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Development of Artichoke Production Strategies in Florida: Cultivar Selection and Vernalization by Gibberellic Acid

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Globe artichoke (*Cynara cardunculus* var. *scolymus* L.) requires vernalization by prolonged chilling, generally 200 to 500 hours of temperatures below 7 °C. To produce artichokes under subtropical climates in Florida, flower bud initiation must be artificially induced. A field experiment was conducted in Balm, Florida to evaluate gibberellic acid (GA_3) as a vernalization technique for two cultivars, Green Globe Improved (GGI) and Imperial Star (IS). Transplants were planted in the field on 10 Nov. 2015. Plants were sprayed with GA_3 at 0 or 20 mg/L at 43 and 64 days after planting. Harvests were performed between 23 Mar. 2015 and 5 May 2016. Cumulative chilling hours below 7 °C during the growing season were 103 hours. Without GA_3, 0% and 38% of GGI and IS plants produced buds, respectively. With GA_3, 25% and 67% of GGI and IS plants produced buds, respectively, and earliness of bud development was improved by 14 days for IS. The improved bud induction by GA_3 increased marketable yield from 0 to 0.48 t/ha for GGI and from 0.71 to 2.91 t/ha for IS. Both cultivars produced compact, high-quality buds that weighed up to 480 g for GGI and 417 g for IS. These results suggest that IS is a more suitable cultivar than GGI in Florida because of its relatively low chilling requirement. Although GA_3 is effective in inducing bud initiation for artichokes, the application rate and timing need to be optimized to improve the effectiveness.

Globe artichoke (*Cynara cardunculus* var. *scolymus* L.), usually referred to simply as "artichoke", belongs to a genus of thistle-like plants in the sunflower family and is cultivated for its flower buds. Almost 100% of artichokes produced commercially in the United States are currently grown in California. In 2015, artichokes were planted on 2,630 hectares in California, producing 39,825 tons and generating $69 million gross sales (U.S. Department of Agriculture, 2016). One artichoke plant can produce several buds, which retail price ranges from $1 to $5 per bud (Agehara, 2017). California artichoke production in 2016 was valued at $25,117 per hectare (U.S. Department of Agriculture, 2017), demonstrating a higher production value than most major vegetable crops in Florida (U.S. Department of Agriculture, 2014). Artichokes are also attractive to consumers because of the high antioxidant capacity and beneficial health effects (Halvorsen et al., 2006; Shinohara et al., 2011). Therefore, the development of artichoke as a new specialty crop could provide new market opportunities for growers and consumers in Florida.

Artichoke requires vernalization to induce bud development (Rangarajan et al., 2000). The vernalization process is accomplished by prolonged chilling, generally 200–500 hours of temperatures below 7 °C (Agehara, 2017; García and Cointry, 2010; Rangarajan et al., 2000; Sałata et al., 2012). To produce artichokes under subtropical climates in Florida, therefore, flower bud initiation must be artificially induced. Gibberellic acid is a natural plant hormone that plays important roles in the regulation of flowering particularly for long-day and biennial plants (Mutasa-Göttgens and Hedden, 2009). The efficacy of exogenous GA_3 to induce artichoke bud formation is reported in many studies (Dumičić et al., 2009; Firpo et al., 2005; Halter et al., 2005; Mauromicale and Ierna, 1995; Sałata et al., 2013). For example, Dumičić et al. (2009) reported 20% to 100% yield increases in 'Imperial Star' artichoke by double applications of GA_3 at 30 and 15 mg·L^{-1}. Halter et al. (2005) reported a 59% yield increase in 'Green Globe' artichoke by a single application of at 50 mg·L^{-1}.

Most previous studies evaluated vernalization effects of GA_3 in artichoke under temperate and Mediterranean climates (Dumičić et al., 2009; Mauromicale and Ierna, 1995; Sałata et al., 2013). However, the effectiveness of GA_3 in artichoke bud induction depends on climatic conditions (Sałata et al., 2013). The objective of this study is to examine vernaization effects of GA_3 on bud induction of two artichoke cultivars, Green Globe Improved (GGI) and Imperil Star (IS), grown under a subtropical climate in Florida.

Materials and Methods

A field experiment was conducted at the Gulf Coast Research and Education Center in Balm, FL, from Nov. 2015 to May 2016. Treatments consisted of factorial combinations of two cultivars (GGI and IS) and two concentrations of GA_3 (0 and 20 mg·L^{-1}). ProGibb LV Plus (Valent BioSciences, Libertyville, IL) containing 5.7% GA_3 was used. Spray treatments were performed using a CO_2-pressurized backpack sprayer (Model T; Bellspray, Opelousas, LA) at the rosette stage on 23 Dec. 2015 and 13 Jan. 2016. The spray volume was 468 L·ha^{-1}.

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The soil at the experiment site is classified as a Myakka fine sand siliceous hyperthermic Oxyaquic Alorthod. At pre-plant, the surface (top 18 cm) soil had pH of 6.8 and organic matter of 15 g·kg^{-1}. Planting beds were 81 cm wide at the base, 71 cm wide at the top, 25 cm high, and spaced 152 cm apart on center. Raised beds were fumigated with Pic-Clor 60 at 336 kg·ha^{-1} and covered with a black virtually impermeable mulch film. Pre-plant fertilizers were incorporated in the soil at 56N–49P–93K kg·ha^{-1} during the bed preparation. Additional fertilizers were applied weekly via drip irrigation at 7.8N–1.1P–4.3K kg·ha^{-1} from 24 Nov. 2015 to 29 Mar. 2016. In total, these fertilizers supplied 276N–92P–221K kg·ha^{-1}.

Seedlings grown at a commercial transplant nursery (Plants of Ruskin, Ruskin, FL) were transplanted on the raised beds in a single row per bed at 91-cm in-row spacing on 10 Nov 2015. Each bed was irrigated through two drip tapes, each of which was placed 10 cm from the bed center at 2.5-cm depth. The drip tapes had emitters spaced 30 cm apart with a flow rate per emitter of 0.95 L·ha^{-1}. Artichoke buds were harvested 11 times between 23 Mar and 5 May 2016 and graded according to the U.S. Dept. of Agriculture (USDA) grade standards (U.S. Department of Agriculture, 2006).

There were four replicate plots for each treatment arranged in a split-plot design with cultivar as a main plot factor and GA_3 concentration as a subplot factor. Each replicate plot consisted of eight plants. All data analyses were run in SAS (version 9.4; SAS Institute, Cary, NC), and $P < 0.05$ were considered statistically significant. Treatment and interaction effects were tested using the restricted maximum likelihood method with the DDFM=KR option in the MIXED procedure. Multiple comparisons of least squares means were performed by the Tukey–Kramer test in the MIXED procedure.

Results and Discussion

Artichoke requires vernalization to produce buds by prolonged chilling, generally 200–500 hours of temperatures below 7 °C (Agehara, 2017; García and Cointry, 2010; Rangarajan et al., 2000; Sałata et al., 2012). During this experiment, cumulative chilling hours below 7 °C were 103 hours. Without GA_3, 0% and 38% of GGI and IS plants produced buds, respectively (Table 1). This poor bud formation indicates that the subtropical climate in Florida is not suitable for artichoke production because of insufficient chilling particularly for GGI. However, foliar applications of GA_3 at the rosette stage significantly improved bud formation (Table 1). With GA_3, 25% and 67% of GGI and IS plants produced buds, respectively, and the first harvest date of IS was advanced by 14 days from 11 Apr. to 28 Mar. 2016 (Table 1). As a result, foliar applications of GA_3 increased marketable bud number per plant from 0 to 0.22 for GGI and from 0.5 to 1.75 for IS, thereby increasing marketable yield from 0 to 0.48 t·ha^{-1} for GGI and from 0.71 to 2.91 t·ha^{-1} for IS. These increases were statistically significant for IS (Table 2). Importantly, artichoke buds displayed high quality regardless of GA_3 treatment (Fig. 1).

Table 1. Bud formation and first harvest date of two artichoke cultivars as affected by foliar applications of gibberellic acid (GA_3).[z]

Cultivar	GA_3 (mg·L^{-1})	Bud formation (%)	First harvest date
GGI	0	0.0 c[y]	–
	20	25.0 b	11 Apr. 2016
IS	0	37.5 b	11 Apr. 2016
	20	62.5 a	28 Mar. 2016

GGI = 'Green Globe Improved'; IS = 'Imperial Star'.
[z]Spray treatments of GA_3 were performed on 23 Dec. 2015 and 13 Jan. 2016, which were 43 and 64 days after planting, respectively.
[y]Means within a column followed by the same letter are not significantly different according to the Tukey–Kramer test at $P \leq 0.05$.

Table 2. Marketable yield of two artichoke cultivars as affected by foliar applications of gibberellic acid (GA_3).

Cultivar	GA_3 (mg·L^{-1})	Bud number (no./plant)	Marketable yield (t·ha^{-1})
GGI	0	0.00 c	0.00 c
	20	0.22 bc	0.48 bc
IS	0	0.50 b	0.71 b
	20	1.75 a	2.91 a

GGI = 'Green Globe Improved'; IS = 'Imperial Star'.
[z]Spray treatments of GA_3 were performed on 23 Dec. 2015 and 13 Jan. 2016, which were 43 and 64 days after planting, respectively.
[y]Means within a column followed by the same letter are not significantly different according to the Tukey–Kramer test at $P \leq 0.05$.

The efficacy of GA_3 to induce artichoke bud formation is reported in previous studies (Dumičić et al., 2009; Firpo et al., 2005; Halter et al., 2005; Mauromicale and Ierna, 1995; Sałata et al., 2013). In this study, although the same efficacy of GA_3 was demonstrated, the effectiveness was relatively low. In fact, the highest marketable yield was 2.91 t·ha^{-1}, accounting for only 21.4% to 24.8% of the average yield in California recorded in 2005 to 2006 (11.7 to 13.6 t·ha^{-1}) (Smith et al., 2008). The effectiveness of GA_3 in artichoke bud induction depends on the growth stage at the time of treatment, application rate, cultivar, planting date, and climatic conditions (Sałata et al., 2013). It is recommended that up to three applications of GA_3 be used, staring at the vegetative, rosette stage when plants have 5–8 expanded leaves (Firpo et al., 2005; García and Cointry, 2010;

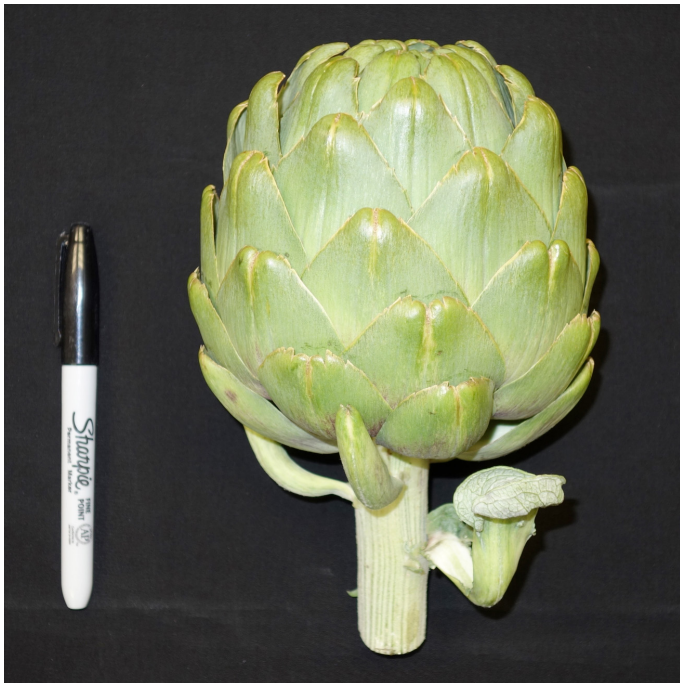

Fig. 1. A large marketable 'Imperial Star' artichoke bud.

Sałata et al., 2013). Previously tested GA_3 concentrations range from 15 to 300 mg·L^{-1} (Dumičić et al., 2009; Firpo et al., 2005; Halter et al., 2005; Schrader, 1994). Sałata et al. (2013) applied GA_3 at 60 mg·L^{-1} once at the 8-leaf stage or twice at both 8- and 12-leaf stages, and reported that plants treated once produced 400 g higher artichoke yield per plant than untreated plants or plants treated twice. By contrast, Firpo et al. (2005) tested much higher concentrations of GA_3, 150 and 300 mg·L^{-1}, and found the maximum yield with 300 mg·L^{-1} for all four tested cultivars. The inconsistent optimum GA_3 concentrations reported in these studies may be due to the different growing conditions or chilling hours. The study by Sałata et al. (2013) was conducted under a continental climate with cold winters in Poland, whereas the study by Firpo et al. (2005) was conducted under a temperate climate with mild winters in central Argentina. Yields also varied greatly between the two studies: the highest number of buds per plant reported by Sałata et al. (2013) and Firpo et al. (2005) was 12.6 and 4.0, respectively. In this study, double applications of GA_3 at 20 mg·L^{-1} were evaluated under a subtropical climate, and yields were similar to those reported by Firpo et al. (2005). Therefore, the optimum GA_3 concentration to maximize artichoke bud induction in Florida is probably much higher than 20 mg·L^{-1}.

Conclusions

Without artificial vernalization, the subtropical climate in central Florida is not suitable for artichoke production because of insufficient chilling. The results of this study suggest that IS requires lower chilling hours than GGI for bud induction, and that GA_3 is an effective vernalization strategy to overcome chilling requirements of both artichoke cultivars. With GA_3, it is possible to harvest high-quality artichoke buds from late March to mid-April. However, artichoke yields obtained by the tested GA_3 application method are much lower than the average yield in California. Optimization of GA_3 application rate and time appears to have the greatest potential to maximize the yield of artichoke buds in Florida.

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