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Sprouting Temperature and Growth Regulators Influence Cut Flower Quality of *Sandersonia aurantiaca*

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Abstract. **Tubers of *Sandersonia aurantiaca* Hook. were soaked in 1000 mg·L^{-1} GA$_3$, 20 mg·L^{-1} uniconazole, 200 mg·L^{-1} benzyladenine, or water for 2 hours and then sprouted at 12, 18, or 24 °C. The effects of these treatments on flower stem quality were then determined at forcing temperatures of 18, 24, or 30 °C. Stem length increased with sprouting temperature only at a forcing temperature of 18 °C. Floret numbers increased with sprouting temperature at all forcing temperatures, but the effect was greatest at the 18 °C forcing temperature. The 12 °C sprouting treatment reduced floret numbers at all forcing temperatures. Soaking tubers in GA$_3$ increased stem length but drastically reduced floret numbers, while soaking in uniconazole reduced stem length but had no significant effect on floret numbers. Soaking in BA strongly promoted branching, which resulted in large increases (>30%) in floret numbers per stem with little change in stem length. Of the three growth regulators, only BA was effective in improving cut flower stem quality. Chemical names used: gibberellic acid (GA$_3$); (E)-(+)-(S)-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)-pent-1-ene-3-ol (uniconazole); *N*$_6$-benzylamino purine (benzyladenine; BA).**

The summer-flowering, tuberous perennial *Sandersonia aurantiaca* Hook. (Colchicaceae) is being cultivated as a new cut flower crop in a number of countries, including New Zealand and Japan. The fork-shaped tuber of this species has a growing point at the end of each fork and the tuber is divided before sprouting to encourage uniform sprouting from both forks (Brundell and Reyngoud, 1985). The emerging shoot develops rapidly into a thin stem up to 90 cm tall. Bright orange bell-shaped florets are suspended on pedicels from nodes on the stem. Typically, there is one floret per node and florets appear from about the 10th stem node. Branches can appear on the stem and also bear florets. The length of the stem and the number of florets on the stem are important flower quality parameters in sandersonia, and branching is desirable as this increases the number of florets, enhancing the visual contrast of orange florets against the bright-green foliage.

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Currently, efforts are being made to produce sandersonia cut flowers on a year-round basis using protected cultivation, but little information on the environmental control of flower quality is available to guide growers in selecting growing conditions. In commercial practice in New Zealand, tubers are sprouted in a warm environment before planting when subsequent growing temperatures are cool (e.g., winter). This practice promotes rapid and uniform shoot emergence from cool soil, although the effects of sprouting temperature on flower stem quality under cool growing temperatures have not been studied. Clark (1994) found that stem length and floret number per stem were similar after tubers were sprouted at 20, 23, or 26 °C and then grown in a greenhouse over spring and summer. Little is known about the timing of flower initiation in sandersonia. The growing point in the dormant tuber is vegetative, and consists of two bract and two leaf initials. By the time the new shoot from the sprouted tuber reaches the soil surface, up to 12 new primordia, including flower primordia, have formed (Brooking, unpublished data). The initiation and early expansion of many floral and stem structures must therefore begin during sprouting or soon after, and we hypothesized that environmental and cultural treatments applied at sprouting time would influence stem length and number of florets per stem. The sprouting period could be an effective time to apply treatments to improve flower quality.

The objectives of this study were to: a) determine if temperature during tuber sprouting affected cut flower stem quality parameters and whether there were interactions between sprouting temperature and subsequent growing temperature; and b) determine if the growth regulators gibberellic acid, uniconazole, and benzyladenine applied as tuber soaks at sprouting time affected cut flower stem quality. Gibberellic acid (GA$_3$) was selected because it promotes stem elongation in many plants, including *Lilium* (Zieslin and Tsujita, 1988). It also can promote flower initiation in some plants, for example, orchids (Chen et al., 1994) and other ornamentals (Harkness and Lyons, 1994; Henny and Hamilton, 1992), and is used commercially to increase the number of flowers produced by *Zantedeschia* tubers (Funnell, 1993). For comparative purposes uniconazole was included in the study, as some of the physiological effects of this regulator are the opposite of those of GA$_3$. Uniconazole, an inhibitor of gibberellin biosynthesis, can retard stem elongation in many ornamental plants (Barrett and Nell, 1992), including *Lilium* (Bearce and Singha, 1990). Benzyladenine (BA) was the third growth regulator tested, as this compound can promote branching in a very wide range of plants (Imamura and Higaki, 1988; Keever and Foster, 1990), and we anticipated that it might increase branching and floret numbers in sandersonia.

Materials and Methods

Tuber material. Tubers of 7- to 10-g grade, which had been chilled at 4 °C for 12 weeks to break dormancy (Clark, 1994), were received from a commercial supplier on 23 Aug. 1993. After 2 weeks further storage at 4 °C, the tubers were divided (pieces >4 g each) and dipped in an aqueous fungicidal solution containing 0.25 g·L^{-1} methyl-1-(butylcarbamoyl)-2-benzimidazole (benomyl) and 1.6 g·L^{-1} bisdimethyl-thiocarbamoyl disulfide (thiram) for 2 min before being air-dried for 18 h at room temperature (20 °C).

Experimental design. The experiment had a sequential treatment structure. In the first part, a set of 16 sprouting treatments was applied to the tuber pieces. Twelve of the treatments were factorial in structure, with three sprouting temperatures × four growth regulator soaks. Four additional treatments resulted from growth regulator application towards the end of sprouting in the 24 °C sprouting treatment only. In the second part of the experiment, sprouted tubers from each of the 16 sprouting treatments were allocated to one of three forcing temperature treatments. These 16 treatments were set out as a randomized incomplete-block design with three replicates per treatment and a block size of eight plots. Each block was represented by a single trolley and each trolley had five rows of four pots with one row as a guard row. Trolleys were arranged in pairs so that the guard rows were always on the outside. A plot consisted of two pots with three plants per pot.

Sprouting treatments. Soaking treatments were applied either at the start of sprouting (early soaking) or at the end of sprouting (late soaking). The growth regulator concentrations were selected in a small-scale preliminary

experiment with many concentrations. From this preliminary work we were able to select concentrations at which the regulators modified stem characteristics without producing floral or foliar abnormalities. The early soaking treatment consisted of immersing freshly cut tuber pieces for 2 h in the following aqueous growth regulator solutions: 1000 mg·L^{-1} GA_3 (GroCel; Crop Care Holdings Ltd., Nelson, New Zealand), 20 mg·L^{-1} uniconazole (Sumagic; Shell, Auckland, New Zealand), 200 mg·L^{-1} BA (ABG-3062, Abbott Laboratories, N. Chicago, Ill.), or tap water control, all with 0.1% wetting agent (Multi-Film X-77; Ivon Watkins-Dow Ltd., New Plymouth, New Zealand) added. Soaking was carried out at room temperature (20 ± 3 °C). After the early soaking, the tuber pieces were drained for 5 min before being sprouted at a constant 12, 18, or 24 °C. In addition, nonsoaked tubers were exposed to the 24 °C sprouting treatment (ST); on the 8th d of sprouting, these previously nonsoaked tubers were subjected to a late soaking treatment using the same protocols as in the early soaking. Sprouting took place in 10-L plastic buckets between layers of moistened sphagnum. The buckets were sealed in polyethylene bags and placed at constant temperatures of 12, 18, or 24 °C. At intervals of 2 to 3 d, five tuber pieces from the water control at each temperature were dissected under a binocular microscope to monitor the course of primordia initiation at the shoot apex. Sprouting treatments were terminated when there were an average of nine primordia (2 bract + 7 leaf) present on the shoot apex and root initials were visible. This occurred after 10, 14, and 25 d at 24, 18, and 12 °C, respectively.

Growing conditions. Sprouted tuber pieces were planted in a 1 peat : 1 pumice : 1 gravel medium in 1.25-L plastic pots. The medium was amended with 3 g·L^{-1} three-month Osmocote (14N–6.1P–11.6K), 6 g·L^{-1} nine-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). The plants were then transferred to three controlled-environment (CE) rooms at the HortResearch National Climate Laboratory at Palmerston North. Forcing temperatures (FT) were 18, 24, or 30 °C. The vapor pressure deficit was 0.7 kPa in all rooms. Daily lighting consisted of a 12-h main light period at 700 μmol·m^{-2}·s^{-1} photosynthetic photon flux (*PPF*) at pot level plus daylength extension at 8 μmol·m^{-2}·s^{-1} *PPF* for 1 h each side of the main light period. The high *PPF* was supplied by four 1000-W Sylvania 'Metalarc' high-pressure discharge lamps and four 1000-W quartz-halogen lamps and the low *PPF* by four 150-W incandescent lamps. The plants were on six trolleys in each room and the position of the trolleys was changed twice per week. Each plant was irrigated to excess daily with modified Hoagland's nutrient solution (Brooking, 1976). The elongating flower stems were supported with plastic netting attached 40 cm above pot height.

Data collection. Flower stems were harvested once the two oldest florets on the stem were fully reflexed. At harvest the following eight parameters were recorded: number of days from planting to flower harvest, stem length from the surface of the growing medium to the shoot apex, height of first (lowest) leaf and height of first (lowest) floret on the stem as measured from the medium surface, node (leaf position) of first floret, number of branches on the stem, total florets on the stem (counts of florets on the main stem plus counts of florets on branches), and the number of leaves on the main stem.

Data analysis. All data were collected on an individual plant basis but plot means were calculated prior to analysis. The data were analyzed using the GLM procedure in SAS (SAS Institute, 1990) and two separate combined analyses were performed: a) three STs × three FTs × four growth regulators applied at the start of sprouting; and b) four growth regulators × two application times (24 °C, ST only) × three FTs. Count variables were log-transformed before analysis. Treatment effects were compared using appropriate least significant difference (LSD) values computed at 5% significance level. Data on the percentage of branched stems were analyzed using a generalized linear model with binomial error and logit link (SAS Institute, 1993) and again two combined analyses were performed.

Results and Discussion

Sprouting and forcing temperature effects. Sprouting temperature effects were statistically analyzed using combined analysis (a). Stem length was affected by ST only at the 18 °C FT (Fig. 1a); the flower stems became longer as ST increased, with stems in the 24 °C ST being 10 cm longer than in the 12 °C treatment (Fig. 1a). For stem length, the interaction between ST × FT was significant ($P \leq 0.05$) (Table 1).

Forcing temperature had a much larger effect on stem length than did ST, largely due to the inhibitory effect of the 30 °C FT on growth. At 30 °C the stems were very short (Fig. 1a), leaves and florets were small and distorted, and green parts became bleached, indicating that the combination of high temperature and high light was too severe for the successful culture of sandersonia.

The effects of ST on the height of the first leaf were small and restricted to the 18 °C FT (data not shown); the first leaf was significantly higher (2.5 cm) on the stem in the 24 °C ST than in the 12 °C treatment. There was a high degree of constancy in the nodal position of the first floret in this study; 78% of all flower stems harvested had their first floret at node 10 ± 1 and ST had no significant effect on this parameter.

The main effect of sprouting temperature on floret numbers was very highly significant (Table 1). Total floret numbers per stem were higher after sprouting at 18 or 24 °C than at 12 °C at all FTs (Fig. 1b), although the effects of ST were greatest at the 18 °C FT. At the 18 °C FT there were on average 4.5 more florets per stem after sprouting at 24 °C than at 12 °C. Three of these extra 4.5 florets were on the main stem. There were three more leaves on the main stem in the 24 °C ST (leaf number data not shown), so the increase in floret numbers was associated with an increase in the number of axillary sites available for floret initiation.

The percentage of stems with branches was higher in the 18 and 24 °C ST than in the 12 °C treatment (Fig. 1c) and chi square analysis showed that this effect of ST was significant ($P \leq 0.05$). Sprouting temperature had a small effect on floret numbers via branching. There were on average three florets per branch and the extra branching in the 18 and 24 °C STs relative to the 12 °C treatment was sufficient to add one floret to the total florets per stem.

Sprouting temperature had a small but significant effect ($P \leq 0.05$) on the number of days from planting to harvest. Under 18 °C FT plants from the 12 °C ST took 3 d longer to flower than did plants from the 24 °C ST, but the difference became smaller as FTs became warmer. Time of flower harvest at FTs of 18, 24, and 30 °C averaged 57, 41, and 52 d, respectively.

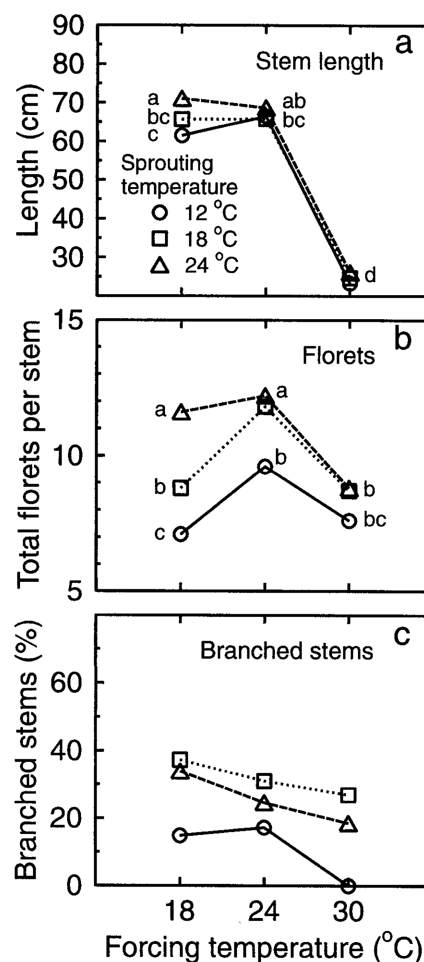

Fig. 1. Effects of three sprouting temperatures and three forcing temperatures on (**a**) stem length, (**b**) number of florets per stem and (**c**) percentage of branched stems in sandersonia. In Fig. 1 a and b all means were compared by LSD ($P \leq 0.05$) and means with the same letter do not differ significantly.

Table 1. Significance of main effects and of interactions between sprouting and forcing temperature treatments and growth regulator and time of application treatments on flower stem parameters in sandersonia as derived from two statistical analyses.

	Analysis 1[z]			Analysis 2[y]			
Parameter	Sprouting temp (STemp)	Forcing temp FTemp	STemp × (FTemp)	Growth regulator (GReg)	Application time (ApTime)	GReg × FTemp	GReg × ApTime
Stem length	***	***	*	***	*	***	***
Total florets per stem	***	***	NS	***	*	NS	NS
Height of first leaf	*	***	NS	***	***	***	**
Height of first floret	NS	***	NS	***	*	***	***
Node of first floret	NS	*	NS	***	*	NS	***
Number of leaves	**	***	*	***	*	NS	**
Days to flower harvest	*	***	NS	***	***	***	***
Percent branched stems	*	NS	---[x]	***	NS	---	---

[z]Three sprouting temperatures × three forcing temperatures × four growth regulator treatments applied at the start of sprouting.
[y]Three forcing temperatures × four growth regulators × two application times at 24 °C sprouting temperature.
[x]Not evaluated.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Warm STs clearly promoted organogenesis in sandersonia, resulting in an increase in the number of leaves, florets, and branches produced. Our results parallel those obtained in *Gladiolus*, another summer-growing geophyte of South African origin, in which warm STs also promote shoot bud growth and differentiation (Cohat, 1993).

Flower quality standards in New Zealand prescribe that high-quality sandersonia stems have to be longer than 70 cm and bear >10 florets, and that commercial value rises with increments of 10 cm in stem length and of three in florets per stem. In this quality context, our results are commercially significant as they show that ST can modify floret numbers by four to five per stem and stem length by 10 cm. The lowest ST (12 °C) reduced flower stem quality based on floret numbers at all FTs, indicating that cool ST should be avoided in the culture of sandersonia. However, in general, the largest ST effects on quality were seen at the lowest FT (18 °C). Under these cool growing conditions, the highest quality stems in terms of length and floret numbers were obtained from the warmest ST (24 °C) and, further, after sprouting at 24 °C the quality of stems produced at 18 °C FT was as high as that of stems produced at 24 °C FT.

Growth regulator effects. Growth regulator effects were statistically analyzed using combined analysis (b), and significant effects were recorded on all measured parameters. For four parameters the interaction between FT and growth regulator was significant (Table 1) because, in general, the growth regulators had small effects at the inhibitory 30 °C FT and much larger effects at both the 18 and 24 °C FTs (Fig. 2). Sprouting temperature × growth regulator interactions were generally smaller and less significant than FT × growth regulator interactions and are not reported here. Time of growth regulator application had small but significant effects on most parameters and there were significant growth regulator × application time interactions (Table 1).

Soaking the tuber in GA_3 increased stem length by 20 cm at the 18 and 24 °C FT (Fig. 2a), but the effect was confined to the lower internodes, as evident in the changes in heights to the first leaf and first floret on the stem (Fig. 2 d and e). The stem elongation response to GA_3 was greater after late than after early soaking (Fig. 3a). The GA_3 soaks reduced the number of florets on the stem by about five (Fig. 2b), with late-forming florets high on the stem being most affected. This effect was related partly to a reduction in the number of leaves (axillary sites for florets) on the main stem, partly to reduced floret initiation, as there were empty axillary sites high on the main stem, and partly to the absence of branches (Fig. 2c) and therefore florets on branches. Early soaking reduced floret numbers more than did late soaking (Fig. 3b). Flower harvest was also delayed by up to 10 d (Fig. 2f), an effect related to slow floret development. Not all GA_3 effects on floret production were del-

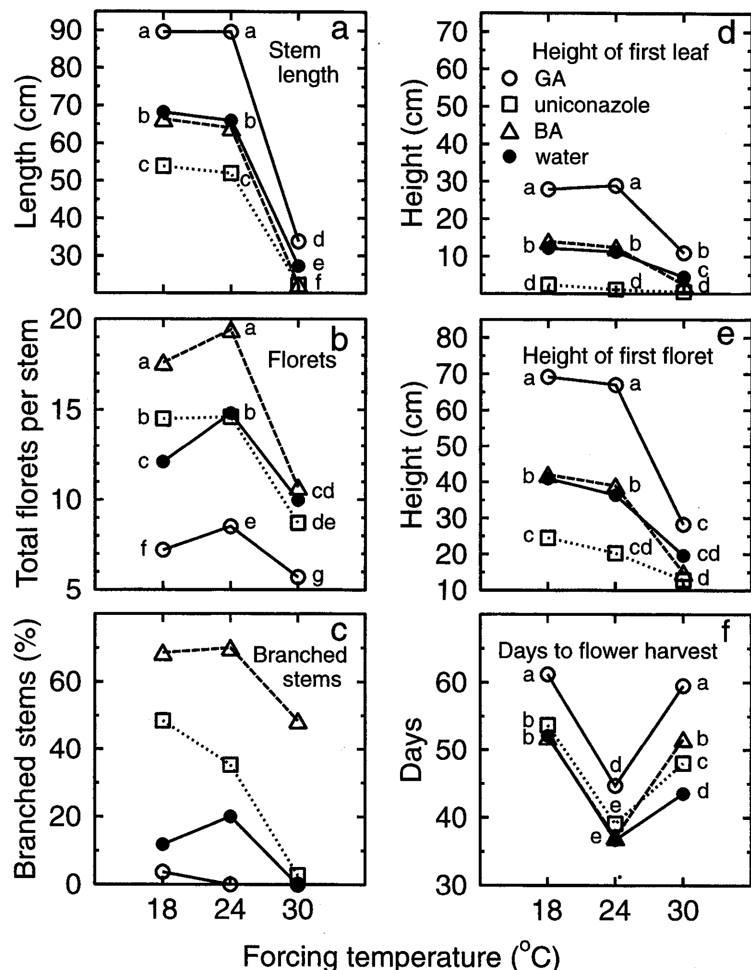

Fig. 2. Effects of GA_3, uniconazole, and BA on (**a**) stem length, (**b**) number of florets per stem, (**c**) percentage of branched stems, (**d**) height of the first leaf, (**e**) height of the first floret and (**f**) days to flower harvest in sandersonia at three forcing temperatures. The values shown are averaged over two application times. All means were compared by LSD ($P \leq 0.05$) within parameters and means with the same letter do not differ significantly.

eterious, however, as after early soaking the first floret appeared at the eighth node on the stem, two nodes lower than in all other treatments (Fig. 3c). Thus, GA_3 promoted the initiation of early florets at nodal positions where they do not normally form, while inhibiting the initiation of late florets.

On balance, the GA_3 soak did not improve flower stem quality of sandersonia, as it promoted stem growth at the expense of floret initiation. The antagonism between stem growth and floret initiation might have been reduced had a lower concentration of GA_3, a shorter soaking period, or a different gibberellin been tried. The recent availability of new 'designer' gibberellins that promote flowering more strongly than vegetative growth (Mander et al., 1995) offers possibilities. In *Gladiolus* both stem length and floret numbers per spike can be increased by applying GA_3 as a soil drench or foliar spray to young plants close to the time of floral initiation (Bhattacharjee, 1984; Dua et al., 1984). In Iris

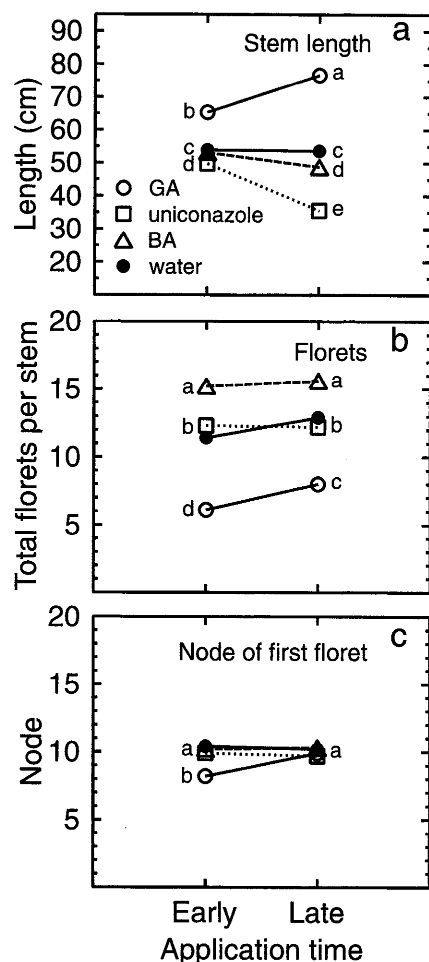

Fig. 3. Effects of early and late tuber soaks in GA_3, uniconazole, and BA on (**a**) stem length, (**b**) number of florets per stem and (**c**) the nodal position of the first floret in sandersonia sprouted at 24 °C. The values shown are averaged over three forcing temperatures. All means were compared by LSD ($P \leq 0.05$) within parameters and means with the same letter do not differ significantly.

both stem growth and floral development can be promoted concurrently using bulb soaks of GA_3 (Sano, 1975).

Uniconazole soaks reduced stem length by up to 15 cm (Fig. 2a) and the effect was restricted to the lower internodes on the stem. The height to the first leaf and first floret was reduced by 10 and 15 cm, respectively (Fig. 2 d and e) and the effect was stronger following late application (Fig. 3a). The growth regulator did not alter the distribution of florets on the main stem, as the florets were distributed along the top 30 cm as in the control treatment (water soaked). Total florets per stem were affected by uniconazole only at the 18 °C FT where there was an increase of about three florets per stem (Fig. 2b), (significant at $P \leq 0.05$). The extra florets at the 18 °C FT were on the additional branches obtained (Fig. 2c), not on the main stem (data not shown). Uniconazole had little effect on other measured parameters.

The uniconazole soaks did not improve overall quality, for the increase in floret numbers did not compensate for loss of stem length. However, uniconazole treatment produced a short plant with foliage lowered to the level of the medium surface and the lowest floret at a height of only 25 cm. Sandersonia was thereby transformed into a compact, flowering pot plant. Uniconazole applied as a tuber/bulb soak is also very effective in reducing flower stem length in *Lilium* (Bearce and Singha, 1989) and *Zantedeschia* (Funnell, 1993).

Benzyladenine strongly promoted branching and increased floret numbers but had little effect on other measured parameters. After BA treatment 70% of the stems had branches, compared with 12% to 20% in the water control (Fig. 2c; 18 and 24 °C FTs). In the water control, only 9% of branched stems had two branches, whereas after BA treatment 28% of branched stems had two branches and 4% had three branches (data averaged over all FTs). Greater branching resulted in an increase of about five in total florets per stem (Fig. 2b), as the extra florets were on the branches and not on the main stem. Benzyladenine had little effect on floret numbers at the 30 °C FT; although branching was affected, the number of florets per branch was reduced to less than one. Applications of BA at the start or end of sprouting were equally effective in increasing total floret numbers per stem (Fig. 3b).

Our results show that flower stem development in sandersonia is sensitive to both temperature and growth regulator treatments at sprouting time and that a wide range of stem characteristics can be modified. This sensitivity is consistent with the observation that many flower and stem structures are being initiated at sprouting time. Treatments applied at different times provided indirect evidence that the various stem structures are initiated at different times during sprouting. For example, GA_3- and uniconazole-induced modifications of stem length were more significant after late application, which suggests that stem internode growth starts late in the sprouting period. However, GA_3-induced lowering of the nodal position of the first floret (Fig. 3c), occurred only after early application, suggesting that floral induction occurs earlier in the sprouting period.

Conclusions

We conclude that the sprouting period is an effective time to apply treatments for improving flower stem quality in sandersonia and, further, that we have identified two treatments capable of increasing quality. Warm STs improved quality by increasing floret numbers and were most effective at cool FTs when stem length was also increased. By sprouting tubers at 24 °C, high-quality stems were produced at 18 °C FT. The implications for greenhouse production of sandersonia flowers in cool seasons is that less heating will be required to produce high-quality stems if tubers are sprouted at warm temperatures before planting. The 18 °C growing conditions used in this experiment are, however, relatively mild and further work is needed to determine the coolest FT that can still produce high flower stem quality after warm sprouting. Benzyladenine was the only growth regulator to improve flower stem quality, and it did so by promoting branching, which increased floret numbers. Further evaluation of benzyladenine as a tuber soak for improving stem quality appears warranted. Use of GA_3 and uniconazole as tuber soaks had both positive and negative effects on a range of parameters, but, on balance, neither regulator improved cut flower stem quality. Uniconazole soaks did, however, produce compact and attractive plants, indicating their potential for use in developing sandersonia as a flowering pot plant.

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