of about 9 days for the varieties tested (Apeldoorn, Merry Widow and Yellow Mast), slightly longer than Chrysal and about 1 day more than the control (Staden, 1975, 1976). In Japan, the vase-life of forced William Pitt tulips has been studied (Yokoi *et al.*, 1977). Vase-life was longest when the blooms were stored at a low temperature (5°C) using a preservative (Substral).

Chrysal was included in vase-life testing of a range of varieties by Meylan and Tripod (1979), and was said to result in excessive extension and weakening of the stem in some cultivars (Palestrina, Rosario, Perry Como, Don Quichotte, Caresse, Hadley, Orange Sun, Mirjoran and Cleopatre). Commercial flower preservatives used for a range of cut flowers were reviewed by Lemper (1981). For tulips, Chrysal VB (2 ml/litre) plus sugar (25 g/litre) was considered most appropriate.

In trials in the US with several varieties, the effects of the commercial preservatives Rogard and Oasis on post-harvest quality were examined (Staby *et al.*, 1978). In different varieties, using a preservative gave different results, and generalisations were not possible. Effects of preservatives included greater stem elongation, greater water uptake, slight to considerable vase-life extension, and phytotoxic effects on stem or petals. In US trials with variety Preludium, there was little effect on vase-life of using silver nitrate (25 ppm) or Physan 20 (each with 6% sucrose), compared with water (Doss, 1986).

Chemical effects: restriction of stem extension

In tulips, excessive growth of the neck detracts from quality in the vase (Benschop and De Hertogh, 1971). In trials in the US with varieties Golden Harvest, Hibernia and Paul Richter, it was found that adding the growth retardant ancymidol (at 25 ppm) to the vase water restricted this extension growth without loss of vase-life or quality (Einert, 1971). Another growth retardant, 2,4-dichlorobenzyl-tributylphosphorium chloride, was ineffective at concentrations which were not phytotoxic. Pre-treatment of Apeldoorn flowers with Ethrel was investigated in Holland (Swart, 1983). Neck growth in the vase was reduced, but flowers were small and their development and opening were poor.

In Norway, the growth retardant Ethrel was evaluated as a vase additive, using several tulip varieties (Rasmussen, 1982). Blooms were stood in water containing Ethrel (10 to 1000 ppm a.i.) for between 5 minutes and 4 hours. Effective treatments resulted in better keeping qualities, stems remaining firm and flower shape being maintained, while vase-life was unchanged. The optimum treatment was 50 ppm for 5 minutes, applied just after cutting; with Apeldoorn, preferably with coloured buds. The following additives were also tested, either alone or with Ethrel, but they did not extend vase-life: Chrysal, Proflovit, CCC, HQS, sucrose, silver nitrate and STS.

Radiation treatment

Radiation treatments (20 to 100 kR, no further details available) were evaluated as a preservative treatment in Holland, and were found to be ineffective (Hekstra, 1966).

Effects of narcissus on tulips and other cut flowers

It is well known that daffodils should not be placed in the same vase as other flowers. Tulips placed with daffodils in the same vase, or in water previously used for daffodils for 24 hours, showed mottling and wilting; when placed together after 24 hours' separate storage, keeping quality was unaffected (Gugenhan, 1970). Damage to tulips - flaccid stems and leaf and flower scorching - was demonstrated when they were placed for 4 hours in water (with or without a flower preservative) with daffodils, or even in water containing diluted (1%) narcissus sap (Barendse, 1974; Sytsema and Barendse, 1975). Other species showing damage or reduced vase-life when placed with daffodils included rose, carnation, anemone, freesia and iris. The effect of sap varied between cultivars: Carlton sap was more harmful than sap from cultivar Geranium. The ability of preservatives to enable tulips to be placed in the same vase as daffodils has been investigated (Terfrüchte, 1981). Flora Bric was effective, while other materials (Zwiebelchrysal, Andural P, Compo Blumenfrisch and Phylokarte) were not. If narcissus have to be placed with other flowers immediately, they may be first placed in dilute bleach (5 to 7 drops per litre) for 1 to 6 hours, then rinsed, or activated charcoal (1 tablespoon per litre) may be used (De Hertogh, 1989; Nowak and Rudnicki, 1990).

The narcissus sap effect was investigated by Blankenship and Richardson (1987), using narcissus King Alfred and tulip Parade for experiments. A daffodil flower, water previously used for daffodils, or the cationic fraction of the vase water, all caused stem curvature and flower senescence in tulip, but not vascular blockage. 1-aminocyclopropane-1-carboxylic acid (ACC) was found in narcissus scapes, but not in the vase water; and cobalt (an inhibitor of ethylene synthesis) did not negate the effect of the sap on stem curvature, so an ethylene response was eliminated. ACC or Ethrel added to tulip vase water reduced stem length but did not cause curvature. The auxin 4-indole-3-ylbutyric acid (at 0.1 mM or more) elicited a curvature in tulip similar to that caused by daffodil sap, and reduced stem length, suggesting the effect was caused by auxin leaking in the sap.

DISCUSSION

Measurement of keeping quality

It is highly advisable for producers of cut-flowers to carry out their own vase-life tests, to ensure that their products will give customer satisfaction and, if necessary, to highlight any problems in production which should be corrected. Ideally, vase-life tests should be carried out under standardised conditions. The most important factors affecting keeping quality are temperature, relative humidity, light, air velocity and ethylene concentration (Systema, 1975). Researchers have often adopted the following conditions for vase-life testing, and these should be followed as far as practical, according to individual circumstances and recognising that elaborate facilities will often not be available: controlled temperature (in the range 20 to 23°C), controlled humidity (in the range 40 to 80% relative humidity), cool white fluorescent lighting (either continuous or for 12 hours per day), continuous air exchange at low velocity, and an ethylene-free atmosphere (ideally filtering circulated air with an ethylene scrubber) (Halevy and Mayak, 1979). In the case of daffodils and tulip, the major factor affecting vase-life is temperature, along with ethylene in the case of tulips, while little information is available on the other factors (humidity, light and air velocity).

Water quality is a major factor in vase-life tests (Halevy and Mayak, 1979). Because the quality of tap-water varies, the use of deonised water is preferable, and tests should be carried out in vessels which are cleaned and disinfected before each test. The start and end points of vase-life tests are also important. Vase-life tests should begin from the point the flowers are placed in the consumer's vase, so all earlier storage and transport should be similated in tests. The end of vase-life must also be objectively defined, preferably in relationship to the end of an acceptable display in the consumer's home.

Varietal differences

Keeping quality is a major criterion in selecting cultivars of flowers. In the case of daffodils and tulips, vase-lives generally are at the lower end of acceptability. The main differences are found in tulips, where the short vase-life of Darwin hybrid cultivars is an evident disadvantage, partly illustrated by the decreasing popularity of these types. A comparison of reported vase-lives for several narcissus varieties indicated those with longer and shorter vase-lives, but the variation between measurements within a variety were also considerable, suggesting differences due to pre- and post-harvest factors rather than true varietal effects. Improved keeping quality is an important factor in breeding programmes, and, because varieties appear to respond differently to flower preservatives and other chemical additives, responses to standard additives should also be included when screening.

Pre-harvest conditions

Other than for seed-raised, annual crops, keeping quality of the cut-flowers may be influenced not only by the pre-harvest conditions in the season of flower production, but also by previous years' growing history. In the case of bulbs such as daffodil and tulip, the flower is initiated in the year previous to cropping, and as the bulb is a perennating organ, even earlier seasons' growing conditions may interact with subsequent growth and development. Certainly, the overall yield and timing of forced daffodils can vary from year to year, making precise planning of forcing schedules less accurate than desired, so it is conceivable that previous history also has more subtle effects on quality. This highlights needs for growers to maintain a consistent high standard of husbandry, and for research into the after-effects of environmental and cultural factors on flower-bulb crops. Two points which are clear from the literature review are that only bulbs from a reliable stock should be forced, and that very early-lifted bulbs should be avoided.

Pre-harvest conditions during bulb forcing or flower production affect cut-flower quality more obviously. In many flower crops, low light levels and high temperatures are often unfavourable to quality production (Halevy and Mayak, 1979). This is probably related to lowered carbohydrate levels in the plant under these conditions, and can be improved by cutting in bud and giving sugars to the cut flower. This is the case in bulbs such as tulip (Yokoi *et al.*, 1977), freesia (Yokoi *et al.*, 1975) and iris (Kosugi *et al.*, 1976), and in daffodils a major recommendation is to avoid high glasshouse temperatures. Other factors - such as mineral nutrition, growing medium and irrigation - do not, in general, greatly affect the keeping quality of cut flowers (Halevy and Mayak, 1979).

In daffodils, forcing at high temperatures and forcing too early reduce flower quality. Recent Dutch recommendations have stressed another aspect of the flower production phase, namely using conditions which encourage a long leaf sheath which holds the foliage firmly: favourable conditions include longer cold treatments at 9°C and later forcing.

Tulip flower quality can be increased in a number of ways. *Botrytis* can damage leaves and flowers, and should be controlled. A number of physiological orders affect tulip, and appropriate measures should be taken to prevent bud blasting (good growing conditions, freedom from ethylene) and stem topple (correct humidity, calcium treatments). Lower glasshouse temperatures are also an advantage. Pre-harvest spray treatments with ancymidol have been used to produce tulips which do not grow excessively in the vase.

Harvesting

Dutch and US advisory literature recommends cropping daffodils at bud-burst to goose-neck stages, and tulips when the bud has coloured (half-coloured in the case of Darwin Hybrids). Recent UK literature, and practice, has been to crop at an earlier stage, particularly in the case of daffodils, where cropping at a fat, upright pencil stage is used - a result of the development of the export trade. This practice means that quality is sacrificed to some extent - presumably to an acceptable extent, given the progress of exports. It is difficult to imagine that this trend for early cropping could be reversed, so it is important (1) to define the acceptable limits of early picking by an easily described developmental stage, and (2) to develop post-harvest handling techniques which will maximise the development and longevity of the bloom.

It is advised that daffodils (of standard varieties) should not be picked until the swelling bud within the spathe has grown almost to fill the spathe, leaving only a small empty space at its tip (less than 1 cm long). Tight quality checks are needed to ensure that flowers are not cropped before they reach this stage. A guide to the effects of cropping the main varieties before, at and after this critical stage would be useful. As regards ensuring good development after cropping, it is likely that work on chemical additives would be beneficial (see below).

In some flowers, harvesting in the afternoon results in better keeping quality, presumably because carbohydrate levels are higher then (Halevy and Mayak, 1979). There is no information about such diurnal effects in daffodil and tulip.

Storage

Storage is a complex stage, as it includes all phases from the immediate treatment of the flower after cropping, through short- or long-term storage including packing, transportation and the various phases of marketing, to final display in the vase. Important factors in storage include temperature, humidity, ethylene and other aspects of air composition, and whether the flowers are stored dry or in water with or without additives.

Most cut flowers, including daffodil and tulip, are stored cool, close to the freezing point. Practical limits of cool storage for these crops have been determined from extensive trialling, and a total storage time of not more than 7 to 10 days (dry at 1-2°C) is recommended. Although longer and warmer storage have been reported, these inevitably lead to reduced keeping quality. Important points are the rapid removal of field heat after cropping, thorough cooling before packing and transportation, and maintaining a cool-chain throughout distribution. Vacuum cooling may be used, although, working by evaporation, the method itself causes water loss. Using too low a storage temperature leads to frost damage, triggered mainly by the ice-nucleating effect of bacteria. Working on roses, Mayak and Accati-Garibaldi (1979) found that using the antibiotic streptomycin reduced frost injury in cut-flowers that had been inoculated with microbes. The effects of storage temperatures below -0.6°C have not been reported for daffodil and tulip.

Both daffodils and tulips are harvested and stored in bud for opening by the consumer. Dry storage is generally satisfactory at the storage temperatures given above, provided other factors, mainly humidity, are favourable. For tulips, a one-hour post harvest treatment in water is an advantage, especially for flowers of short-lived varieties or when cropped at a relatively immature stage; harvesting with the bulb intact is also advantageous. Usually, a relative humidity of 90 to 95 per cent is recommended. At such humidities, gentle air movements will be needed to maintain temperature control of the store, but excessive air velocity will cause water loss and loss of quality even at high humidities. Halevy and Mayak (1981) suggested that ultra-humid storage (99-100% relative humidity), used successfully for leafy vegetables, should be tested for flowers.

During the whole storage process, it is important to avoid exposure of flowers to ethylene, a gaseous plant hormone which stimulates senescence. Low concentrations of ethylene stimulate further ethylene production (autocatalysis). Although daffodil and tulip petal senescence is not considered especially sensitive to ethylene, both crops show reduced quality when ethylene is present. Air exchange should be sufficient to counter ethylene production by the flowers and any diseased tissue, and sources of ethylene should be avoided, mainly fruit and vegetables and fumes from internal combustion engines. Ethylene scrubbers may be used, although their effectiveness has been questioned (Halevy and Mayak, 1981). These consist of materials such as potassium permanganate absorbed on silica gel or vermiculite, and in the form of filters or blankets (used in stores) or sachets (included with the product).

Controlled atmosphere storage has been investigated with many flowers, for example with reduced oxygen and elevated carbon dioxide levels. Increased carbon dioxide concentrations reduce ethylene effects. Within limits, increased carbon dioxide levels were beneficial in trials with daffodils and tulips. Unlike many flowers, daffodils stored well in 100 per cent nitrogen. Modified atmosphere storage - where flowers are stored dry in a sealed pack of partly or selectively permeable material - has given erratic results with other cut-flower crops, and requires accurate definition of suitable conditions (Halevy and Mayak, 1981). Low-pressure (hypobaric) storage has also given variable results with cut-flowers, and does not appear to have been investigated for daffodils and tulips.

Light is not generally considered a major factor in flower storage, although it could lead to water loss by opening the stomata. Tulip stomata are reported to be continuously open except for about three hours after sunset, daytime closure occurring only after severe wilting (Rees, 1972), while daffodil stomata also appeared relatively insensitive to stress (Barton-Wright and Pratt, 1931); it may, therefore, be worthwhile examining the effects of antitranspirants on daffodils and tulips before and after harvesting.

Some storage disorders occurring with cut flowers do not apply to daffodil and tulip, such as flower abscission and foliage discolouration. In daffodils, a problem is geotropic curvature of the stems, best treated by upright storage. In tulips, excessive post-harvest stem extension can occur: this can be enhanced by sugar in preservatives, which should be avoided, and pre-harvest sprays with the retardant ancymidol have been used successfully. Yellowing of tulip foliage can be a problem during longer periods of storage (Rudnicki *et al.*, 1986), and the use of BA and GA, as in other species, may be useful to delay senescence (Halevy and Mayak, 1981; Novak and Mynett, 1985).

Water and water quality

As daffodils and tulips are usually stored dry, the effects of water (and of any chemical additives) will apply mainly to the stages of retail display and consumer use, although a post-harvest treatment is also an option, particularly for tulips. Although daffodils and tulips have relatively short vase-lives, this is not due to a loss of water conductivity by the stem over time (Halevy and Mayak, 1981). Hence, in these flowers, the factors which may cause loss of water uptake - such as microbial growth, vascular blockage resulting from harvesting injury, deposition of mucilages, and air embolism - are not major considerations.

The quality of tap water varies, and in some cases better vase-life has been obtained when deionised or distilled water, or water which has been de-gassed to reduce the air content (either by micro-filtration or by boiling) has been used. Tulips did not appear, from one study, to be sensitive to water quality, and no data are available for daffodils. Factors which could be important in water quality and cut-flower longevity include acidity (a low pH is widely beneficial), the presence of wetting agents (effective in some crops), total dissolved solids, and specific ions (many of which are toxic). Tulips, but not daffodils, are sensitive to fluorine.

Chemical additives

Additives may be used at four stages: post-harvest (conditioning or hardening), pulsing, bud opening and holding. Conditioning is carried out to restore turgidity lost in harvesting, often by placing in water overnight in the cool store; a germicide is often added. Pulsing is a short (12 to 24 hour) pre-shipment treatment, designed to last throughout shelf-life; a high concentration of sugar is often used, and exact details vary with species. Impregnation is a type of pulsing, in which the cut stem bases are placed in a solution of a silver salt (such as silver nitrate) for 5 to 10 minutes: the silver travels only a short way into the stem and acts as a bactericide. A bud opening treatment is used for some flowers, usually with a lower sugar concentration than used for pulsing. Finally, vase or holding water often contains a commercial preservative, usually with a low concentration of sugar plus a bactericide. As stated previously, for daffodils and tulips only the final stage usually applies, perhaps with a post-harvest conditioning treatment for tulips. Trials with daffodils of commercial preservative formulations have given variable results, often showing no benefit, but in other cases extending vase-life by up to 50 per cent. Contradictory results were also obtained testing commercial preservatives on tulips: one US study concluded that preservatives gave different results in different cultivars, so that generalisations were not possible. In one report, using HQS, CCC and sucrose (together) doubled vase-life. The types of additives will now be considered separately.

Sugars Sucrose is usually used, the concentration depending on the stage of use (see above); other metabolic sugars like glucose and fructose can also be effective. Sugars used alone have generally been ineffective or inconsistent in both daffodils and tulips, although uptake occurs, resulting in ovary growth in daffodil and stem extension in tulip. With tulips, good results, sometimes up to 7 days longer vase-life, have been obtained in some cases in combination with silver, when used as a pulse, or when used in the home rather than at an earlier stage.

Minerals Certain non-toxic mineral salts, such as potassium salts and calcium and ammonium nitrate, result in improved water uptake in some cases. In tulips, calcium carbonate (with sugar and bactericide) had a beneficial effect on tulips, while calcium nitrate prolonged the vase-life of some bulb flowers (Widmer and Struck, 1973). Aluminium (as the sulphate) is used as a preservative for some flowers, lowering pH and inducing stomatal closure, but was ineffective in tulips. Silver salts (such as silver nitrate and silver acetate) are useful bactericides, and STS is also mobile in the plant and effective as an inhibitor of ethylene production. In daffodils, silver salts were generally ineffective in trials when used alone, although using silver nitrate with sucrose led to up to 4 days longer vase-life in some trials. In other research with daffodils, using silver or cobalt (with sucrose and HQS) increased vase-life by a third or a half, respectively. In tulips, silver salts also gave weak or no consistent effects, although STS reversed growth inhibition due to ethylene or Ethrel, and, tested in some combinations (with CCC and sucrose) increased vase-life by 50 per cent in some trials. Nickel was also ineffective in tulips. Boron, zinc and copper are other minerals which have sometimes been investigated as additives, but they do not appear to have been tested in daffodils and tulips.

Germicides Flower preservatives usually include a bactericide and sometimes a fungicide. Silver salts are the most active (see above). In one report on tulip vase-life, potassium permanganate was as effective (in mixtures) as silver nitrate. The citrate or sulphate of 8-hydroxyquinoline is often used, being broad spectrum germicides as well as having chelating and acidifying properties. Both HQC and HQS have been used in preservative mixtures for daffodils and tulips, with some useful effects. In daffodils, significant vase-life extension was obtained in some trials using HQC with sucrose. Among other germicides which have been tested on these crops, among slow-release chlorine compounds DICA slightly increased vase-life in daffodils, and of quaternary ammonium bactericides benzalkonium chloride (benzalkone) was effective in tulip but Physan was ineffective in tulips and harmful in daffodils. Other germicides which do not appear to have been investigated in daffodils and tulips include thiabendazole, dichlorophen (Panacide) and chlorhexidine. According to one report, Benlate extended daffodil vase-life by several days.

Organic acids and antioxidants Citric, tartaric and other organic acids are widely used to lower pH, while benzoic acid (as sodium benzoate) is an antioxidant, free-radicle scavenger and ethylene inhibitor. Of these materials, sodium benzoate delayed senescence of daffodils in tests.

Ethylene inhibitors Several materials previously mentioned inhibit ethylene action or production, such as silver, nickel, cobalt, 8-hydroxyquinoline and benzoic acid. In daffodils, these additives which have had beneficial effects are silver, cobalt, 8-hydroxyquinoline salts and sodium banzoate; in tulips, silver salts have had most effect. Rhizobitoxine is a specific inhibitor of ethylene synthesis, and analogues of this material were effective in extending vase-life in daffodils.

Growth regulators Although ethylene is the natural growth regulator most studied in relation to flower longevity because of its involvement in the control of senescence (see above), the other groups of regulators - cytokinins, auxins, gibberellins and abscisic acid - have also been shown to affect vase-life. Cytokinins are used to extend vase-life most successfully in carnations. In tulips, there have been some conflicting findings of the effects of BA, while a small increase in vase-life has sometimes been reported for treatments with this material in daffodils.

There have been fewer reports generally of beneficial effects due to applied auxins and gibberellins. In daffodils, NAA was reported to give several days' longer vase-life in one case, but only small effects in another. GA has been reported to result in substantial increases in vase-life when used with HQC or silver and sucrose in both daffodil and tulip, and in another report on daffodils GA almost doubled vase-life.

Abscisic acid stimulates stomatal closure and advances senescence, and so would be expected to have variable effects on keeping quality. ABA has not been tested on daffodils and tulips.

Growth retardants Retardants such as Alar, CCC, Ethrel and ancymidol have beneficial effects on vase-life in some cases. In tulips, CCC was effective in extending vase-life when used in combination with other additives, but the most useful effect was using ancymidol or

Ethrel to restrict excessive post-harvest stem extension; pre-harvest sprays or vase treatments can be used. From one report, Alar was said to extend daffodil vase-life by several days.

Inhibitors A variety of growth and metabolic inhibitors has been investigated as additives, with variable effects. These include maleic hydrazide, morphactins and enzyme inhibitors (such as sodium azide and 2,4-dichlorophenol), which do not appear to have been evaluated on daffodils or tulips. Polyamines also inhibit ethylene production. The protein synthesis inhibitor cycloheximide reduced stem elongation in cut tulips and slightly extended vase-life in daffodils.

Summary From the large number of reports on the effects of additives on the keeping quality of daffodils and tulips, a confusing picture emerges. This is probably the result of a number of projects carried out under very different protocols over a long time span. The difference in conditions of vase-life tests can be illustrated by the very different vase-lives reported: in some daffodil tests, for example, the vase-life of untreated controls was only 3 days, and in others, 12 days, greatly affecting whether a 50 per cent increase in vase-life as a result of using a preservative is considered worthwhile or not! Despite this variety of results, some general conclusions can be drawn, to point towards future research needs. In daffodils, several ethylene inhibitors increased longevity in some cases, and phytohormones such as GA appear to have promising effects, whereas responses to sugars and germicides is generally poor. In tulips, mixtures of HQS, sucrose and CCC with silver or GA are useful, although varietal responses need to be defined closely.

Concluding remarks

Given that suitable varieties are used, keeping quality of daffodils and tulips is most affected by harvesting stage and storage conditions. This is reflected in the guidelines for producers included in this report. Effects of pre-harvest conditions on vase-life and quality are small - or, perhaps, poorly understood. A striking finding of the literature review was the extent of experimental work carried out on chemical additives, which is hardly matched by the practical application of preservatives, despite some marked claims of vase-life extension. Although initial attempts have been made in developing computer models to predict cut-flower (including daffodil and tulip) vase-life, it is clear that more information on the effect of factors such as ethylene and chemical additives is needed (van Doorn and Tijskens, 1991a, b). Several areas for future R & D were highlighted in the course of the review, and these are summarised in the next section.

CONCLUSIONS

Guidelines for producers - daffodils

Daffodils have a relatively short vase-life, and this must be maximised by good handling at harvest and during storage and transport. Quality cut-daffodils should develop a large, properly formed flower held on a firm stem.

1. Varieties Most important UK daffodil varieties have an acceptable vase-life, but the vase characteristics of novel varieties should always be checked before being put into production.

2. Bulb stocks Little is known of how previous growing conditions affect subsequent flowering or post-harvest quality, but it is important to avoid bulbs which have been lifted early (in June), if good flower size is to be achieved.

3. Flower production Advisory information should be carefully followed to ensure a good yield of high-quality blooms. In forcing, cool storage should not be shortened and temperatures below 9°C should not be used, in order to promote strong leaf sheaths and upright foliage. In the glasshouse, ensure good light levels and grow at 13 to 16°C, depending on variety.

4. Flower cropping For standard varieties for export, harvest at upright green pencil stage, once the bud has swollen nearly to fill the surrounding spathe: there should be only a small space at the top of the spathe, although the extent of this will vary between varieties. For UK, and especially local, markets, cropping at a later stage of development will give a better quality flower. Double varieties are cropped with the sheath splitting, and tazetta varieties with one (Soleil d'Or) to three (Ziva) florets open.

5. Initial flower treatment The flowers should be placed vertically in crates and moved promptly to a cool store (1 to 2°C).

6. Flower storage Flowers are stored dry but relative humidity in the store should be 90 per cent. Time out of the cold store (eg, for packing) should be minimised. Storage should be as short as practicable, but not more than 7 days at 1 to 2°C. Once packed in closed market boxes, these should be allowed to cool fully before transportation.

7. Distribution Hold flowers at 1 to 2°C throughout storage and distribution. The total period of flower storage, cool-chain and distribution should not exceed 7 to 10 days.

8. Retailing If not displayed in a cool counter, place in water (not with other flowers). Consumers should be advised to trim the base of the stem and not to mix daffodils with other flowers (unless the daffodils have been stood separately in water for 24 hours then rinsed, fresh water being used).

9. Chemical treatments Flower preservatives and other additives are not usually used, and, as some adverse effects of some additives have been reported, are best avoided until further trials have been conducted.

Guidelines for producers - tulips

Tulips also have a relatively short vase-life, so good cropping and storage are vital. Quality cut-tulips will be varieties with longer vase-lives, and the flower, when open, should be fully coloured, with the characteristics of the variety. Excessive growth of the stem in the vase is usually considered unattractive.

1. Varieties Darwin Hybrid varieties have short vase-lives and are prone to faults such as white petal tips; they should be avoided.

2. Bulb stocks It is important to use bulbs of adequate size and free of diseases such as *Botrytis tulipae* (tulip fire).

3. Flower production Advisory information on bulb forcing should be followed, to produce a good yield of high quality, carefully scheduled blooms. Precautionary action should be taken against pests (eg, aphid), diseases (eg, fire) and disorders (eg, topple) which affect flower quality. In the glasshouse, cool growing conditions (10 to 13°C), especially immediately after housing, produce stronger blooms; later, temperatures of up to 18°C can be used, depending on variety.

4. Flower cropping Tulips should be harvested when the bud has just coloured but remains tight, or, in the case of Darwin Hybrid varieties, when colour is visible along the edges of the petals. Preferably, crop with the bulb intact and remove it later before packing.

5. Initial flower treatment The flowers should be moved promptly to a cool store (0 to 2°C). There are advantages to using an initial (1 hour) treatment in water.

6. Flower storage Flowers can be dry-packed in sleeves and stored for up to 5 days dry at 0 to 2°C under high relative humidity (90%). For longer storage (especially with varieties with short vase-lives), store in water.

7. Distribution Cool-chain distribution should be used, avoiding exposure to sources of ethylene gas, which is given off by vegetables and fruit.

8. Retailing Tulips should be placed in water for 2 hours, not mixed with other flowers. Customers should be advised to trim the base of the stem, to avoid exposure to ethylene sources, and not to put daffodils in the same vase.

9. Chemical treatments Flower preservatives and other additives are not normally used, and, as excessive stem extension and phytotoxic effects may result from the use of some additives, should be avoided until further trials have been conducted.

Recommendations for R & D

1. Definition of optimum harvesting stage Trials are needed to define, accurately, the limits of acceptable harvesting stages, and to demonstrate the effects of too early or too late harvesting, for the important cultivars. It is likely that excessively early cropping is a major cause of loss of customer satisfaction, especially for daffodils.

2. Effects of chemical additives on keeping quality Experimental work on preservatives has been carried out under a wide range of conditions, and the most promising chemical treatments need to be examined critically under present-day, UK conditions with the important cultivars. Claims of 50 per cent or more vase-life extension, found in the literature, are too significant to be ignored, and, if verified, could make daffodil and tulip vase-life very acceptable. For daffodils, ethylene inhibitors and GA appear most promising, while, for tulips, HQS, sucrose, CCC, silver and GA should be examined. The effects of water acidity and of wetting agents should also be studied.

3. Novel storage techniques Several storage strategies have not yet been evaluated with daffodils and tulips, and should be investigated. These include: the use of antitranspirants to retard water loss before and after harvesting; sub-zero storage techniques; and ultra-humid storage.

4. Ethylene scrubbers There is a general need to develop more efficient ethylene scrubbing materials to enhance storage of cut-flowers.

5. Effects of pre-harvest conditions In any future work on scheduled production of bulbs and bulb flowers, the effects of previous growing conditions on keeping quality should be considered.

GLOSSARY

Abscisic acid (ABA) Natural growth regulator/growth inhibitor

1-aminocyclopropane-1-carboxylic acid (ACC) Ethylene precursor

Ancymidol Synthetic growth retardant

Alar (n-dimethylamino succinamic acid) Synthetic growth retardant

Benlate (a.i., benomyl) Fungicide

Benzalkonium chloride Bactericide

6-benzyladenine (BA) Cytokinin growth regulator

Chlormequat chloride (CCC) Synthetic growth retardant

Citric acid Acidifier, used to aid water uptake

Cobalt Inhibitor of ethylene

Cycloheximide Inhibitor of protein synthesis

2,4-dichlorophenoxyacetic acid (2,4-D) Selective systemic herbicide, growth inhibitor

Ethrel (a.i., ethephon) Ethylene-releasing growth retardant

Ethylene Natural, gaseous plant growth regulator

Ethylene scrubber Material which absorbs ethylene

Germicide General term to include bactericides, fungicides, etc

Gibberellic acid (GA) Natural growth regulator

8-hydroxyquinoline citrate (HQC) Bactericide

8-hydroxyquinoline sulphate (HQS) Bactericide

4-indole-3-ylbutyric acid (IBA) Synthetic auxin growth regulator

Kinetin Cytokinin growth regulator

Naphthaleneacetic acid (NAA) Synthetic auxin growth regulator

Preservative (floral) Usually a combination of a sugar and a bactericide

Pulse Short period of uptake of a preservative, etc (as opposed to continuous use)

Rhizobitoxine Inhibitor of ethylene synthesis

Silver (nitrate) Bactericide; inhibitor of ethylene action

Silver thiosulphate (STS) Inhibitor of ethylene action

Sodium benzoate Bactericide

Sucrose Cane sugar, the usual sugar used as a flower preservative

Tween 20 A surfactant (wetter)

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