Variety Trials

Ornamental Kale as a Cut Flower under High Tunnels in the Southeastern United States

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ADDITIONAL INDEX WORDS. **hoop house, local, organic, season extension, floriculture, ornamental cabbage, protected environment**

SUMMARY. **The potential to expand the production of ornamental kale (*Brassica oleracea* var. *acephala*) grown as a specialty cut flower in the southeastern United States appears promising, especially for the winter holidays. This 2-year replicated study investigated the effects of two fall plantings and three cultivars on ornamental kale yields grown under organic high tunnels. In addition to the production study, informal interviews of local florists were conducted. The earlier planting dates resulted in longer stem lengths (≥5 cm) and fewer days to harvest (≥5 days) across both seasons. Commercial stem length goals were not achieved (≥60 cm) but local florists did not appear to have the same standards (≥31 cm). The cultivars Crane Bicolor and Lucir White had longer stems and larger heads than Crane Red. Our high tunnel system provided favorable air temperatures for vegetative growth from late September through early November indicating an earlier planting date may be possible. Commonly accepted nighttime temperatures required to induce color changes occurred in early to mid-November during our study period.**

Ornamental kale is widely used as a cool-season bedding plant but there is also a growing interest in selected cultivars, which feature tall, thin-stemmed, cabbage-like heads, as cut flowers (T. Spencer, personal communication) (Fig. 1). In the United States, ornamental kale is increasingly incorporated into bouquets, especially during the fall and winter holiday season. One to three stems of ornamental kale are generally used in mixed flower bouquets and/or single stems are sold directly to consumers, so they can make their own arrangements. Major ornamental kale plant breeders include Takii Seeds (Kyoto, Japan), Sakata Seed (Yokohama, Japan), Ishii Seed Growers (Shizuoka City, Japan), and Evanthia (Monster, The Netherlands) (H. Furuichi, personal communication).

In North America, ornamental kale is grown year-round in California, as a fall crop in Canada, and in small areas along the U.S. east coast; it is also grown year-round in Colombia and Ecuador for export (T. Spencer, personal communication). The U.S. domestic wholesale cut flower market, for growers having $100,000 or more in sales, is valued at $374 million [U.S. Department of Agriculture (USDA), 2016]. It is difficult to more specifically assess the value of this crop since ornamental kale is represented in the "other cut flowers" category estimated to be worth $130 million (USDA, 2016).

Specialty and/or locally grown cut flowers may be profitable for their unique qualities, faster harvest to consumer transition resulting in a longer post-harvest vase life, and for delicate flowers which are difficult to transport without damaging (Ortiz et al., 2012; Owen et al., 2016; Wien, 2009; Yue and Hall, 2010). The increasing interest among U.S. consumers to purchase American-grown and/or locally grown flowers alongside other agricultural products (Connor, 2018; Feldmann and Hamm, 2015; Low and Vogel, 2011; Yue et al., 2011) is a value-driven trend. Support from floriculture industry groups is evident. For example, the Association of Specialty Cut Flower Growers (1988) states that it strives to "help foster and promote the local availability of high quality floral material" and the third-party verified label American Grown Flowers (2014) promotes "bouquets and bunches of domestic origins with high quality, freshness and consistency."

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
0.0254	mil(s)	mm	39.3701
1.6093	mph	$km \cdot h^{-1}$	0.6214
33.9057	oz/yard^2	$g \cdot m^{-2}$	0.0295
3.9063	tablespoon(s)/gal	$mL \cdot L^{-1}$	0.2560
2.2417	ton(s)/acre	$Mg \cdot ha^{-1}$	0.4461
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Fig. 1. Ornamental kale photos: (A) partially pruned ornamental kale growing through polypropylene flower netting under a high tunnel, (B) T. Jayalath holding a mixed bouquet of ornamental kale, and (C) individual ornamental kale cultivars (top to bottom: Crane Bicolor, Lucir White, and Crane Red).

Ornamental kale is a popular crop in Japan, where it is grown primarily under high tunnels (T. Spencer, personal communication). High tunnels reduce weather-related production risks, improve product quality and consistency, assist with organic growing efforts, help increase productivity on limited amounts of land, and amplify season extension opportunities (Carey et al., 2009; Jayalath et al., 2017; Lamont, 2009; O'Connell et al., 2012). The use of high tunnels has been growing steadily in the United States although primarily for vegetable production (Carey et al., 2009; Hochmuth and Toro, 2014; Knewston et al., 2010). Inclusion of cut flowers in high tunnel systems that also produce vegetables, herbs, fruits, etc. provides additional options to rotate crops which can help address disease, pest, and nutrient management issues. In addition, cut flowers may benefit from increased stem elongation compared with the open field. This is due to decreased light intensity under high tunnel environments due to a semitransparent polyethylene plastic roof as well as reduced wind.

Seasonal production strategies in Japan appear to be adaptable to the southeastern United States, including Georgia, which shares a humid subtropical climate according to the most frequently used Köppen climate classification system (American Takii, 2013; Kottek et al., 2006). In Japan, seedlings are transplanted to high tunnels during periods of high temperature and humidity (T. Spencer, personal communication). This period of warm weather (between 55 and 80 °F) is reported to encourage vegetative growth and stem elongation (American Takii, 2013; Sakata Seed America, 2018).

Generally, ornamental kale reaches an optimum stem length (60 to 70 cm) ≈2 to 3 months after transplanting (American Takii, 2013; Kristl, 2001; Sakata Seed America, 2018). Optimum stem length criteria is based on Japanese flower market standards that consider shipping, processing, and ultimately use in a variety of applications such as bouquets and table arrangements (H. Furuichi, personal communication). The United States does not have its own ornamental kale standards yet.

The consensus is that a minimum of 10 to 14 d with nighttime temperatures ≤55 to 60 °F is required to achieve good leaf color contrasts (American Takii, 2013; Kristl, 2001; Sakata Seed America, 2018). Even more intense leaf color contrasts may develop if nighttime temperatures remain between 35 and 45 °F for a few weeks (Sakata Seed America, 2018). Cold-storing ornamental kale between 45 and 50 °F is recommended post-harvest (H. Furuichi, personal communication).

There are very limited studies exploring ornamental kale and/or cut flowers under high tunnels in the United States. In 2002, a field and pot study evaluated ornamental kale production in North Carolina using conventional practices (Greer et al., 2003). Results indicated that ornamental kale should be planted ≈75 d before consistently cool temperatures (i.e., end of June planting date in North Carolina), that applications of gibberellic acid to the leaves did not result in increased stem length, and that plant spacing affected the average stem length (Greer et al., 2003). The most generous plant spacing trialed in North Carolina (8 × 8 inches) yielded the longest average stems (Greer et al., 2003). Johnny's Selected Seeds (Fairfield, ME) conducted a trial to provide growers with guidelines about planting dates and management practices applicable in Maine (Kristl, 2001). Results demonstrated that transplanting ornamental kale in June resulted in an early October harvest thus requiring ≈120 d in the field in Maine (Kristl, 2001).

High tunnel vs. field system experiments for selected cut flowers have been published primarily for New York and Indiana. A high tunnel vs. field comparison of six cut flower species in New York, ornamental kale not included, suggested that similar transplant dates yield earlier and more concentrated harvest periods under high tunnels but did not always increase the number of stems per plant (Wien, 2009). Owen et al. (2016) conducted a high tunnel and field system comparison of seven conventionally grown cut flowers from July through October in Indiana. Although ornamental kale was not included, selected cut flower species demonstrated increases in the total number of stems per week when grown under high tunnels, and stem length was greater for most flower types compared with the field (Owen et al., 2016). Overall, the number of flowers per plant was not different between the high tunnel and field but flower quality was greater for selected species (Owen et al., 2016). Lastly, Ortiz et al. (2012) found that high tunnels could result in earlier yields, more stems, and longer stems for selected cut flowers including snapdragon (Antirrhinum majus 'Rocket Red'), dianthus (*Dianthus barbatus* 'Amazon Neon Cherry'), stock (*Matthiola incana* 'Katz Lavender Blue'), zinnia (*Zinnia elegans*

'Benary Giant Scarlet'), dahlia (*Dahlia ×hybrida* 'Karma Thalia Dark Fuschia'), lisianthus (Eustoma *russellianum* 'Mariachi Blue'), and sunflower (*Helianthus annuus* 'Sunrich Yellow' and 'Premier Lemon') compared with the field in Indiana.

To our knowledge, no studies have been published about growing ornamental kale under high tunnels in the United States although it is common practice in other parts of the world. Therefore, the objectives of our research were to evaluate the effects of planting date and cultivar on ornamental kale crop yields grown under an organic high tunnel system in Georgia. Ornamental kale cultivars included in our experiment were selected based on similar advertised stem height (≈60 to 90 cm), differing color characteristics, and the availability of untreated seed suitable for certified organic production until organic seeds are available. Additional mustard family (Brassicaceae) crops including broccoli (*Brassica oleracea* var. *italica*), cauliflower (*B. oleracea* var. *botrytis*), and turnip (*Brassica rapa* var. *rapa*) were planted under the high tunnels around the same time. Results for the broccoli and cauliflower study are available separately (O'Connell and Tate, 2017).

Materials and methods

Site background. The study was conducted at the University of Georgia (UGA) Durham Horticulture Research Farm located in Watkinsville, GA (lat. 33.88689°N, long. 83.41941°W) from 2014 to 2016. This site is considered USDA hardiness zone 8a which corresponds to average annual minimum temperatures between 10 and 15 °F (USDA, 2012). Soils at this site are categorized as a well-drained Cecil sandy loam soil with a red sandy clay loam subsoil (CYB2) (USDA, 1968). The project site has been certified organic since 2012 and all agricultural production methods were performed under the guidelines of the USDA National Organic Program (NOP) certification standards (7 U.S.C. § 6501). There was no recent history of mustard family crops in the project area before our study.

Two gothic-shaped high tunnels (96 ft long × 30 ft wide × 12 ft tall) with automated 6-ft-tall drop-down curtains were used for the experiment (Snow Arch Series; Atlas Greenhouses, Alapaha, GA). High tunnel features included bows every 6 ft, an inflated double polyethylene film roof [6 mil thick (SunView4; Poly-Ag Corp., San Diego, CA)] and front and rear twin-wall polycarbonate end walls with two 8-ft-wide sliding doors (i.e., 16-ft end wall opening possible on each end wall). These high tunnels systems have an estimated wind load capacity of 90 mph with a 3-s wind gust. The high tunnels were oriented east-west to minimize high tunnel surface area exposed to the prevailing westerly winter winds.

Experimental design. A replicated comparison of multiple ornamental kale transplanted at two different fall planting dates and managed with certified organic practices under high tunnels was carried out over two growing seasons. Differences in crop yields and days to harvest after transplanting were evaluated while pest and disease issues were monitored. In addition, the microclimate inside and outside the high tunnels were compared.

The experiment was a split-plot design and treatments were replicated four times (two blocks in each high tunnel). The main plot was planting date and the sub-factor was cultivar. Ornamental kale cultivars evaluated included Crane Bicolor, Crane Red, and Lucir White (Harris Seeds, Rochester, NY). In 2014, planting dates were 7 and 21 Oct. In 2015, planting dates were 22 Sept. and 6 Oct., 2 weeks earlier than the first season. Dates were modified in the second season to achieve a greater overlap of the harvest period during the winter holiday season (i.e., mid-November through early January).

Crop management and data collection were carried out by block. Each ornamental cut kale block consisted of one 10-ft-long row that contained 30 plants. Each 3-ft-wide raised bed contained three rows of ornamental kale (i.e., one row of each cultivar) with an in-row spacing of every 4 inches and a between-row spacing of 9 inches. Blocks were rerandomized each year.

Crop management. Ornamental kale seedlings were grown in a certified organic heated greenhouse. The gothic-shaped greenhouse was 96 ft long × 30 ft wide × 12 ft tall with bows every 6 ft, an inflated double polyethylene film roof, an evaporative cooling wall, a climate controller (Step 50-A; Wadsworth Control System, Arvada, CO), and twin-wall, polycarbonate end walls with one 4-ft-wide sliding door (Snow Arch Series, Atlas Greenhouses).

The greenhouse was maintained at temperatures of 55/70 °F night/day. Three-week-old seedlings were acclimated to the outside environment for 1 additional week before transplanting under the high tunnels. Seeds were sown into 72-cell packs filled with potting media (Sunshine Natural & Organic Mix #1; Sun Gro Horticulture, Agawam, MA) on 9 Sept. 2014 and 25 Aug. 2015. Overhead irrigation was administered by hand as needed. A 4N–1.3P–2.5K soluble fish and seaweed fertilizer (AgGrand Organic Series; Amsoil, Superior, WI) was applied during weeks 3 and 4 after seeding at a rate of 2 tablespoons/gal of water.

Fertilizer rates were based on soil testing recommendations for edible kale provided by the UGA Agricultural and Environmental Services Laboratories (UGA, 2014). Pre-plant soil amendments and fertilizers used included compost, feathermeal, phosphate (P_2O_5), potash (K_2O), boron (B), and lime ($CaCO_3$) (Table 1). Fertilizers were applied by block and incorporated ≈1/2 inch into the soil with hand rakes. About 6 weeks after planting, crops were side-dressed with an additional 40 lb/acre nitrogen (N) (Table 1). In 2014, plant tissue analysis conducted around 6 weeks after transplanting indicated that the N concentrations were ≈6%. This N concentration was greater than the regional recommendations of ≈4% to 5% for edible kale; therefore, in 2015, the pre-plant fertilizer N rate was decreased by 20% (i.e., ≈120 lb/acre N) (Table 1). A plant tissue analysis conducted around 6 weeks after transplanting in 2015 indicated that the N concentrations remained at ≈6% even though the fertilizer inputs had been reduced.

Black polypropylene landscape fabric, secured with metal fabric pins, was used as a weed barrier and heat sink. Long slits were cut in the fabric and pinned opened, creating a planting row ≈4 inches wide. Hand weeding was carried out around the base of

Table 1. Soil amendments and fertilizer inputs for ornamental kale grown under high tunnels during two fall/winter seasons in Watkinsville, GA.

Yr	Material	Rate (dry wt)[z]	Source
2014–15			
	Calcitic lime	1 to 2 tons/acre $CaCO_3$	Hi-Cal pulverized lime; Franklin Industrial Minerals, Crab Orchard, TN
	Rock phosphate (0N–3.0P–0K)	20–200 lb/acre P_2O_5	Calphos; Canton Mills, MN City, MN
	Potash (0N–0P–41.5K)	140–190 lb/acre K_2O	Sulfate of potash; Great Salt Lake Mineral Corp., Overland Park, KS
	Compost (1N–0P–0K)	10 tons/acre	University of Georgia Bioconversion Center; Athens, GA
	Feathermeal (13N–0P–0K)	140 lb/acre nitrogen (N)	Hydrolyzed poultry feathers; Mason City By-Products, Mason City, IA
	Boron (10% B)	2 lb/acre boron (B)	Boron 10%; Cameron Chemicals, Virginia Beach, VA
	Naturesafe (10N–0.9P–6.7K)[y]	40 lb/acre N	Naturesafe all season fertilizer; Griffin Industries, Cold Spring, KY
2015–16			
	Potash (0N–0P–41.5K)	105–150 lb/acre K_2O	Sulfate of potash, Great Salt Lake Mineral Corp.
	Compost (1N–0P–0K)	10 tons/acre	University of Georgia Bioconversion Center
	Feathermeal (13N–0P–0K)	120 lb/acre N	Hydrolyzed poultry feathers, Mason City By-Products
	Boron (10% B)	2 lb/acre B	Boron 10%, Cameron Chemicals
	Naturesafe (10N–0.9P–6.7K)[y]	40 lb/acre N	Naturesafe all season fertilizer, Griffin Industries

[z]Calcium rate expressed as calcium carbonate ($CaCO_3$); phosphorus rate expressed as phosphate (P_2O_5); potassium rate expressed as potash (K_2O); 1 ton/acre = 2.2417 $Mg \cdot ha^{-1}$, 1 lb/acre = 1.1209 $kg \cdot ha^{-1}$.
[y]Applied ≈6 weeks after planting.

the plants as needed throughout the season. Two horizontal layers of polypropylene flower netting (6-inch mesh) were stretched over 4-ft-tall posts every 3 to 4 ft providing support to the ornamental kale stems as they grew (Hortonova; Tenax Corp., Baltimore, MD). Side leaves were pruned off by hand every 3 to 4 weeks as well as at the final harvest. Therefore, pruning occurred a total of two to three times during the growing season depending on the number of days to harvest per block.

Drop-down sidewall curtains were lowered (i.e., opened) when ambient air temperatures inside the tunnels at 6 ft above the soil line exceeded 60 ± 2 °F. The side curtain threshold temperature was chosen (60 to 65 °F) based on a suitable range of temperatures for excellent crop growth of ornamental kale, broccoli, cauliflower, and turnip. When rain or strong winds (>15 mph) occurred, the side and/or end wall doors were closed as long as the high tunnel temperature was not predicted to surpass 80 °F. This protocol was necessary to keep roof/sidewall runoff from flooding the high tunnel soil, rain blowing into the tunnels, and/or strong winds from damaging the plants or sidewall curtains.

Irrigation was administered for ≈60 to 90 min every 2 to 4 d, depending on the growth stage of plants and weather conditions. There was one drip tape with emitters every 8 inches and a flow rate of 0.4 gal/min per 100 ft (Chapin Tape; JainUSA, Watertown, NY). One layer of intermediate weight rowcover [1.2 oz/yard^2 (Gro-Guard #40; Atmore Industries, Atmore, AL)] was hung over wire hoops to create a low tunnel over the plants when the nighttime temperatures were predicted to be ≤32 °F. The low tunnel apex was ≈3 ft above the soil line. Rowcover edges were held in place with sand bags. Placement of rowcovers was carried out during the late afternoon (4:00 to 6:00 PM) and removed the following morning (8:00 to 9:00 AM).

Pest management decisions were based on observations from biweekly scouting and treatment actions were based on established integrated pest management (IPM) thresholds for organic systems when available. The following products were used to manage pest pressure: insecticidal soap (M-Pede; Dow AgroSciences, Indianapolis, IN) for cabbage and potato aphids (*Brevicoryne brassicae* and *Macrosiphum euphorbia*, respectively); neem oil (Neem Concentrate; Green Light, San Antonio, TX) combined with insecticidal soap for whiteflies (*Bemisia* sp.); *Bacillus thurigiensis* (Dipel DF; Valent BioSciences Corp., Libertyville, IL) for cabbage loopers (Trichoplusia ni) and cabbage worms (*Artogeia rapae*); and spinosad (Entrust SC Naturalyte, Dow AgroSciences) for fire ants (Solenopsis invicta). No chemical actions to manage disease were required for this crop either season.

An environmental monitoring station was set up in each block as well as in an adjacent field. Each station was located in the middle of a raised bed, ≈33 to 34 ft from the nearest end wall and 8 ft from the nearest sidewall. Monitoring stations in the open field, which was planted with an oat (*Avena sativa*) cover crop, mimicked the high tunnel configuration. Air temperature and relative humidity sensors were housed inside solar radiation shields 3 ft above the soil surface [Hobo dataloggers with S-THB-M002 sensors (Onset Computer Corp., Bourne, MA) in 2014 and Em50 dataloggers with VP-4 sensors (Decagon Devices, Pullman, WA) in 2015]. Temperature and relative humidity were logged at 15-min intervals and averaged for each hour.

Data collection and statistical analysis. Individual blocks of ornamental kale were harvested when greater than 80% of the block was deemed at its best quality (i.e., good color contrast and by the end of January). Good color contrast was based on observations of multitone ornamental kale (i.e., not all green) sold in retail outlets, online/seed catalog photo examples, and observing plant color transitions as ornamental kale flower centers transitioned from green to their contrasting color(s) (i.e., less mottling in the centers and contrast color becoming more opaque). Photos of harvested cuts provide examples of what was considered good color contrast (Fig. 1). Harvesting by the end of January was a goal to capture potential U.S. holiday markets and get the high tunnels ready for spring crops.

The number of marketable and nonmarketable stems per block were separated and recorded. Disorders of the nonmarketable stems were characterized (i.e., stem too short or crooked, pest damage, misshapen heads, etc.) then 10 marketable stems were measured for stem length, stem diameter, and head diameter. Stem length was defined as where the stem was cut near the soil line to the bottom of the pruned head. Stem diameter was measured half way up the harvested stem with a utility slide caliper. Head diameter was defined as including the inner core color (i.e., white, white/pink, or red/purple) along with two whorls of green leaf tissue that surrounded the core (Fig. 1). The inner core color was never pruned. In the second season, an additional category, stem plus head length, was also measured. Head length was defined as the bottom to the top of the head.

The main factors of interest in this study were a comparison between two planting dates and three ornamental kale cultivars. Therefore, the continuous response variables included in this dataset were marketable yield, stem length, stem diameter, head diameter, and stem plus head length (second season only). These variables were about normally distributed, so the statistical analysis was carried out using a mixed effects analysis of variance (ANOVA) model (SAS version 9.4; SAS Institute, Cary, NC). The data did not require any transformation and block was considered a random effect. Tukey's mean separation method with 95% confidence level was used to determine if there were significant differences between planting dates or cultivar type for each crop. Each year was analyzed separately to account for different weather patterns.

The response for variable, nonmarketable yield was analyzed differently because it was comprised of small positive integers that were not continuous. A logistic regression model was used to predict the proportion of the total harvested cuts that were nonmarketable using planting date or cultivar type as explanatory variables for each crop type (SAS version 9.4). Block was considered a random effect. Each year was analyzed separately as described previously.

Statistical analysis was not conducted on microclimate data [i.e., air temperature, relative humidity, growing degree days (GDD)] or days to harvest (DTH). However, these data provide useful comparisons between high tunnel and field microclimate across the growing season and between years at our research site. These data may also provide a basis of comparison for high tunnel and/or cut flower research conducted in different locations.

Finally, three local florists Elizabeth Ann Florist (Watkinsville, GA), Peddler's Wagon (Watkinsville, GA), and Petals on Prince (Athens, GA) were brought six stems of each ornamental kale cultivar and informally interviewed. These florists represented ≈20% of the retail floral shops in this area. Each florist was asked a series of questions including 1) are you familiar with these? 2) would you buy them and if so for how much per stem? 3) what is the minimum stem length you would accept? 4) is local and/or organic important to you or your customers? and 5) any other thoughts to share? Answers were summarized and provide some insight into potential concerns and opportunities for this crop with the local cut flower market.

Table 2. Effect of planting date and cultivar on days to harvest (DTH), growth characteristics, and cull rates for ornamental kale grown under high tunnels during two fall/winter seasons in Watkinsville, GA.

Season[z]	Planting date	Cultivar	DTH (d)[y]	Stem length (cm)[x]	Stem + flower length (cm)	Flower diam (mm)[x]	Stem diam (mm)	Culls (% of total harvest)
2014–15								
	7 Oct.		70	29 a[w]		127 a	15 a	1 a
	21 Oct.		75	21 b		105 a	14 a	15 b
		Crane Bicolor	72	26 a		141 a	16 a	3 a
		Crane Red	73	22 b		97 b	14 b	5 a
		Lucir White	72	27 a		111 b	14 b	3 a
2015–16								
	22 Sept.		63	39 a	50 a	61 b	14 a	10 a
	6 Oct.		72	34 b	46 a	79 a	12 b	8 a
		Crane Bicolor	68	39 a	51 a	77 a	14 a	8 a
		Crane Red	68	31 b	43 b	50 b	13 b	19 b
		Lucir White	68	39 a	51 a	84 a	13 b	5 a

[z]Each growing season was analyzed separately.
[y]Average DTH after transplanting.
[x]1 cm = 0.3937 inch, 1 mm = 0.0394 inch.
[w]Values followed by the same letter are not significantly different within a column according to Tukey's mean separation test ($P \leq 0.05$).

Results

QUALITY. The average days to harvest ranged from 70 to 75 d and 63 to 72 d in the first and second seasons, respectively (Table 2). The first planting date was ready to harvest 5 d faster than the second planting date in 2014–15 and 9 d faster than the second planting date in 2015–16 (Table 2). Cultivar type did not influence the total days to harvest. Neither planting date nor cultivar had a significant effect on percent marketability which ranged from 81% to 99%. The latest planting date (i.e., 21 Oct.) had a greater cull rate in 2014–15 primarily due to shorter than desired stem length (Table 2). In addition, trends indicated that 'Crane Red' had greater cull rates, primarily due to shorter than desired stem length, although this was only statistically significant in 2015–16 (Table 2).

The earlier planting dates resulted in longer stem length across both seasons (Table 2). The average stem length surpassed 30 cm during the second season for both planting dates and all three cultivars. Stem plus head length, which was only collected in the second season, averaged 43 to 51 cm across all cultivars. Heads accounted for 11 to 13 cm of the stem plus head length measurement. 'Crane Bicolor' and 'Lucir White' had greater values than 'Crane Red' for both stem length and stem plus head length (Table 2). The planting date and cultivar interaction was not significant for stem length.

The effect of planting date on head diameter was not consistent across the seasons but the effect of cultivar was significant. 'Crane Bicolor' had a larger head diameter than 'Crane Red' both seasons and 'Lucir White' had a larger head diameter than 'Crane Red' in 2015–16 (Table 2). In addition, head diameters were ≈25% to 50% wider in 2014–15 compared with 2015–16. The effect of planting date on stem diameter was not consistent across the seasons but 'Crane Bicolor' had thicker stem diameters compared with 'Crane Red' and 'Lucir White' (Table 2).

MICROCLIMATE. The 2014–15 season was colder than the 2015–16 season (Fig. 2). The combination of earlier planting date and yearly weather variations resulted in a gain of ≈500 GDD during the second season under the high tunnels compared with the first season. Average hourly air temperatures dropped below 55 °F under the high tunnels for ≥10 d in early Nov. 2014–15 but not until mid-Nov. 2015–16 (Fig. 2).

Each year when the daily temperatures were warm and the high tunnel system was ventilated more frequently, the average daily air temperature at the crop canopy was ≈2 °F greater than the open field (data not shown). As the season progressed into the colder months and the high tunnel system was closed more frequently, the average daily air temperature was 2 to 7 °F warmer than the open field with maximum gains of 9 to 12 °F (data not shown). Overall, the relative humidity (RH) between the high tunnel and field system was similar when ventilation occurred frequently; it fluctuated between 50% and 100% RH over the season (data not shown).

FLORIST IMPRESSIONS. Two of the three florists interviewed were familiar with ornamental cut kale and had previously used it in arrangements (Elizabeth Ann Florist, Peddler's Wagon, and Petals on Prince, unpublished data). All three florists remarked that the color and quality of the fresh stems was better than what they could currently purchase from wholesalers and valued individual stems at $2 to $3 because of their novelty and high quality. Thirty-one centimeters (i.e., 12 inches) was considered an acceptable stem length by all three florists interviewed. Preference for small or large head diameter was variable and depended on how they envisioned using the ornamental kale. All color combinations presented (green and white with minor pink blush, green and white with major pink blush, green and red/purple) were considered attractive.

Each florist reported that customers requested local flowers more often than organically-grown and that local was synonymous with "freshness" in their opinion, denoting longer vase life. Inclusion of ornamental kale in holiday arrangements (e.g., Thanksgiving, Christmas, St. Patrick's Day), winter weddings, and early spring farmers markets were specifically mentioned as desired applications. Two florists also reported that the ornamental kale stems can "smell like cabbage" as they age making them better suited for special event arrangements. Overall, the florists were excited and impressed with the quality and colors of the ornamental kale and indicated they would be interested in purchasing stems if available via the local market (Elizabeth Ann Florist, Peddler's Wagon, and Petals on Prince, unpublished data).

Discussion

Ornamental kale has the ability to be a fall/winter high tunnel crop in Georgia, especially if a specialty market exists that will accept shorter stems and/or the system can be improved to increase stem length. A warmer season in conjunction with earlier plant support efforts in the second year yielded better results in terms of stem length although the crop was still ≈10 to 20 cm short of stem length preferred by commercial outlets in Japan (i.e., 60 to 70 cm) (American Takii, 2013; Sakata Seed America, 2018). These standards appear to have become the default suggestion for U.S. growers; however, our preliminary interviews suggested that local florist markets may be willing to accept stem lengths ≥31 cm. All three cultivars investigated achieved stem lengths ≥31 cm in our second season but cultivars Crane Bicolor and Lucir White stems were consistently longer than Crane Red.

Similarly, the Japanese industry standard for ornamental kale head size is ≈8 to 10 cm wide (T. Spencer, personal communication.). However, the florists we spoke with were interested in larger heads as well. They indicated that large heads would be preferred for many types of arrangements. A more thorough follow-up survey investigating preferred ornamental kale qualities for the U.S. market may have implications for management strategies, plant breeding efforts, preferred cultivars, etc. Trends indicated that 'Crane Bicolor' and 'Lucir White' had larger head diameters compared with the 'Crane Red'. All cultivars had larger head diameters in 2014–15 which could have been a result of the greater nitrogen fertilizer rate the first season or possible inconsistencies with measurements year to year due to the subjective nature of head diameter measurements (i.e., the core color plus two whorls of green leaf tissue).

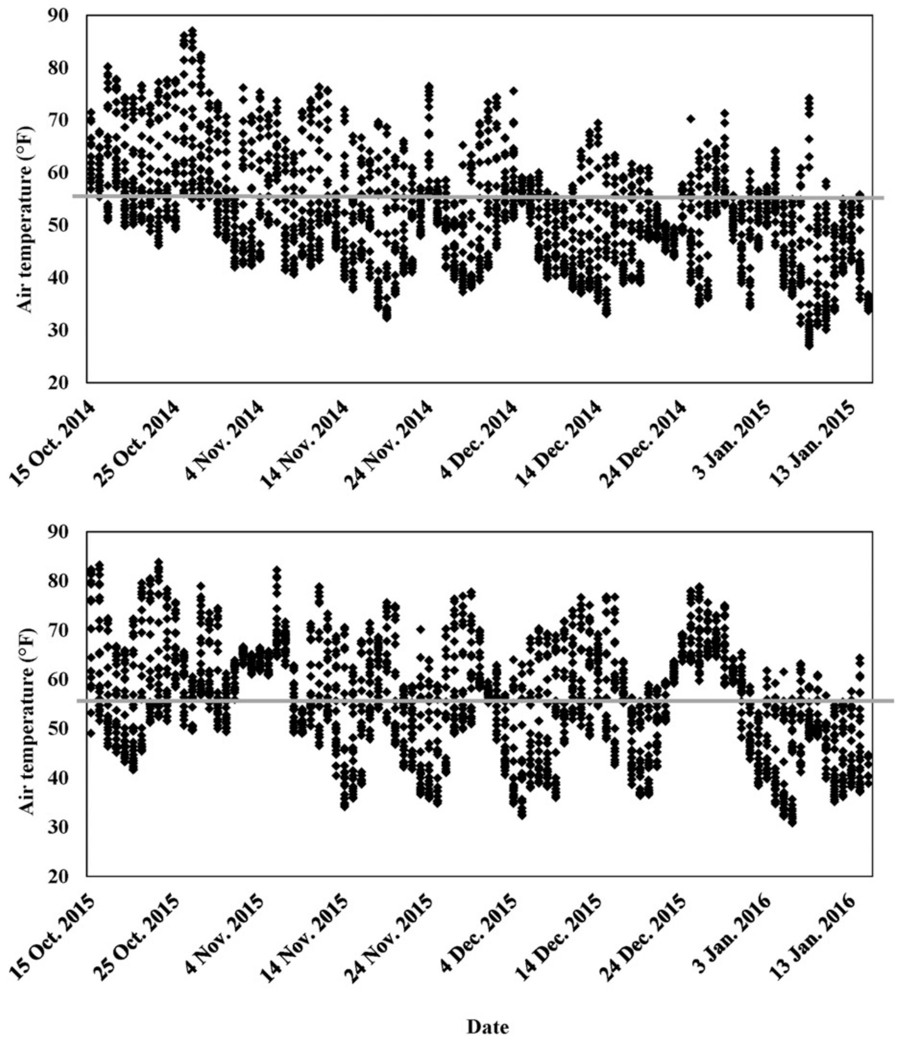

Fig. 2. Average hourly air temperatures from mid-October to mid-January under high tunnels during two fall/winter seasons in Watkinsville, GA. The solid gray line at 55 °F indicates the upper temperature threshold for optimum ornamental kale color contrast development; (°F – 32) ÷ 1.8 = °C.

Ornamental kale seedlings did not display signs of heat stress during the early vegetative growth phase when the average hourly air temperatures at the crop canopy ranged from ≈60 to 75 °F and the relative humidity was often >75%. This indicates that an earlier planting date may be possible and should be investigated for effects on stem length, harvest dates, etc. Temperature ranges under the high tunnels during the fall season appeared similar to the optimum temperatures for vegetative growth recommended by the American Takii ornamental kale management guide (2013). It should also be noted that high tunnel side curtains were closed when temperatures were 60 ± 2 °F at 6 ft above the soil line. This temperature set point was based on managing multiple crops growing under the high tunnels at the same time. Both the vegetative or color-changing stages of the ornamental kale might be optimized with warmer or cooler set points, respectively. Many high tunnel growers choose to cultivate a wide variety of crops, including from different plant families, under their high tunnels at any given time (Fitzgerald and Hutton, 2012; Knewston et al., 2010). Providing optimum growing conditions for a wide diversity of crops becomes a challenge and may require tailoring management strategies such as a focus on the most profitable crop, the most popular crop, or the most-disease susceptible crop.

Color contrasts were achieved in early and mid.-December for the majority of ornamental kale each year, which overlapped with major U.S. holidays such as Hannukah, Christmas, and New Year's Day. This alignment between holidays and temperatures inducing color changes may provide an advantage to Georgia growers since they can help fulfill market demands without holding plants in the high tunnels (i.e., taking up space with a crop until the holidays arrive) longer than necessary compared with many other locations. Ten to fourteen consecutive nights with nighttime temperatures ≤55 °F occurred in the first season in early November and in the second season in mid-November.

Our plants were spaced every 4 × 9 inches, yet recommendations exist as close as every 4 × 4 inches (Sakata Seed America, 2018). More compact plant spacing may maximize the use of high tunnel space, encourage stem elongation and minimize the time spent pruning lower leaves off the stems as they may become shaded and fall off naturally. Greer et al. (2003), however, found the opposite to be true, which was that greater plant spacing, 8 × 8 inches, yielded longer stems (≈48 cm). Furthermore, narrower plant spacing may not be recommended with organic, low spray, and/or southeastern U.S. regional growing practices, which often encourage maximizing air circulation to help reduce pest and disease pressure.

During our experiment, pest pressure was minimal and disease pressure was absent for this crop. Transplants were treated for whiteflies once before moving into the high tunnels and then sprayed for aphids about four times and caterpillar pests two times each season under the high tunnels. These limited actions were less resource intensive than the other crops concurrently grown under our high tunnels including broccoli and cauliflower (O'Connell and Tate, 2017).

In addition to warmer temperatures in 2015–16, we were quicker to deploy the horizontal flower netting after transplanting. Stems appeared to be straighter as a result of this earlier action (i.e., less bent stems near the soil line). Therefore securing at least one if not two layers of flower netting at transplanting is recommended. Adjustments (i.e., moving the netting up) can be made as the plants grow to support the weight of the plants, encourage straight vertical stem growth, access the side leaves for pruning, spraying, etc.

Future efforts to improve stem elongation to expand potential markets may include adding shadecloth or other light decreasing materials to the high tunnels, evaluating planting density, and assessing fertilizer rates and/or application timing. In addition, investigating if color development reverts if temperatures rise above the optimum threshold (i.e., >55 °F) for a defined length of time or effects from bolting would be valuable. Bolting can occur when temperatures rise above 70 °F after an extended period of temperatures <50 °F (Kelley et al., 2017). Negative effects from fluctuating temperatures are a potential risk for Georgia growers wishing to sell ornamental kale in winter or spring markets.

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