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Squash Grown in Protected Structures and Marketed as Specialty Produce

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Mini or "baby" vegetables have become increasingly popular items for restaurant chefs and retail sales. Summer squash (*Cucurbita pepo* L.) is generally open-field cultivated and climate, insect, and disease pressures create challenging conditions for growers and shippers who produce and market this delicate, immature fruit. In order to overcome these challenges, in Spring 2012 and Fall/Winter 2012, five squash cultivars, including zucchini and yellow-summer, were grown hydroponically in a protected agriculture structure known as a tunnel and compared for yield of baby-size fruit. Squash fruit less than 10 cm (4 inches) in length were graded as "baby," while those longer than 10 cm (4 inches) were graded as "fancy." In Spring and Fall/Winter 2012, 'Gentry' produced the most (number and weight) baby squash while 'Lazor' and 'Spineless King' produced the most fancy fruit. 'Gentry' also produced more culls than the other cultivars. 'Gentry' produced over 375 baby squash per m^2 in Spring and over 250 per m^2 in Fall/Winter (30 harvests and 43 harvests, respectively), while the other cultivars produced only about 25% of that. 'Lazor' produced more male blossoms suitable for sale, compared to the other cultivars. Squash plants will produce numerous high quality baby-sized fruit and edible blossoms when grown hydroponically in a reduced pesticide environment in a tunnel where they can be harvested, packaged, and distributed to buyers over several months of the year.

Recent consumer trends in the United States have led to increased demand for mini or "baby" vegetables, including baby carrots, beit alpha cucumbers, mini sweet peppers, micro-greens, micro-herbs, and baby lettuces. They are often marketed as "ready-to-eat" in the supermarkets and are popular for high-end specialty restaurants for use in exotic cooking techniques and unique gourmet side-dishes or garnishes. Since baby vegetables are delicate and require intense production operations in order to ensure high yield and quality, and therefore higher financial return to the grower, they are particularly conducive to protected agriculture production.

The unique characteristics of summer squash render this crop a potentially lucrative niche in the baby vegetable and edible blossom markets. Baby summer squash are harvested when immature at a length of 10 cm (4 inches) or less. Summer squash longer than 10 cm are considered "fancy" grade. The desirable characteristics of tender skin, only partially developed seeds, and "ready-to-eat" size increases the value of baby squash in the gourmet produce markets to $11 to $13 per kg ($5 to $6 per lb), as compared to only $3.75 per kg ($1.69 per lb) for fancy squash. The male blossoms of a summer squash plant are edible and can be sold to restaurants for as much as $1 per blossom.

The delicate nature of the baby squash fruit and blossoms highlights the advantage of producing them under a protected structure. A protected, hydroponic, high-density growing system could potentially maximize yield and quality of this product. This growing system also reduces the need for pesticides during the season, thus potentially adding value to the product at the market. Male and female flowers are produced on the same plant, and new female flowers are produced and fruit set in response to squash removal (Mossler, 2001). As a result, summer squash are harvested multiple times during the season, approximately every 2 to 3 d. Multiple harvests make this crop particularly suitable for protected agriculture since the season can be extended to coincide with market windows, further increasing the value of the product at market.

While studies have been conducted on hydroponic greenhouse production of baby squash in Florida, its production potential under a less expensive, simpler structure, such as a tunnel, has not been extensively researched (Shaw et al., 2004, 2005). The objective of this study was to identify squash cultivars suitable for the baby squash and edible blossom market that could be successfully grown in a tunnel in Florida using hydroponic and integrated pest management (IPM) strategies.

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Table 1. Squash cultivars evaluated for hydroponic specialty squash production in a tunnel in Florida using soilless media.

Cultivar	Type	Shape	Color	Maturity (days)	Plant type	Disease resistance[z]
Gentry	Summer, yellow	Semi-crook	Butter yellow	43	Open bush, vigorous	---
Lazor	Summer, yellow	Straightneck	Lemon yellow	42	Vigorous bush	IR: ZYMV
Emerald	Summer, zucchini	Cylindrical	Medium – dark green	45	Open bush	---
Payroll	Summer, zucchini	Cylindrical	Medium green	45	Open bush	IR: Sf, WMV, ZYMV
Spineless King	Summer, zucchini	Cylindrical	Medium – dark green	45	Open, upright	IR: Sf, WMV, ZYMV

[z]IR: intermediate resistance; ZYMV: zucchini yellows caused by *Zucchini yellow mosaic potyvirus*; Sf: powdery mildew caused by *Sphaerotheca fuliginea*; WMV: watermelon mosaic caused by *Watermelon mosaic potyvirus*.

Materials and Methods

Squash types and cultivars evaluated included summer yellow 'Gentry' and 'Lazor,' and summer zucchini 'Emerald', 'Payroll', and 'Spineless King' (Table 1). On 10 Jan. 2012 and 11 Sept. 2012, seeds from each cultivar (SeedWay, Inc.) were sown in Styrofoam trays (128 cell count, Todd Planter Flats; Speedling, Bushnell, FL) filled with a potting mix of three parts sphagnum peat : two parts vermiculite (v/v). Transplants were grown in a glass house and irrigated as needed.

In both seasons, the experiments were conducted in a 27 × 5 × 3 m (87 ft × 15 ft × 9 ft 8 inches) passively ventilated tunnel located at the University of Florida (UF) Institute of Food and Agricultural Sciences (IFAS) Partnership for Water, Agriculture and Community Sustainability (PWACS) research and demonstration center at Hastings, FL. The structure was covered with UV-absorbing polyethylene film, the ventilated side walls were covered with 50-mesh insect screen and the floors were covered in white landscape fabric. The experiment was established in four rows in a north-south configuration.

The experiment was arranged as a randomized complete-block design with four replications in Spring 2012 and Fall/Winter 2012. All cultivar types were randomized throughout each block. On 24 Jan. 2012 and 25 Sept. 2012, 2-week-old squash seedlings were transplanted into 11.4-L (3 gal) black polyethylene nursery pots with four, 0.6-cm- (0.25 inch) diameter drainage holes drilled equidistant from each other and 2.5 cm (1 inch) from the bottom of the pot to create a reservoir. Pots were filled with pine bark screened to a size of less than 2.5 × 2.5 cm^2 (1 × 1 $inch^2$). Pots were placed in four rows, with each row comprising one block (replication) of the experiment. Plots contained eight plants (one plant per pot) arranged in rows, for a total of 160 plants. Within-row spacing and between-row spacing was 60 cm (2 ft) from center to center for a plant density of 3.4 plants/m^2.

Squash plants were fertigated through individual 1.9 L/h (0.5 gal/h) pressure-compensating emitters (Netafim USA, Fresno, CA) at a flow rate of 33 mL/min. Nutrient levels remained constant throughout the season using water-soluble 16N–1.8P–10.8K and 0N–22.9P–28.2K fertilizers. Two fertilizer proportional injectors placed in series were used to inject the nutrient stock solutions from two 114-L (30-gal) drums with each irrigation event (dilution rate 1:100; v/v). Irrigation duration and frequency was automated using a timer and was adjusted over the course of the season to meet plant demand.

Each plant was individually trellised vertically on twine using a plastic clip at the base of the plant to secure the squash plant to the twine and horticulture twist ties placed every 15 cm (6 inches) to vertically secure the main stem of the squash plant. Laterals were pruned from the plants to encourage indeterminate growth.

Bumblebees (*Bombus impatiens*) were introduced for pollination and their presence in the tunnel limited chemical pest control measures. Pests and diseases were controlled using integrated pest management practices. Arthropod pests were controlled with beneficial biological agents and insecticidal soap sprays. Aphids were controlled using parasitic wasps (*Aphidius colemani*), whiteflies were controlled using predatory mites (*Amblyseius swirskii*), and two-spotted spider mites were controlled using predatory mites (*Neoseiulus californicus*). Beneficials (i.e., Aphipar, Swirski-Mite and Spical) and bumblebees (i.e., NATUPOL–class B) were acquired from Koppert Biological Systems (Romulus, MI). Powdery mildew was controlled using repeated sulfur sprays.

Four plants in each plot were harvested manually approximately three times per week. There were 30 harvest dates from 24 Feb. 2012 [31 d after transplant (DAT)] to 9 May 2012 (106 DAT) in the Spring season, and 43 harvest dates from 26 Oct. 2012 (31 DAT) to 1 Feb. 2013 (129 DAT) in the Fall/Winter season. Harvested fruit were graded by size, shape, and quality. USDA grade standards for baby squash have not been published; however, baby squash at retail markets weigh approximately 20–30 g (0.7–1.0 oz) per fruit (Schmidt, 2003). Based on size and weight of baby squash sold in local supermarkets, fruit 5–10 cm (2–4 inch) in length were graded as "baby" and fruit over 10 cm (4 inches) in length were graded as "fancy." Fruit that were unmarketable due to being misshapen, damaged, or having poor color development, regardless of size, were graded as "cull." Weight and number of fruit in each of these three grades and the number of male squash flowers were recorded per plot and are expressed per m^2 (Figs. 1–7).

Each season was statistically analyzed separately due to the existence of potentially significant interactions between environment (season) and cultivar. Data were analyzed within cultivar type by fitting a general linear model using the procedure GLM as implemented in the statistical software SAS (V.9.3 SAS Institute, Cary, NC) that considered a replicate and a cultivar effect. Fisher's least significant difference (LSD) tests with $P \leq 0.05$ were employed for means separation among treatments (cultivars). The response variables analyzed corresponded to the totals over all the harvests per season.

Results and Discussion

Minimum temperature outside the tunnel in Spring 2012 was 1.7 °C (35 °F) and maximum was 34 °C (94 °F); mean temperature for the season was 20 °C (69 °F). Minimum temperature outside the tunnel in Fall/Winter 2012 was –4 °C (25 °F) and maximum was 29 °C (84 °F); mean temperature for the season was 16 °C (60 °F). Overall, minimum, maximum, and average outside temperatures were about 10 °F warmer in Spring than in Fall/Winter.

In Spring and Fall/Winter, 'Gentry' produced significantly more baby fruit (388 and 264 fruit/m^2, respectively) than the other

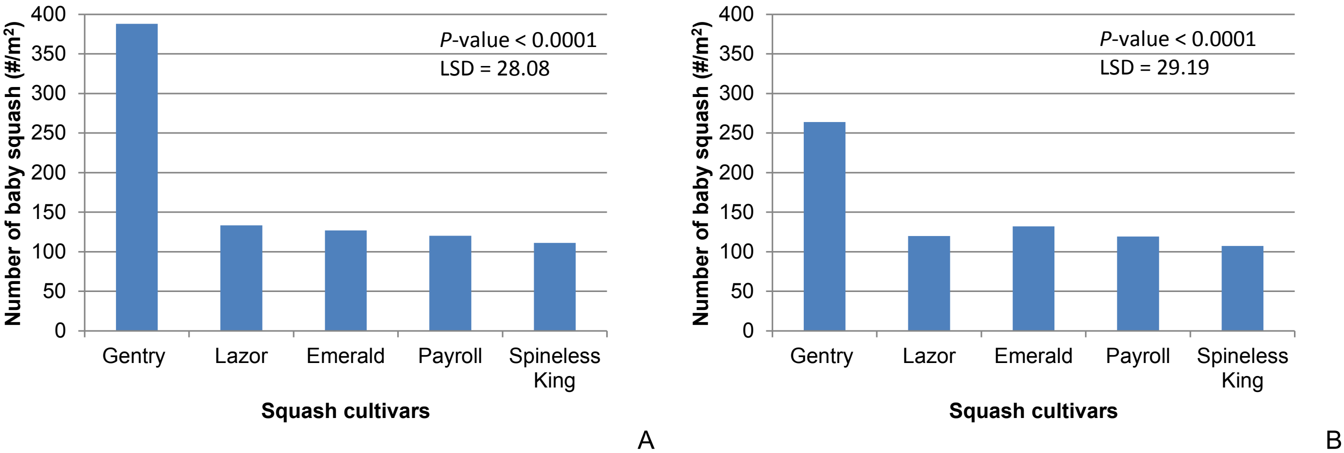

Fig. 1. Number of baby squash (#/m^2) produced by several summer squash cultivars in a hydroponic tunnel production system at the UF/IFAS PWACS demonstration center in Hastings, FL in (**A**) Spring 2012 and (**B**) Fall/Winter 2012. Squash graded as "baby" were less than 10 cm (4 inches) in length. Mean separation between cultivars was by Fisher's Least Significant Difference Test, 5% level.

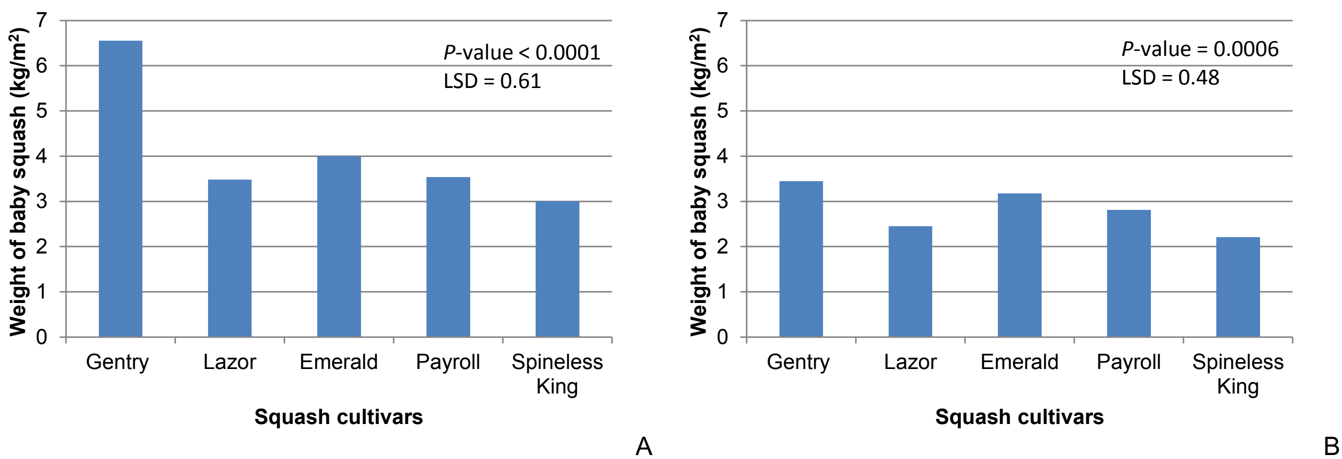

Fig. 2. Weight of baby squash (kg/m^2) produced by several summer squash cultivars in a hydroponic tunnel production system at the UF/IFAS PWACS demonstration center in Hastings, FL in (**A**) Spring 2012 and (**B**) Fall/Winter 2012. Squash graded as "baby" were less than 10 cm (4 inches) in length. Mean separation between cultivars was by Fisher's Least Significant Difference Test, 5% level.

cultivars, which had similar yields of baby fruit ($P < 0.0001$ and $P < 0.0001$, respectively) (Fig. 1). In Spring, 'Gentry' yielded a significantly greater weight of baby squash (6.55 kg/m^2) and 'Spineless King' yielded significantly lower weight of baby squash (3.00 kg/m^2) than the other cultivars ($P < 0.0001$) (Fig. 2). In Fall/Winter, 'Gentry' produced a greater weight of baby squash (3.45 kg/m^2) than all other cultivars except for 'Emerald' ($P = 0.0006$). 'Spineless King' produced lower weight of baby squash (2.21 kg/m^2) than the other cultivars except for 'Lazor.' In Fall/Winter there were more harvests over a longer period of time than in the Spring and yield of 'Emerald' at the later harvest dates increased (data not presented). Potentially, 'Emerald' may have yielded similar total weight of baby squash as 'Gentry' if the Spring harvests had been extended.

Number and weight of fancy fruit produced were increased at the expense of baby fruit production when harvesting occurred less frequently than every other day. Such events typically occurred on a Monday harvest after a three day break instead of two. In Spring, 'Lazor' produced significantly more fancy squash (31 fruit/m^2) than all other cultivars except for 'Spineless King', and 'Spineless King' produced more fancy squash (27 fruit/m^2) than 'Emerald' and 'Gentry' (14 and 6 fruit/m^2, respectively) ($P = 0.0014$) (Fig. 3). In Fall/Winter, 'Lazor' produced significantly more fancy squash (8 fruit/m^2) than all other cultivars except for 'Spineless King', and 'Spineless King' produced more fancy squash (5 fruit/m^2) than 'Emerald' (1 fruit/m^2) ($P = 0.0201$). In both Spring and Fall/Winter, 'Lazor' yielded significantly higher weight of fancy squash (2.65 and 0.69 kg/m^2, respectively) than the other cultivars except 'Spineless King' (Fig. 4) ($P = 0.0018$ and $P = 0.0236$, respectively). In Spring, 'Spineless King' yielded higher weight of fancy squash (1.92 kg/m^2) than 'Gentry' (0.45 kg/m^2). These findings suggest that 'Lazor' and 'Spineless King' may need to be harvested more frequently for the baby squash market.

In both Spring and Fall/Winter, 'Gentry' produced significantly more culls (86 and 19 fruit/m^2, respectively) and yielded significantly greater weight of culls (1.10 and 0.23 kg/m^2, respectively) compared to all other cultivars ($P < 0.0001$, $P < 0.0001$, $P < 0.0001$, and $P < 0.0001$, respectively) (Figs. 5 and 6). In the Fall/Winter, 'Lazor' produced greater number and weight of culls than 'Spineless King.' The greater number and weight of culls yielded

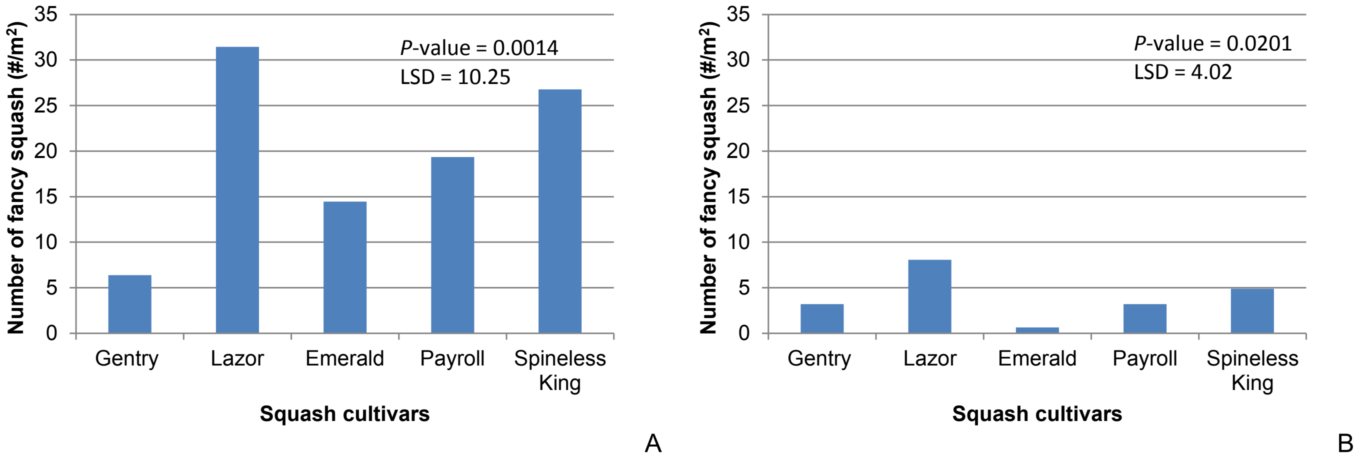

Fig. 3. Number of fancy squash (#/m²) produced by several summer squash cultivars in a hydroponic tunnel production system at the UF/IFAS PWACS demonstration center in Hastings, FL in (**A**) Spring 2012 and (**B**) Fall/Winter 2012. Squash graded as "fancy" were more than 10 cm (4 inches) in length. Mean separation between cultivars was by Fisher's Least Significant Difference Test, 5% level.

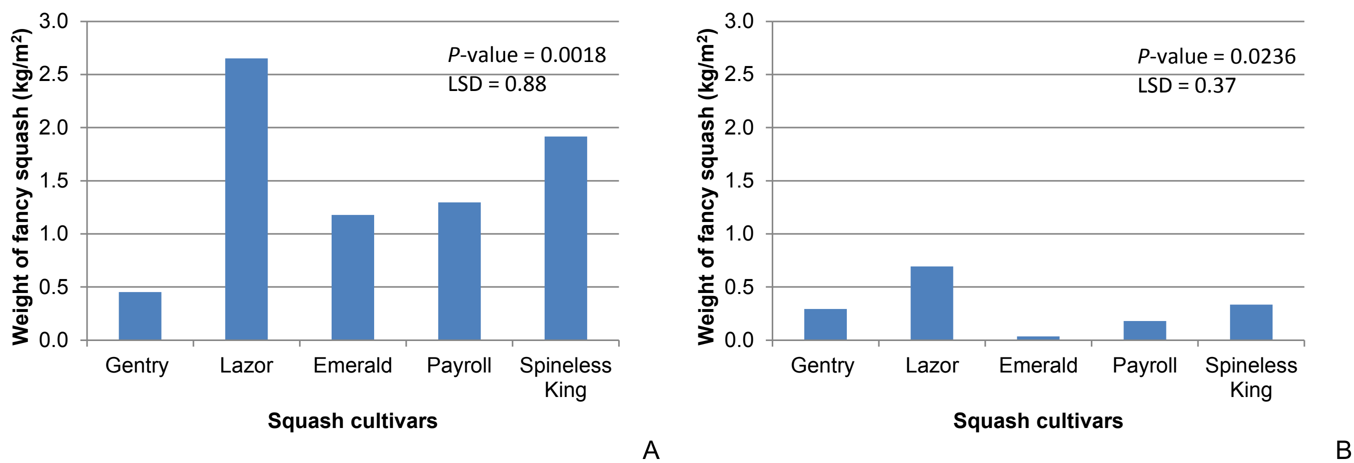

Fig. 4. Weight of fancy squash (kg/m²) produced by several summer squash cultivars in a hydroponic tunnel production system at the UF/IFAS PWACS demonstration center in Hastings, FL in (**A**) Spring 2012 and (**B**) Fall/Winter 2012. Squash graded as "fancy" were more than 10 cm (4 inches) in length. Mean separation between cultivars was by Fisher's Least Significant Difference Test, 5% level.

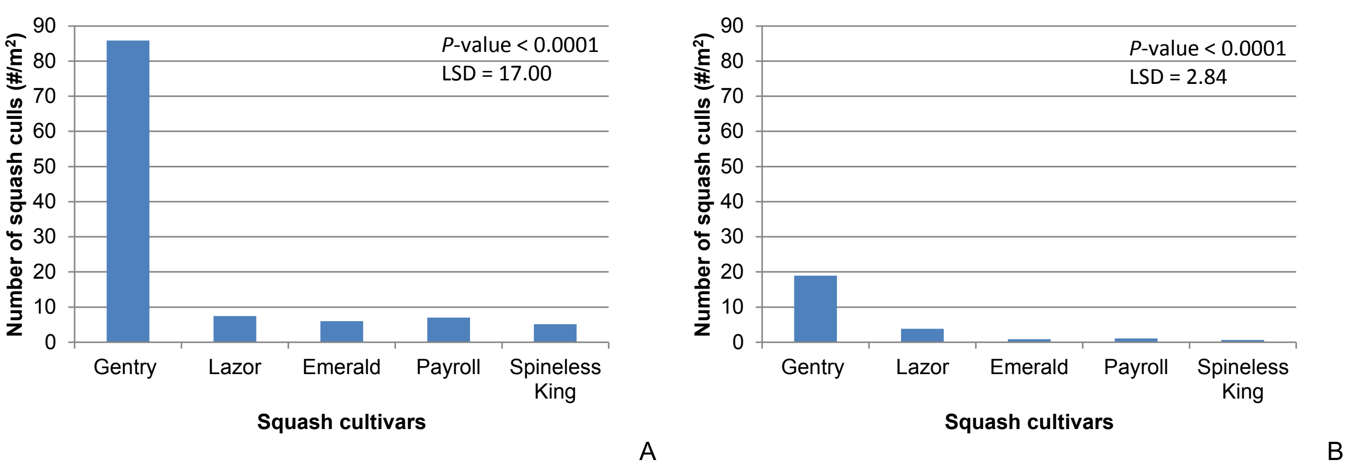

Fig. 5. Number of culled squash (#/m²) produced by several summer squash cultivars in a hydroponic tunnel production system at the UF/IFAS PWACS demonstration center in Hastings, FL in (**A**) Spring 2012 and (**B**) Fall/Winter 2012. Culls are fruit that are unmarketable due to being misshapen, damaged, or having poor color development, regardless of size. Mean separation between cultivars was by Fisher's Least Significant Difference Test, 5% level.

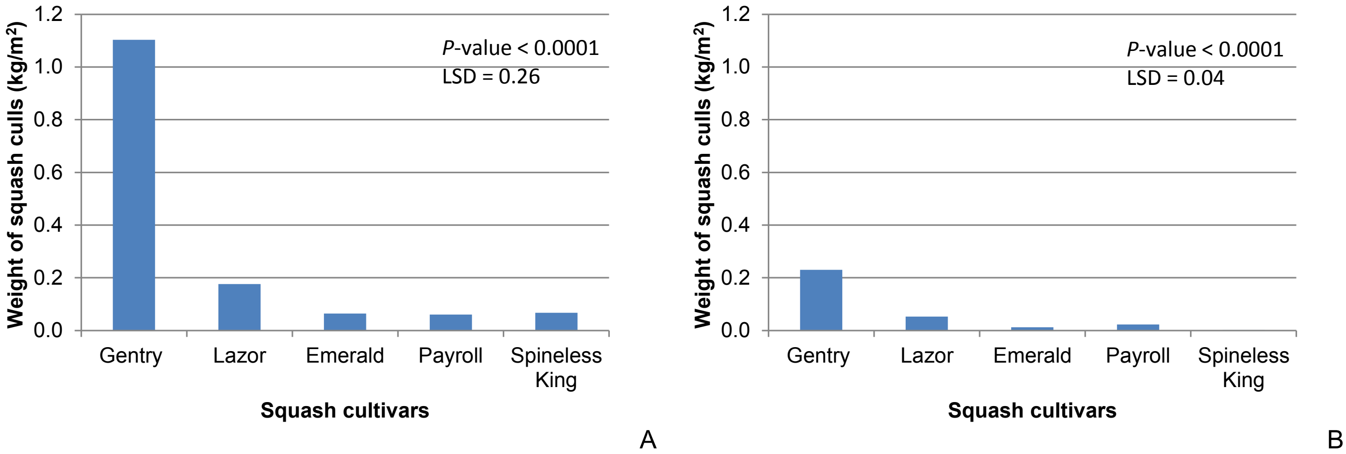

Fig. 6. Weight of culled squash (kg/m^2) produced by several summer squash cultivars in a hydroponic tunnel production system at the UF/IFAS PWACS demonstration center in Hastings, FL in (**A**) Spring 2012 and (**B**) Fall/Winter 2012. Culls are fruit that are unmarketable due to being misshapen, damaged, or having poor color development, regardless of size. Mean separation between cultivars was by Fisher's Least Significant Difference Test, 5% level.

by 'Gentry' compared to the other cultivars may be attributed to the higher yields of baby fruit that 'Gentry' was producing compared with the other cultivars, and not necessarily indicating a proportionately high cull-rate for 'Gentry.' However, while 'Lazor' and 'Spineless King' produced similar yields of baby and fancy squash, 'Lazor' produced significantly more culls, which may be an important factor to consider in terms of cultivar selection for hydroponic tunnel squash production.

The number of female flowers produced indicates the potential number of total fruit yielded by a squash plant, regardless of grade category or cull. In Spring and Fall/Winter, 'Gentry' produced the significantly highest total number of fruit (480 and 286 fruit/m^2, respectively), suggesting that it is a consistently high yielding cultivar for hydroponic tunnel squash production (data not presented).

In both Spring and Fall/Winter, 'Gentry' produced significantly more male flowers (115 and 86 flowers/m^2, respectively) than 'Emerald,' 'Payroll', and 'Spineless King,' and 'Lazor' produced significantly more male flowers (156 and 118 flowers/m^2, respectively) than the other cultivars ($P < 0.0001$ and $P < 0.0001$, respectively) (Fig. 7).

'Gentry' and 'Lazor' were the most successful cultivars in this hydroponic tunnel production system. 'Gentry' would be an ideal cultivar for the baby squash market and could produce a respectable number of male flowers for the edible squash blossom market as well. 'Lazor' would be an ideal cultivar for the edible squash blossom market and would have moderate yields for the baby or fancy squash market (depending on harvest frequency) as well. The three zucchini cultivars had minimal variability in yield or fruit quality.

Based on market prices of $12/kg ($5.50/lb) of baby squash, $3.75/kg ($1.69/lb) of fancy squash and $1 per edible squash blossom, and yields from the Spring and Fall/Winter experiments, potential yearly revenue for hydroponic tunnel production of squash cultivars 'Gentry' and 'Lazor' can be estimated. For 'Gentry,' production of baby squash yields $120/$m^2$ ($11.15/$ft^2$) or $1,200,529/ha ($485,848/acre), production of fancy squash yields $2.78/$m^2$ ($0.26/$ft^2$) or $27,759/ha ($11,234/acre), and

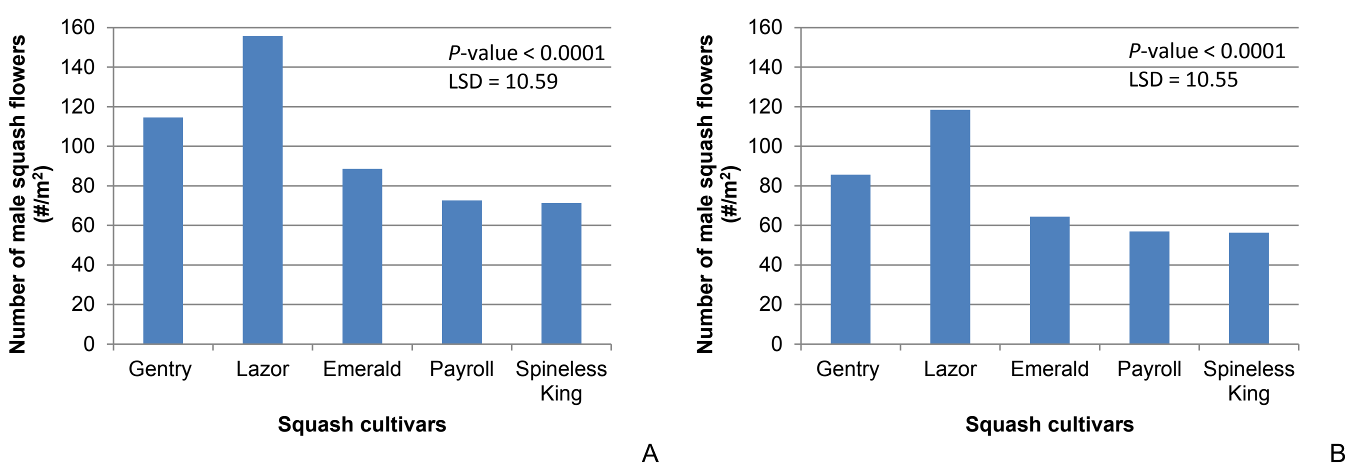

Fig. 7. Number of male squash flowers (#/m^2) produced by several summer squash cultivars in a hydroponic tunnel production system at the UF/IFAS PWACS demonstration center in Hastings, FL in (**A**) Spring 2012 and (**B**) Fall/Winter 2012. Male squash flowers are edible squash blossoms from which fruit do not develop. Mean separation between cultivars was by Fisher's Least Significant Difference Test, 5% level.

production of edible squash blossoms yields $200/m^2 ($18.60/ft^2) or $2,002,484/ha ($810,394/acre). For 'Lazor,' production of baby squash yields $71/m^2 ($6.61/ft^2) or $711,843/ha ($288,079/acre), production of fancy squash yields $12.53/m^2 ($1.16/ft^2) or $125,293/ha ($50,705/acre), and production of edible squash blossoms yields $274/m^2 ($25.48/ft^2) or $2,742,136/ha ($1,109,727/acre). Total revenue from production of 'Gentry' is $322/m^2 (30.01/ft^2) or $3,230,772/ha ($1,307,322/acre), with 37%, 1%, and 62% of the total revenue attributed to the baby squash, fancy squash, and blossoms, respectively. Total revenue from production of 'Lazor' is $358/m^2 (33.25/ft^2) or $3,579,272/ha ($1,448,511/acre), with 20%, 3% and 77% of the total revenue attributed to the baby squash, fancy squash, and blossoms, respectively. This highlights two conclusions: 1) the value of baby squash and blossoms is substantially higher than that of fancy squash, and 2) even though 'Gentry' had significantly higher yield of baby squash than 'Lazor,' the significantly higher yield of blossoms produced by 'Lazor' coupled with their high value resulted in greater total revenue produced by 'Lazor'. These figures are based on the highest dollar values potentially received for each type of squash or flower. Even if per unit returns were reduced to half those stated above, the returns to the grower would be substantial.

Fall/Winter yields of 1) number and weight of baby squash, 2) number and weight of fancy squash, 3) number and weight of culls, 4) female flowers, and 5) male flowers were 1) 68% and 52%, 2) 25% and 26%, 3) 22% and 21%, 4) 60%, and 5) 76% of Spring yields in those categories, respectively. Although the Spring season had higher yields with less harvests than the Fall/Winter season, the results of this experiment illustrate the potential of an extended baby squash and edible blossom production season from October to May using hydroponics, IPM, and protected agriculture. Increased yield and quality (compared to field production) combined with high market prices highlights hydroponic tunnel baby squash as a potentially lucrative niche, especially during favorable market windows.

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