Temperature and Irradiance Effects on Flowering of Two Species of *Leucocoryne*

J.L. Catley

The Horticultural and Food Research Institute of New Zealand Ltd., Private Bag 11 030, Palmerston North, New Zealand

ADDITIONAL INDEX WORDS. bulb, cutflower, geophyte, *Leucocoryne coquimbensis*, *Leucocoryne ixioideis*, senescence

ABSTRACT. The influences of temperature and irradiance on flowering of two species of *Leucocoryne* [*L. coquimbensis* F. Phil and *L. ixioideis* (Hook.) Lindl.] were examined in controlled environment growth rooms. Growing environments had day/night temperatures of 10/5, 15/10, or 20/15 °C, providing mean temperatures of 7.5, 12.5, or 17.5 °C, and photosynthetic photon fluxes (PPF) of 497 or 710 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. Inflorescence emergence data were recorded up to three times a week, measurements of floral development were made twice weekly and destructive harvests were carried out every 2 weeks. Both species of *Leucocoryne* flowered most quickly when grown at a mean temperature of 17.5 °C. *Leucocoryne coquimbensis* flowered first in all temperature regimes (means of 7.5, 12.5, or 17.5 °C), taking an average of 7.1, 5.1, or 4.5 months to flower, whereas plants of *L. ixioideis* took 7.6, 5.4, or 4.7 months to flower. Although taking longer to flower, *L. ixioideis* produced better quality flowers (taller scapes and more florets per inflorescence). Plants of *L. coquimbensis* grown in the two highest temperature regimes produced up to four inflorescences per bulb. As mean temperature decreased, the number of inflorescences produced by each bulb together with the number of florets in each inflorescence and the number of leaves produced before emergence of the inflorescence decreased. Decreases in these attributes were much greater with a 5 °C mean temperature drop from 12.5 °C, than a drop from 17.5 to 12.5 °C. At least half the florets in an inflorescence opened before the first floret began to senesce. The onset of senescence was delayed as mean temperature decreased. The highest irradiance level promoted development of further inflorescences of *L. ixioideis* at all mean temperatures, and at a mean temperature of 17.5 °C for *L. coquimbensis*. Flower stem heights of *L. coquimbensis* increased as mean temperature increased and irradiance level decreased. An increase in irradiance level also promoted scape heights of *L. ixioideis*, although maximum scape heights were attained at a mean temperature of 12.5 °C. Regardless of mean temperature or irradiance level, all cut stems were able to stand without support. These findings suggest days to flowering, inflorescence number and floral quality may be improved by growing these two species of *Leucocoryne* at mean temperatures greater than 17.5 °C, whereas mean temperatures below 12.5 °C will be detrimental to these floral attributes.

Leucocoryne is a geophytic genus from Chile comprised of 11 (Hoffman, 1989) or 12 species (Zoellner, 1972), belonging to the Alliaceae family (Dahlgren et al., 1985). Two of the species, *Leucocoryne coquimbensis* and *L. ixioideis* are summer-dormant geophytes which have potential as cutflower crops. *L. coquimbensis* is endemic to the coast of central Chile from Coquimbo (hence its name) to Aconcagua (latitude 30 to 33°S) (Hoffman, 1989; Rundel, 1981; Zoellner, 1972). *Leucocoryne ixioideis* is found over a narrower latitude band (latitudes 32 to 34°S) with some overlap with *L. coquimbensis*. The habitats of *L. ixioideis* are farther south and farther inland, in the slightly more elevated central provinces of the Cordillera de la Costa (Hoffman, 1989; Zoellner, 1972). Winter rains trigger growth followed by flowering in late spring and early summer (Bryan, 1989). Ohkawa et al. (1997) and van Leeuwen (1992) have shown *L. coquimbensis* requires a minimum of 4.5 months dry storage at an optimum temperature of 20 °C to break dormancy.

At the time of bulb lifting, differentiation of the first inflorescence and sometimes the second inflorescence has occurred (Ohkawa et al., 1998). During storage, floral organ development continues, the rate being dependent on temperature: 20 °C is considered the optimum (Ohkawa et al., 1998). After 9 months

storage at 20 °C the scape begins to elongate, however after $\approx$ 11 months storage, abortion of the first inflorescence can begin and is universal in bulbs stored for at least 12 months (Kim et al., 1998a; Ohkawa et al., 1998). After planting, differentiation of secondary inflorescences continues and begins for tertiary inflorescences (Ohkawa et al., 1998).

The inflorescence of *Leucocoryne* is an umbel of 3–12 florets (Uphof, 1945). *Leucocoryne coquimbensis* has blue florets with white centers and prominent orange-yellow staminodes and *L. ixioideis* has white florets with cream staminodes. Some species have an undesirable aroma when cut which can detract from the floral appeal (Lancaster et al., 2000). The manner in which a flower senesces may be important in determining a species' usefulness as a cutflower or ornamental. McKenzie and Lovell (1992) describe three broad categories of flower senescence. One of these, into which *Leucocoryne* falls, is withering and persistence of the flowers and constituent floral parts. Other genera in this category include *Ipheion*, *Nothoscordum*, and *Triteleia*, genera closely related to *Leucocoryne*.

In New Zealand, *Leucocoryne* is grown in plastic structures that provide rain protection, and where it flowers in spring. However, there is little knowledge of the effects of temperature and light on flowering, flower quality and crop scheduling. Previous studies of *Leucocoryne* by Kim et al. (1998a, 1998b), Ohkawa et al. (1998), Ohkawa et al. (1997), and van Leeuwen (1992) have examined either floral differentiation, bulb weight, storage temperatures or durations, and their effects on flowering. Elgar et al. (2003) also studied vase life. Therefore, until now there has been no attempt to define the effects of the environment on floral growth, or sub-

Received for publication 9 Apr. 2003. Accepted for publication 12 May 2003. I am grateful to H. Nihal de Silva for designing the experiments, to David Brundell and Green Harvest Pacific Ltd for supplying the planting material, and to Daniel Cohen, Alistair Hall, and Eric Walton for reviewing the manuscript. The controlled environment rooms used in this study were maintained by the NZ Controlled Environment Laboratory Technical Services Group. Funding for this study was provided by the New Zealand Foundation for Research, Science and Technology (Contract C06609).

sequent quality, or to describe scape elongation and flowering. As *Leucocoryne* has potential as a cutflower crop, such knowledge will benefit flower growers as it will aid scheduling decisions and potentially improve flower quality. The objectives of this study were to determine the influence of temperature and irradiance on plant growth and development of two species of *Leucocoryne* under controlled environment conditions. The results of these floral development studies are reported in this paper.

Material and Methods

PLANT MATERIAL. Bulbs of seedling populations of *L. coquimbensis* and *L. ixioides* were obtained from a commercial grower. Before receipt, the bulbs were stored dry between 20 and 25 °C for ≈ 28 weeks. Bulbs were prepared for planting immediately on arrival, by removing all secondary bulbs from the main bulb. Each main bulb weighed between 1.0 and 2.5 g. These bulbs were sorted according to weight, then four bulbs of similar weights (± 0.1 g) were planted in 1.25-L pots containing a 1 peat : 1 pumice : 1 gravel (by volume) growing medium. The medium was amended with 3 g·L⁻¹ of 3-month Osmocote (14N–6.1P–11.6K), 6 g·L⁻¹ 9-month Osmocote (18N–2.6P–10K), 3.3 g·L⁻¹ Sierra Micromax (Grace Sierra, Heerlen, The Netherlands), 8 g·L⁻¹ dolomite lime and 3.3 g·L⁻¹ superphosphate (Ravensdown Fertilizer Co-op, Napier, New Zealand). During growth, a modified half-strength Hoagland's A nutrient solution was applied to excess twice daily (Brooking, 1976). Each treatment consisted of 36 pots, and each treatment was allocated to 1.5 trolleys. Trolley positions were reallocated within each room twice weekly to minimize positional effects. A completely randomized design was used for each irradiance and temperature combination.

ENVIRONMENTAL CONDITIONS. The pots were placed on trolleys in three controlled environment growth rooms at the New Zealand Controlled Environment Laboratory belonging to HortResearch in Palmerston North, in a range of growing regimes with day/night temperatures of 10/5, 15/10, or 20/15 °C, providing mean growing temperatures of 7.5, 12.5, or 17.5 °C respectively. Daily lighting in each room consisted of a 12-h light period of 710 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ photosynthetic photon flux (PPF) at pot level. Vapor pressure deficits of 0.4/0.3 kPa (day/night) were maintained in these rooms. The changeover from day to night for temperature and vapor pressure deficit took 2 h, with the 12-h light period starting midway through this period.

The irradiance levels in the main lighting period were provided by four 1-kW high pressure discharge lamps (Sylvania 'Metalarc') and four 1-kW tungsten halogen lamps. An additional irradiance level was achieved by fitting half the trolleys with neutral density synthetic screening to obtain 497 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at pot level. The two irradiance levels of 497 or 710 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in each room provided daily photon receipts of 21.5 or 30.6 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ respectively. Based on a photometric/radiometric conversion factor of 4.59 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{W}^{-1}$ (McCree, 1972), and assuming 50% of outdoor global radiation is photosynthetically active radiation (Monteith and Unsworth, 1990), these daily photon receipts are equivalent to outdoor global radiation receipts of 9.3 and 13.3 $\text{MJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$.

MEASUREMENTS AND DATA ANALYSIS. During growth, all plants were monitored twice a week to record the date of first leaf emergence and emergence dates of the inflorescences. Inflorescences were individually tagged so their heights could be measured every 3 to 4 d. Individual floret opening and senescence were also recorded every 3 to 4 d. Opening and flowering are both defined as when the first floret on an inflorescence begins to

unfurl, and senescence is defined as when the tips of the first floret tepal become translucent. Up to 11 destructive harvests were made during growth at intervals of up to 4 weeks. At each harvest, inflorescences from two randomly selected pots in each treatment (eight plants per treatment) were counted, separated, weighed, oven dried and reweighed.

Statistical analyses were carried out using Genstat 4.1 (Payne et al., 1993). Height and development stage data were analyzed using linear models. Generalized linear models with Poisson error distribution were used for the analysis of count data.

Results

DAYS TO FLOWERING. Days from planting to spathe appearance and from planting to flowering increased with decreasing mean temperature (both $P < 0.001$) for both *Leucocoryne* species (Fig. 1A and B). Although there was no significant species difference in the number of days from planting to the appearance of the first spathe, there was in the number of days from planting to flower opening (both $P < 0.001$). Scapes appeared first in plants of *L. coquimbensis*, and they began flowering significantly earlier than those of *L. ixioides* at all temperatures (Fig. 1A and B). At mean temperatures of 7.5, 12.5, and 17.5 °C it took plants of *L. coquimbensis* 214, 153, and 137 d to flower from planting, in comparison to 228, 164, and 140 d for plants of *L. ixioides*. Spathe emergence of *L. coquimbensis* was more closely followed by scape emergence and flowering than that of *L. ixioides*. Irradiance level had no effect on the timing of any of these floral parameters.

The number of days from flowering of the first inflorescence to flowering of the second inflorescence was substantially shorter than the number of days from planting to flowering of the first inflorescence. *Leucocoryne coquimbensis* produced second inflorescences more quickly than *L. ixioides* at all mean temperatures. The number of days from flowering of the first inflorescence to flowering of the second inflorescence decreased as mean temperature increased (34, 16, and 13 d for *L. coquimbensis* and 44, 27, and 17 d for *L. ixioides*). No further data is available on the number of days it took for additional inflorescences to be produced.

FLORAL ATTRIBUTES. Final scape heights of both species were significantly affected by mean temperature and irradiance level

Fig. 1. Effects of mean temperature on days from planting to spathe emergence (▲), scape emergence (■), and first floret opening (●) of the first inflorescence of *Leucocoryne coquimbensis* (A) and *L. ixioides* (B). The vertical bars about the points are standard error (SE) values of the means. Data from the irradiance levels are pooled as there was no significant effect.

Fig. 2. Effects of mean temperature on spathe length (▲), and scape height (● and ■) of the first inflorescence of *Leucocoryne coquimbensis* (A) and *L. ixioideis* (B). The closed symbols are results for the PPF level of 710 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and the open symbols are those for the PPF level of 497 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. The vertical bars about the points are SE values of the means.

(both $P < 0.001$). For both species mean scape height increased as irradiance levels decreased (Fig. 2A and B), increasing by 61 and 94 mm (respectively) for scapes of *L. ixioideis* and *L. coquimbensis*, when data from the three mean temperatures were combined. As mean temperature increased, mean scape height of *L. coquimbensis* increased whereas the maximum scape height of *L. ixioideis* was reached at a mean growing temperature of 12.5 °C (Fig. 2A and B). For both species at both irradiance levels, a mean temperature drop from 12.5 to 7.5 °C produced the greatest effect on scape heights (Fig. 2A and B). There was also a significant species difference in mean scape height ($P < 0.001$) (Fig. 2A and B). Scapes of *L. ixioideis* were on average 46 mm taller than those of *L. coquimbensis*. All scapes were able to stand without support once cut for the destructive harvests, regardless of mean temperature or irradiance level. Spathe lengths were similar regardless of irradiance level or species, although there was a small but significant temperature effect ($P = 0.021$) (Fig. 2A and B).

For both species the mean number of inflorescences per bulb more than doubled as mean temperature increased from 7.5 to 17.5 °C ($P < 0.001$), although the greatest inflorescence increase occurred as mean temperature increased from 7.5 to 12.5 °C (Fig. 3A and B). There was a small but significant increase in the number of inflorescences per bulb as irradiance level increased ($P = 0.046$) (Fig. 3A and 3B). Plants of *L. coquimbensis* grown in the two highest mean temperature regimes produced up to four inflorescences per bulb, whereas up to three inflorescences per bulb of *L. ixioideis* were produced in the highest mean temperature. Although there was no significant difference in the number of inflorescences each species produced, first appearing inflorescences of *L. ixioideis* contained significantly more florets at all mean temperatures ($P = 0.003$) (Fig. 3C). Floret numbers also increased as mean temperature increased for both species ($P < 0.001$) (*L. ixioideis* 4.9, 6.6, and 8.5 and *L. coquimbensis* 2.6, 5.0, and 7.4). Irradiance level had no effect on floret numbers. No abortion of florets was observed. Observations were also made of inflorescence shape. Pedicel length was quite variable within and between inflorescences of both species (data not shown), and often the umbels were not symmetrical.

At first spathe emergence more leaves of *L. ixioideis* had emerged than for *L. coquimbensis* ($P = 0.009$) (Fig. 4). Leaf numbers also

Fig. 3. Effects of mean temperature on number of inflorescences per bulb of *Leucocoryne coquimbensis* (A), number of inflorescences per bulb of *L. ixioideis* (B), and number of florets in the first inflorescence (C) of *L. coquimbensis* (●) and *L. ixioideis* (■). For A and B, the closed symbols are results for the PPF level of 710 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and the open symbols are those for the PPF level of 497 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. For C, data from the irradiance levels are pooled as there was no significant effect. The vertical bars about the points are SE values of the means.

increased as mean temperature increased (3.2, 5.3, and 6.0 leaves for *L. coquimbensis* and 3.6, 5.5, and 6.8 leaves for *L. ixioideis*) ($P < 0.001$) (Fig. 4). Irradiance level had no effect.

FLOWERING DYNAMICS. Floral development of the first inflorescence in both species of *Leucocoryne* proceeded in an orderly manner, although the timing (Figs. 5 and 6) and magnitude (Fig. 5) of these various phases was significantly affected by mean temperature, and sometimes irradiance (Fig. 6). Results of only the 710 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ irradiance level are presented in Fig. 5 for clarity, but results of the lowest irradiance level are described or depicted elsewhere in the text. Emergence of the scape (d,

Fig. 4. Effects of mean temperature on the number of leaves present when the first inflorescence of *Leucocoryne coquimbensis* (●) and *L. ixioideis* (■) emerged. The vertical bars about the points are SE values of the means. Data from the irradiance levels are pooled as there was no significant effect.

Fig. 5) (and Fig. 5 hereafter) always began after leaf emergence (a) and spathe emergence (b), but before spathe elongation was complete (c). Flowering (e) always began before scape elongation had been completed (i). After first floret opening (e), the rate of scape elongation rapidly slowed to stop, but normally not until after all florets had opened (g), and only after floret senescence had begun (f). After the commencement of flowering (e), further scape elongation (i), decreased as mean temperature decreased and was greater for *L. ixioideis* (145, 110, and 60 mm) compared with *L. coquimbensis* (60, 34, and 28 mm).

In looking more closely at the dynamics of flowering, i.e., floret opening and senescence and the relationship between these two, there were significant differences with mean temperature, irradiance level, and species. For both species, the time between first and last floret opening increased with increasing mean temperature ($P < 0.001$) and irradiance level ($P = 0.025$) (Fig. 6). Similar effects on the time from first to last floret senescence also occurred with increases in mean temperature ($P < 0.001$) and irradiance level ($P = 0.048$) (Fig. 6). The time taken for both the opening and senescence phases to be completed was significantly longer for *L. ixioideis* (Fig. 6).

Successive florets of an inflorescence opened most quickly during the earlier part of the opening phase in all treatments of both species, i.e., half

Fig. 6. Effects of mean temperature and irradiance level on floret opening (white and light gray bars) and floret senescence (black and dark gray bars) of the first inflorescence of *Leucocoryne coquimbensis* (A, C, E) and *L. ixioideis* (B, D, F). The white and black bars are results for the PPf level of $710 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and the light and dark gray bars are those for the PPf level of $497 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. The vertical lines on the white and light gray bars represent the days to when half the florets have opened, and the black and dark gray bars represent the days to when half the florets have senesced (vase life). Some symbols and bars are missing in the 7.5°C mean temperature regime, as there were not enough inflorescences to obtain good estimates. Horizontal bars about the points are SE error values of the means.

Fig. 5. Effects of mean temperature and the irradiance level of $710 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ on the development of *Leucocoryne coquimbensis* (A, C, E) and *L. ixioideis* (B, D, F). Results of the mean temperature of 17.5°C are shown in A and B, 12.5°C in C and D, 7.5°C in E and F. Plots of days to leaf emergence (a), days to spathe emergence (b), days to maximum spathe height and the maximum height (c), days to scape emergence (d), days to first floret opening and scape height at this time (e), days to first floret senescence (f), days to last floret opening (g), days to last floret senescence (h), and days to maximum scape height and height at this time (i) of the first inflorescence. Horizontal and vertical SE bars are not shown as they are smaller than the symbols displayed.

the florets in an inflorescence opened in approximately one-third of the time that elapsed between first and last floret opening (Fig. 6). The time to when half the florets of both species had opened was relatively constant as mean temperature decreased, but decreased slightly as irradiance level dropped (Fig. 6). In all treatments for both species, more than half the florets were open before the first floret began to senesce (Figs. 5 and 6). At the highest mean temperature of 17.5°C , florets of both species along with those of *L. ixioideis* at mean temperatures of 7.5 and 12.5°C began to senesce, before all florets had opened. In contrast to floret opening, senescence proceeded at a relatively constant rate once it began. The time taken for 50% of the florets that opened to senesce (vase life) of *L. coquimbensis* increased with decreasing mean temperature and to a lesser degree with increasing irradiance level (range 27 to 53 d). For inflorescences of *L. ixioideis*, vase life decreased as both mean temperature and irradiance level decreased (range 27 to 20 d) (Fig. 6). Data shown in Fig. 6 for the lowest mean temperature of 7.5°C includes a small number of inflorescences with small numbers of florets so for this mean temperature these data may be less accurate than for the two higher mean temperatures.

Discussion

This study shows the timing, productivity and quality of *Leucocoryne* flowers were strongly influenced by temperature and

to a small extent, irradiance level; and there are often several developmental processes occurring at any one time during flower growth and development. Although seedling populations were used in this study, they appear to be quite homogeneous in their responses to temperature and irradiance.

Flowering of the first inflorescence (Figs. 1 and 5) and the number of leaves that emerged before inflorescence emergence (Fig. 4) were affected by temperature, particularly as mean temperature decreased from 12.5 to 7.5 °C. The numbers of inflorescences each species produced (Fig. 3A and B) were also affected in the same manner, although these figures may be underestimated, as there was exceedingly slow growth at the lowest mean temperature of 7.5 °C, and very few plants of *L. ixiooides* particularly, flowered by the time the experiment ended. Mean temperature had less effect on days to leaf emergence (a, Fig. 5) than days to first flowering (e, Fig. 5). Days to leaf emergence were similar at the two highest mean temperatures, but increased by $\approx 20\%$ as mean temperature decreased from 12.5 to 7.5 °C. In comparison, the number of days from planting to first flowering decreased by almost two-thirds for both species as mean temperature increased from 7.5 to 17.5 °C, (e–i, Fig. 5).

Temperature and irradiance also affect quality, and affected ultimate flower stem quality in this current study. The lowest irradiance level produced the tallest scapes, but did not affect their ability to be self-supporting, and increasing mean temperatures increased the number of florets per inflorescence. Irradiance had a variable effect on inflorescence number. The effects of differing irradiance level became more marked in inflorescences of *L. ixiooides* as mean temperature increased (Fig. 3A), and was as influential as an increase in mean temperature from 12.5 to 17.5 °C for both species (Fig. 3A and B). Although *Leucocoryne* umbel shape was also variable in this study, it is not known if temperature and irradiance affects umbel symmetry.

Species differences were also present. Plants of *L. coquimbensis* flowered first, whereas plants of *L. ixiooides* had more leaves at first flowering than *L. coquimbensis*, and plants of *L. ixiooides* produced the best quality inflorescences containing more florets, on the tallest scapes.

No other studies appear to have been published on growth and flowering of *L. ixiooides*, but there have been studies on *L. coquimbensis* and other closely related genera. Studies of *L. coquimbensis* by Ohkawa et al. (1998) found flowering took ≈ 100 d, which is considerably shorter than in the experiment reported here (≈ 145 d). Storage duration and temperature are similar in these two studies, but in the study of Ohkawa et al. (1998), bulbs weighed more (3.0 ± 0.1 g), were stored cooler at 20 °C, and grown under longer daylengths (12.3 to 18.8 h). These different experimental variables may explain some of the disparities between these two studies as other studies on *Leucocoryne* and *Triteleia* have shown they can all affect flowering time. Work by Ohkawa et al. (1997) showed mean storage temperatures above the optimum of 20 °C increased the number of days to flowering. Han et al. (1991) and Wilkins and Halevy (1985) found when *Triteleia laxa* was grown under a 16-h day in contrast to an 8-h day, flowering occurred 4 to 6 weeks earlier. Han (2001) also found days to flowering decreased as the weight of *T. laxa* corms increased, although Kim et al. (1998b) found no significant changes in flowering time as *L. coquimbensis* bulb weight increased over a narrow range of ± 0.2 g above the critical bulb weight of 0.3 g.

Other production figures from the current study were also compared with those of Ohkawa et al. (1998). Plants in the current study produced less inflorescences (≈ 1.9 per bulb compared with

≈ 3.0), and less florets per inflorescence (≈ 5.8 compared with 8 to 8.6). Scape height in this current study was comparable (≈ 400 mm compared with 390 to 490 mm), which is consistent with the findings of Han et al. (1991), who found there was no correlation between scape heights of *T. laxa* and mother corm weights. In the current study, attached scapes continued to elongate after opening of the first floret (Fig. 5e–i). At mean temperatures of 17.5 °C this increase amounted to ≈ 60 mm for *L. coquimbensis*. This same growth, if not more, may have occurred if these stems had been cut, as Elgar et al. (2003) suggested there may be some growth in storage.

There are several possible reasons why flower quality and production levels in the current study differ with those of Ohkawa et al. (1998). The current study shows the number of inflorescences and scape height are affected by irradiance level but Ohkawa et al. (1998) did not specify irradiance levels or whether offsets were left on planted bulbs. Bulbs of *L. coquimbensis* used in the current experiment were more than the minimum critical flowering weight of 0.3 g for *L. coquimbensis* recommended by Kim et al. (1998b). Although critical bulb size is often required for flowering to occur in a range of bulb species (Le Nard and De Hertogh, 1993) this can vary with apical meristem size (Halevy, 1989), and environmental conditions during growth (Han, 2001; Hartsema, 1961). Han (2001) also found as the weight of mother corms of *T. laxa* increased, more inflorescences containing more florets were produced, although over a narrow weight range above the critical bulb weight of *L. coquimbensis*, Kim et al. (1998b) did not find this. There may also have been significant genetic differences in the provenances of *L. coquimbensis* used in each of these two experiments. Such ecological variation is confirmed by Kroon (1989) who found there was a great deal of variation between *Leucocoryne* populations in scape height, the number of inflorescences produced per bulb, and the number of florets per umbel.

The length of time florets on an individual inflorescence stay open before they start to senesce also affects ultimate *Leucocoryne* inflorescence stem quality. Although the inflorescences in this study were left on the plants, some comparisons with the control treatments of Elgar et al. (2003) can be made using those inflorescences grown at a mean temperature of 17.5 °C in this current study (2.5 °C lower than standard vase life temperature conditions). Unlike the findings of Elgar et al. (2003), all florets in an umbel opened in the current study. In the current study, vase life of both *Leucocoryne* species was ≈ 26 to 27 d at the highest PPF level of $710 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (Fig. 6). This is in contrast to the control treatments of Elgar et al. (2003) (9.1 to 9.6 d for *L. coquimbensis*, and 12 d for *L. ixiooides*). Vase life should be longer in non-cut inflorescences, given other comparable opening conditions, therefore, these differences suggest there is potential to improve the vase life of cut inflorescences of *Leucocoryne*. In the current study, onset of senescence in relation to the completion of floret opening, differed with *Leucocoryne* species, but it is unclear if Elgar et al. (2003) found the same dynamics occurring. Senescence is a function of temperature (Wills et al., 1998), therefore it was not surprising in the current study to find that as mean temperature dropped, the dynamics of floret opening and senescence changed, and vase life increased.

In summary, both species of *Leucocoryne* flowered most quickly with good flower quality at the highest mean temperature of 17.5 °C used in this study. Although taking longer to flower, the population of *L. ixiooides* produced better quality flowers. There were further improvements in inflorescence numbers of both species

when plants were flowered at a higher irradiance level, although scape heights decreased. An increase in mean temperature beyond 17.5 °C, may promote more inflorescences per bulb bearing more florets, and further reduce the time to flowering, although the scape height of *L. ixioides* may be compromised. A reduction in flowering time would undoubtedly add to the financial returns of this crop as a minimum of 4.5 months is a considerable period to have an unproductive crop in the ground.

This study also shows that production and quality levels of these two species decrease as mean growing temperature decreases. This may rule out growing this crop under plastic in all but the warmest areas in New Zealand, as planting normally occurs in early winter. Under these conditions during early growth, irradiance levels would be lower than the lowest irradiance level used in this study so yields and quality may be affected. Greater crop protection to increase mean temperature may be another growing option, particularly if there is a considerable reduction in the time to flowering. Another option could be establishment of long-term storage protocols for leucocoryne, to allow production over the warmer, summer months. Dynamic studies of floret opening and senescence may also provide useful information to extend the vase life of cut inflorescences of *Leucocoryne*.

Literature Cited

- Brooking, I.R. 1976. Soilless potting media for controlled-environment facilities. N.Z. J. Expt. Agr. 4:203–208.
- Bryan, J.E. 1989. Bulbs. vol. II, I-Z. Timber Press, H.K.
- Dahlgren, R.M.T., H.T. Clifford, and P.F. Yeo. 1985. The families of the monocotyledons: Structure, evolution, and taxonomy. Springer-Verlag, Berlin.
- Elgar, H.J., T.A. Fulton, and E.F. Walton. 2003. Effect on harvest stage, storage an ethylene on vase life of *Leucocoryne*. Postharvest Biol. Technol. 27:213–217.
- Halevy, A. 1989. Recent advances in control of flowering and growth habit of geophytes. Acta Hort. 266:35–42.
- Han, S.S. 2001. Flowering of three species of *Brodiaea* in relation to bulb size. Scientia Hort. 91:349–355.
- Han, S.S., A.H. Halevy, R.M. Sachs, and M. Reid. 1991. Flowering and corm yield of *Brodiaea* in response to temperature, photoperiod, corm size and planting depth. J. Amer. Soc. Hort. Sci. 116:19–22.
- Hartsema, A.H. 1961. Recent advances in control and flowering and growth habit of geophytes. Acta Hort. 266:35–42.
- Hoffman, A.E.J. 1989. Chilean monocotyledonous geophytes taxonomic considerations and their state of conservation. Herbertia 45:13–29.
- Kim, H.H., K. Ohkawa, and E. Nitta. 1998a. Fall flowering of *Leucocoryne coquimbensis* F. Phil. after long-term bulb storage treatments. HortScience 33:18–20.
- Kim, H.H., K. Ohkawa, and E. Nitta. 1998b. Effects of bulb weight on the growth and flowering of *Leucocoryne coquimbensis* F. Phil. Acta Hort. 454:341–346.
- Kroon, G.H. 1989. Evaluatie van *Leucocoryne* als nieuwe snijbloem. Prophyta 43:15–16.
- Lancaster, J.E., M.L. Shaw, and E.F. Walton. 2000. S-Alk(en)yl-L-cysteine sulphoxides, alliinase and aroma in *Leucocoryne*. Phytochemistry 55:127–130.
- Le Nard, M. and A.A. De Hertogh. 1993. Bulb growth and development and flowering, p. 29–43. In: A.A. De Hertogh and M. Le Nard (eds.). The physiology of flower bulbs. Elsevier Sci. Publ. Co., Amsterdam, The Netherlands.
- McCree, K.J. 1972. Test of current definitions of photosynthetically active radiation against leaf photosynthesis data. Agr. Meteorol. 10: 443–453.
- McKenzie, R.J. and P.H. Lovell. 1992. Flower senescence in monocotyledons: a taxonomic survey. N.Z. J. Crop Hort. 20:67–71.
- Monteith, J.L. and M.H. Unsworth. 1990. Principles of environmental physics. p. 38. 2nd ed. Edward Arnold, London.
- Ohkawa, K., H.H. Kim, E. Nitta, and Y. Fukazawa. 1998. Storage temperature and duration affect flower bud development, shoot emergence, and flowering of *Leucocoryne coquimbensis*. J. Amer. Soc. Hort Sci. 123:586–591.
- Ohkawa, K., E. Nitta, Y. Fukazawa, and H.H. Kim. 1997. Effects of storage temperature and time on flower bud development, emergence and flowering of *Leucocoryne coquimbensis*. Acta Hort. 430:427 (abstr.).
- Payne, R.W., P.W. Lane, P.G.N. Digby, S.A. Harding, P.K. Leech, G.W. Morgan, A.D. Todd, R. Thompson, G. Tunncliffe Wilson, S.J. Welham, and R.P. White. 1993. Genstat 5 reference manual. vol. release 3. Oxford Univ. Press, Oxford, U.K.
- Rundel, P.W. 1981. The matorral zone of central Chile, p. 175–201. In: di Castri, F., D.W. Goodall, and R.L. Specht (eds.). Ecosystems of the world 11: Mediterranean-type shrublands. Elsevier Sci. Publ. Co., Amsterdam, The Netherlands.
- SAS Institute. 1993. SAS/STAT user's guide. version 6. 4th ed. SAS Inst., Cary, NC.
- Uphof, J.C. 1945. *Leucocoryne* and related genera of South America. Herbertia 12:52–67.
- van Leeuwen, P.J. 1992. Effects of storage temperature on bulb growth and flowering of *Leucocoryne* sp. 6th Intl. Symp. Flower Bulbs:156 (abstr.).
- Wilkins, H.F. and A.H. Halevy. 1985. *Triteleia laxa*, p. 415–417. In: A.H. Halevy (ed.). CRC Handbook of flowering. vol IV. CRC Press, Boca raton, Fla.
- Wills, R., B. McGlasson, D. Graham, and D. Joyce. 1998. Effects of temperature, p. 60–76. In: Postharvest. An introduction to the physiology & handling of fruit, vegetables & ornamentals. 4th ed. Hyde park Press, Adelaide, Australia.