Horticulture, Environment, and Biotechnology (2019) 60:357–362
https://doi.org/10.1007/s13580-019-00124-w

RESEARCH REPORT

# Storage and growth temperatures affect growth, flower quality, and bulb quality of *Hippeastrum*

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Received: 6 March 2017 / Revised: 13 December 2018 / Accepted: 8 January 2019 / Published online: 17 May 2019

## Abstract

The effects of storage and growth temperatures on growth, flower quality, and bulb quality of *Hippeastrum* sp. were studied. Bulbs of *Hippeastrum* sp. 'Apple Blossom' with circumferences in the range of 22–24 cm were selected and stored for 12 weeks at one of three different temperatures (i.e., room temperature [RT: 30 ± 2 °C], 13 ± 2 °C, and 15 ± 2 °C). After storage, the bulbs were grown in a growth chamber at one of three growth temperatures—that is, RT (30 ± 2 °C), 15 ± 2 °C, and 25 ± 2 °C. The results showed that storing bulbs at RT for 12 weeks reduced their quality in terms of fresh weight, diameter, and firmness, whereas storing bulbs at 13 °C or 15 °C retained their quality in terms of fresh weight and firmness. Electron scanning imaging of the starch granules in the bulb scales showed that prior to storage, the leaf base cells were filled with large starch granules of either lenticular shape or spherical shape. After storing for 12 weeks at RT, the starch granules in the bulb scales were sharply reduced in number and were predominantly of the small, spherical form. A growing temperature of 25 °C could stimulate better growth with respect to plant height, flower diameter, bulb diameter, bulb fresh weight, and bulb dry weight, compared with RT (30 °C). A significant interaction between storage and growing temperatures was found for all parameters except for stalk length. A bulb storage temperature of 15 ± 2 °C for 12 weeks combined with a growing temperature of 25 ± 2 °C produced the best results for both flower and bulb production.

**Keywords** Amaryllis · Day to flowering · Bulb firmness · Starch granules · Respiration rate

## 1 Introduction

*Hippeastrum* sp., commonly known as Amaryllis, is commercially used as a potted plant and for cut flowers. It is a geophyte native to South America, whereas the true genus *Amaryllis* is native to Africa. This plant is highly valued in international markets, especially in winter time. Brazil produces about 17 million bulbs per year for marketing, of which 60% is exported worldwide (Tombolato et al. 2013). The flowering of *Hippeastrum* is regulated by bulb size, and the plant does not require low temperatures for flower initiation. However, since floral initiation alternates with leaf formation, flowering may become poor when the plant is grown at high temperatures (23–27 °C). Doorduin and Verkerke (2002) reported that bud desiccation occurs when grown at high temperature. A 'forcing' program is carried out after bulb harvest, where the bulbs are quickly dried and then stored at 13 °C for at least 8–10 weeks or at 5–9 °C for a longer period (Okubo 1993; Tombolato et al. 2013). The storage temperature of the bulb affects flowering and shoot emergence. However, growth and storage temperatures can vary between growers and countries (Kuehny and Miller 2008). Moreover, many studies have reported that cold treatment mainly affects the conversion of starch into mobile sugars that supply carbohydrates for rapid shoot growth and normal flowering during the short interval between sprouting and flowering (Moe and Wickstrom 1973, 1979; Charles-Edwards and Rees 1974, 1975; Davies and Kempton 1975; Haaland and Wickstrom 1975).

Although, there have been many reports on the effect of temperature on *Hippeastrum* growth, few studies have explored the interaction between the effects of storage

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temperature and growth temperature on the growth, flowering quality, and bulb quality of this plant. Therefore, in the current report, the effects of storage and growth temperatures on growth, flower quality, and bulb quality will be investigated.

## 2 Materials and methods

*Hippeastrum* 'Apple Blossom' bulbs were harvested from a field, and bulbs with circumferences ranging from 22 to 24 cm were selected, cleaned, and kept for 12 weeks at different storage temperatures—that is, room temperature (RT: 30 ± 2 °C), 13 ± 2 °C, and 15 ± 2 °C. After storage, the bulbs were grown in a growth chamber (tissue and plant growth chamber model 620 RHS P6, Contherm Scientific) at one of three growth temperatures—that is, RT (30 ± 2 °C), 15 ± 2 °C, and 25 ± 2 °C—under 80% relative humidity (RH), 270 µmol $m^{-2}$ $s^{-1}$ of photosynthetic photon flux (PPF), and 13 h of photoperiod in growing media of 1:2 ratio of perlite and vermiculite and watered with tap water once a day. After shoot emergence, 5 g per pot of slow release fertilizer (13–13–13) were fed to the plants. The experimental design was completely randomized, with 3 × 3 factorial treatments and three replications per treatment. Plant growth and development—that is, the plant height in cm, number of leaves per plant, flower quality, and bulb quality—were measured. The quantity of starch granules in the bulbs after 12 weeks of storage was determined using a scanning electron microscope. Bulb respiration was determined by a $CO_2$/$O_2$ MAP Headspace gas analyzer (Model 900141, Bridge) at 6 and 12 weeks of storage. The total non-structural carbohydrate content was analyzed (Smith et al. 1964), and the reducing sugar content was analyzed by Nelson's reducing sugar procedure (A.O.A.C. 1990).

The bulbs from each treatment were sampled for plant nutrient analysis before storage and after harvest. Nitrogen (N) was determined by the indophenol method (Ohyama et al. 1986), phosphorus (P) was determined by colorimetry (Ohyama et al. 1991), and potassium (K) was determined by atomic absorption spectrophotometry (Mizukoshi et al. 1994).

## 3 Results and discussion

Bulb storage at RT for 12 weeks did not produce desirable results with respect to bulb fresh weight (average 190.4 g), diameter (average 6.6 cm), and firmness (average 38.5 N), compared with pre-storage conditions, whereas bulb storage at 13 °C and 15 °C retained bulb quality in terms of fresh weight and firmness (Table 1). Bulbs stored at RT for 12 weeks lost a greater proportion of their original weight (13.71%), compared with bulbs stored at 13 °C and 15 °C (5.13% and 5.58%, respectively) (Fig. 1). The greater weight loss at RT might be due to increased transpiration rates at the higher temperature. Bulb storage at 15 °C resulted in taller plants than bulb storage at 13 °C, whereas flower quality and bulb quality were not significantly different between treatments (Table 3). At 6 weeks after storage (WAS), bulbs stored at RT had a higher respiration rate than bulbs stored at 13 °C and 15 °C (Fig. 2). Since respiration increases with

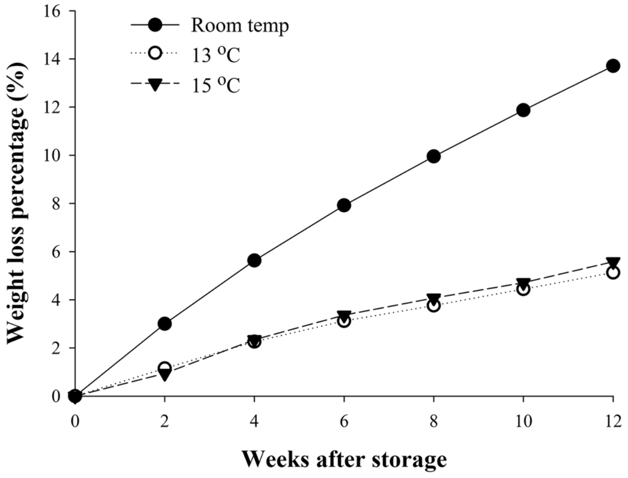

**Fig. 1** The proportion of weight loss of *Hippeastrum* bulbs during storage at different temperatures for 12 weeks

**Table 1** Bulb quality of *Hippeastrum* after storage for 12 weeks at different temperatures

| Storage temperature (°C) | Bulb fresh weight (g) | Bulb dry weight (g) | Bulb diameter (cm) | Bulb firmness (N) |
|---|---|---|---|---|
| Before storage | 230.9a | 23.7 | 7.8a | 39.3ab |
| RT | 190.4b | 22.4 | 6.6c | 38.5b |
| 13 ± 2 °C | 203.8ab | 23.4 | 7.3b | 42.0a |
| 15 ± 2 °C | 208.9ab | 24.2 | 7.3b | 40.9ab |
| LSD ($p \geq 0.05$) | 28.48 | NS | 0.4 | 2.8 |

Means within the same column followed by different letters are significantly different; ($p \geq 0.05$)

*NS* not significant, *RT* room temperature; *N* newton, *LSD* least significant difference

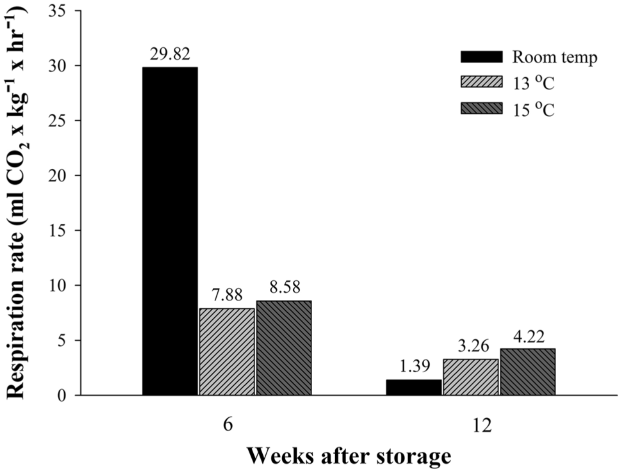

**Fig. 2** The respiration rate of *Hippeastrum* bulbs after storage at different temperatures for 6 and 12 weeks

temperature (Platenius 1942), the increased weight loss in bulbs stored at high temperatures in this study may be due to either respiration or water loss, although it was observed that the weight of the dry matter did not change. Rattanapanone and Boonyakiat (2005) have reported that low temperatures can reduce the respiration rate and the carbohydrate consumption in addition to inducing a reduction in the sugar accumulation, whereas high temperatures induce growth and development as well as senescence. In addition, the high temperature brought about increased respiration rate and decreased photosynthetic rate, although causing low bulb growth rate (Ijira and Ogata 1997). However, at 12 WAS, the respiration rate of the bulbs stored at RT was lower than that of the bulbs stored at 13 °C and 15 °C (Fig. 2).

Figure 3 shows the electron scanning images of the *Hippeastrum* bulb scales. Prior to storage, the scale cells were filled with large starch granules of either lenticular or spherical shape (Fig. 3a). After 12 weeks of storage at RT, the starch granules were sharply reduced in number and were predominantly small and spherical in shape (Fig. 3b). At the same time, the starch granules in the bulbs stored at 13 °C and 15 °C remained virtually unchanged in number, were larger than before storage and were predominantly spherical in shape, although some were distinctly elongated (Fig. 3c, d). Cabálková et al. (2008) reported that small granules likely represent transitory starch—that is, the product of recent photosynthesis soon to be mobilized for use elsewhere in the plant. The large granules were oval in shape. The largest granules were either elongated spheroids or, rarely, asymmetrical and likely represented reserve starch. Similar results were obtained by Ohyama et al. (1988) who reported that two types of starch granules were observed in the planting bulb scales and that the small granules (with a spherical shape) were utilized earlier than the large granules (with a lenticular shape) during winter. In this experiment, it was demonstrated that at low temperatures (13 °C and 15 °C), starch granules in bulb scales represented reserve

**Fig. 3** The changes in the starch granules of *Hippeastrum* bulbs after storage at different temperatures for 12 weeks, observed using scanning electron microscopy (**a** before storage; **b** stored at room temperature; **c** stored at 13 °C; and **d** stored at 15 °C)

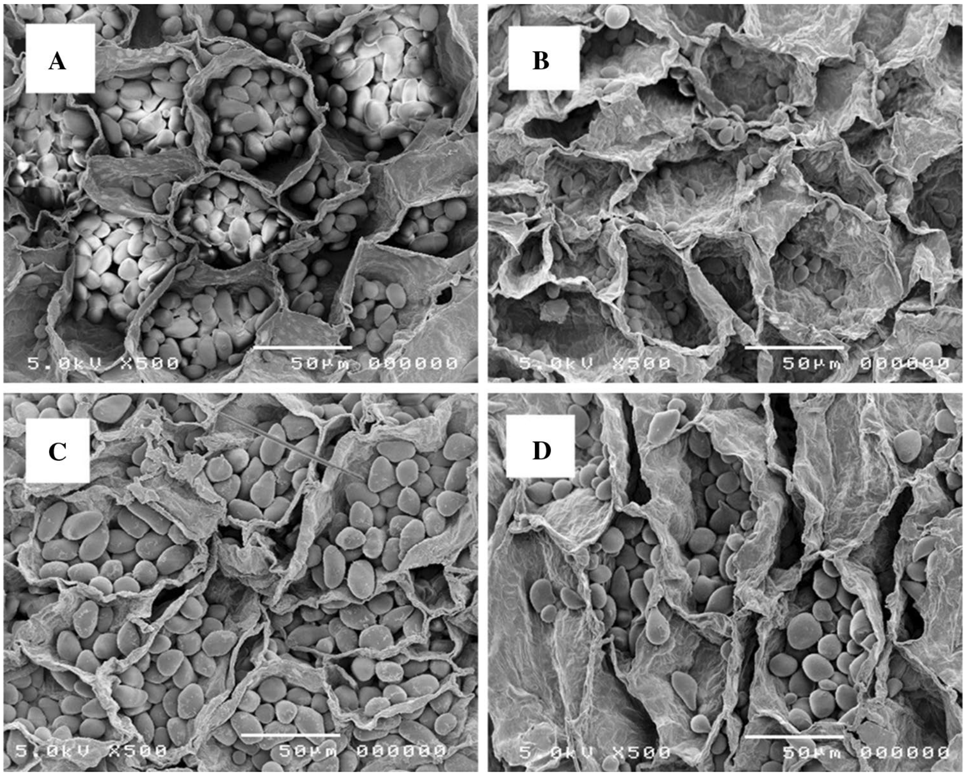

**Table 2** Total non-structural carbohydrate, nitrogen, phosphorus, and potassium contents of *Hippeastrum* bulb after storage for 12 weeks at different temperatures

| Storage temperature (°C) | TNC (mg/bulb) | Total soluble sugar | N (mg/bulb) | P (mg/bulb) | K (mg/bulb) |
|---|---|---|---|---|---|
| Before storage | 2034.2a | 848.7 | 478.6 | 193.9a | 201.8b |
| RT | 1193.0b | 753.6 | 541.3 | 107.3ab | 333.5a |
| 13 ± 2 °C | 1352.4ab | 920.5 | 528.1 | 135.2ab | 294.3ab |
| 15 ± 2 °C | 1390.4ab | 954.2 | 551.7 | 77.1b | 404.4a |
| LSD ($p \geq 0.05$) | 747.7 | NS | NS | 88.15 | 117.24 |

Means within the same column followed by different letters are significantly different; ($p \geq 0.05$)

*NS* not significant, *K* potassium, *N* nitrogen, *P* phosphorus, *RT* room temperature, *TNC* total non-structural carbohydrate, *LSD* least significant difference

starch. Moreover, storage at low temperature appears to induce aquaporin yTIP gene expression in stalks upon planting (Balk et al. 1999). Because aquaporins typically induce water transport in plants during cell growth in terms of cell enlargement, plants stored at ambient temperature would lack aquaporin yTIP gene expression, resulting in water deficiency in buds and inhibition of stalk growth (Eisenbarth and Weig 2005; Ehlert et al. 2009).

The chemical constituents of the *Hippeastrum* bulb were analyzed after 12 weeks of storage at one of three treatment temperatures. The results showed that different storage temperatures had no statistically significant effect on total soluble sugar and N concentrations, whereas P, K, and non-structural carbohydrate (TNC) concentrations were significantly different between treatments (Table 2). The bulbs stored at RT had lower TNC concentrations than before storage, whereas the bulbs stored at low temperatures showed no significant changes in TNC. The soluble sugar concentration of bulbs stored at low temperatures increased (albeit not statistically significantly) during storage (Table 2) through a process commonly termed 'low temperature sweetening' that results from the conversion of starch to sugars after exposure to low temperatures.

At 9 weeks after planting (WAP) at different growth temperatures, the growth, flower quality, and bulb quality of *Hippeastrum* were measured, and the results revealed that the plants grown at 25 °C were better with respect to plant height, flower diameter, bulb diameter, bulb fresh weight, and bulb dry weight than the plants grown at RT (Table 3, Fig. 4). This suggests that the optimum temperature for growing *Hippeastrum* was 25 °C. Bose et al. (1979) have reported that the plant height of *Hippeastrum* was the best when grown at 25 °C, and Doorduin and Verkerke (2002) have also found that at 25 °C, *Hippeastrum* had the most number of leaves per plant and a greater bulb circumference than plants grown at 15 °C. Epharath et al. (2001) have shown that growing *Hippeastrum* plants at 27 °C/27 °C (day/night) could increase leaf area. In this experiment, it was observed that growth temperature greatly influenced the diameter of the flower and the number of days to flowering: it was found that a greater flower diameter was achieved when the plant was grown at 15 ± 2 °C or 25 ± 2 °C than at RT. In addition, plants stored either at 13 ± 2 °C or 15 ± 2 °C, and then grown at 25 ± 2 °C flowered earlier than those stored under similar conditions but grown at 15 ± 2 °C (18 and 51 days to flower, respectively). This might be because of slower bulb development (Ijira and Ogata 1997) at the low growing temperature. Cohat (1993) has reported that growth temperature affects the number of days to flowering in gladiolus, and that higher temperatures could decrease the bulb diameter. However, it was observed that plants stored at RT and then grown at RT took more days to flower than did plants stored at 13 ± 2 °C and 15 ± 2 °C (62, 25.5, and 23 days to flowers, respectively). This might be because high storage temperatures decrease the number of starch granules in mother bulbs, causing insufficient food reserves and resulting in a delay in flowering with this treatment. Roberts and Blaney (1996) have reported that in the initial period of growth, the bulbs mobilize food reserves for root and shoot development, with concurrent loss of bulb size, weight, and firmness; after that, the bulb weight begins to increase through photosynthesis.

This research concludes that a storage temperature of 15 ± 2 °C for 12 weeks combined with growth at 25 ± 2 °C results in better flower and bulb production.

**Table 3** Plant growth, flower quality, and bulb quality of *Hippeastrum* treated at different storage and growth temperatures for 9 weeks after planting

| Treatment | Plant growth | | Flower quality | | | Bulb quality | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Plant height (cm) | Leaves no. | Stalk length (cm) | Flower diameter (cm) | Days to flower | Bulb diameter (cm) | Bulb firmness (N) | Bulb fresh weight (g) | Bulb dry weight (g) |
| Storage temp. (°C) | | | | | | | | | |
| RT | 38.8ab | 4.1b | 46.8a | 17.3a | 43.3a | 7.2a | 49.1a | 244.9a | 22.4a |
| 13 | 33.3b | 5.1a | 43.3a | 16.0a | 31.5b | 7.0a | 37.3b | 256.3a | 24.3a |
| 15 | 44.0a | 4.8a | 42.5a | 16.0a | 29.0b | 7.0a | 41.8ab | 277.1a | 26.1a |
| Growth temp. (°C) | | | | | | | | | |
| RT | 33.2b | 4.6a | 42.2a | 15.1b | 36.8b | 6.9b | 42.3ab | 216.8b | 22.0b |
| 15 | 30.4b | 4.8a | 46.3a | 17.5a | 47.3a | 6.9b | 50.0a | 242.5b | 22.2b |
| 25 | 52.5a | 4.7a | 44.0a | 16.7a | 19.7c | 7.4a | 35.9b | 319.0a | 28.5a |
| Storage temp. × Growth temp. (°C) | | | | | | | | | |
| RT × RT | 30.3b | 4.8abc | 48.8a | 17.3a | 62.0a | 6.8c | 42.1b | 180.4c | 20.4b |
| 13 × RT | 29.4b | 4.5abc | 40.1a | 14.0b | 25.5d | 7.1abc | 41.0b | 236.9bc | 24.3b |
| 15 × RT | 39.8b | 4.5abc | 37.8a | 14.0b | 23.0de | 6.7c | 43.8b | 233.2bc | 21.3b |
| RT × 15 | 30.5b | 3.7c | 46.5a | 18.5a | 48.0b | 7.2abc | 71.1a | 239.9bc | 20.5b |
| 13 × 15 | 30.5b | 5.7c | 47.0a | 17.5a | 51.0b | 6.9bc | 35.2b | 273.2bc | 23.9b |
| 15 × 15 | 30.3b | 4.7abc | 45.5a | 16.5a | 43.0c | 6.6c | 43.6b | 214.5bc | 22.3b |
| RT × 25 | 55.5a | 4.0bc | 45.0a | 16.0ab | 20.0ef | 7.5ab | 34.0b | 314.5ab | 26.2b |
| 13 × 25 | 40.0b | 5.0abc | 42.8a | 16.5a | 18.0f | 7.1bc | 35.9b | 258.8bc | 24.7b |
| 15 × 25 | 62.0a | 5.3ab | 44.3a | 17.5a | 21.0ef | 7.7a | 37.9b | 383.7a | 34.7a |

Means within the same column followed by different letters are significantly different; ($p \geq 0.05$)

*NS* not significant, *RT* room temperature, *N* newton

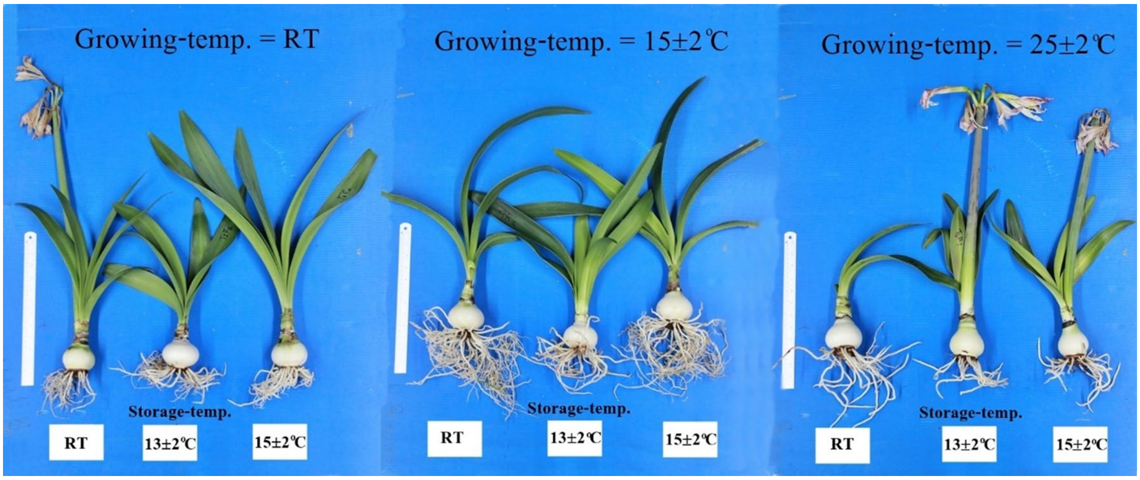

**Fig. 4** The growth of *Hippeastrum* treated at different storage and growth temperatures at 9 weeks after planting; *RT* room temperature

**Acknowledgements** This research was supported by Chiang Mai University Research Fund. Thanks to H. M. The King's Initiative Centre for Flower and Fruit Propagation for plant materials.

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