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Yield, Market Quality, and Bitterness of Lettuce Cultivars Grown Hydroponically in a North Florida Greenhouse during the Summer

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Production of lettuce (*Lactuca sativa*) during the summer in Florida normally ceases in fields and greenhouses due to extreme heat and humidity. Recent introductions of heat tolerant cultivars, advances in hydroponic systems and protected agriculture structures may make it possible for lettuce production in Florida during the summer months. In greenhouses, Nutrient Film Technique (NFT) is the most common hydroponic system used for lettuce production. Temperature for NFT solution during the summer in Florida will often be over 90 °F, causing lower oxygen levels and increasing the risk of diseases such as Pythium root rot. In addition, tip burn, a physiological disorder related to poor calcium nutrition in the expanding leaves, can be a serious disorder in lettuce during very high temperatures. During the lettuce production stage of this research trial, a nutrient solution chiller was attached to the nutrient reservoir and set to 72 °F. Lettuce grown under very high ambient temperatures often has a bitter taste making the product unmarketable, but the preliminary sensory data of lettuce cultivars grown under these modified growing conditions, yield acceptable levels of bitterness.

Florida is the third-largest producer of lettuce in the United States, and has nearly year-round growing potential. Typical commercial field lettuce production in Florida extends from late September through May. While lettuce is traditionally considered as a cool season crop, growing environment (i.e. planting time) and production practices can contribute to bitter taste (Rubatzky and Yamaguchi, 2012; University of Illinois, 2017). The key components of lettuce flavor are sweetness and bitterness. The presence of glucose, sucrose, and fructose contributes to the sweetness perception, and glucose is the sugar that contributes most (Chadwick et al. 2015). Planting late in the growing season could result in increased (e.g. Butterhead), decreased (e.g. Crisphead), and no change (e.g. romaine) bitterness perception depending on the lettuce variety (Bunning et al., 2010). Heat exposure is another determinant of the taste profile. Lettuce thrives at a daily temperature range of 60 to 70 °F (University of Illinois Extension, 2017). While a higher growing temperature has been found to correlate with higher bitterness ratings, other evidence reveals no significant correlation of bitterness taste and heat exposure (i.e. number of days with temperature exceeding 86 °F) (Simonne, et al., 2002; Bunning, et al., 2010). Furthermore, bolting and leaf position have a considerable impact on the accumulation of bitterness compounds (Seo et al., 2009; University of Illinois Extension, 2017). Bolting of a plant refers to the transition from vegetative to reproductive growth when it starts flowering and seeding. Once a lettuce plant bolts, it becomes bitter. Therefore, factors that boost bolting would increase bitterness taste indirectly. Genotype and high growing temperature are the two major contributors of quick bolting (Simonne, et al. 2002; University of Illinois Extension, 2017). Lettuce varieties green leaf, crisphead, red leaf, romaine, and butterhead are bolting resistant, while 'Slobolt' is one of the varieties that bolt quickest (Bunning, et al. 2010; Simonne, et al., 2002).

Using the correct cultivar and protected agriculture structure increases the potential for lettuce production year-round and can help meet the demand of this fast-growing commodity for local market sales in Florida. A recent Florida survey shows the importance of the demand for local food year-round, especially in urban areas (Hochmuth and Toro, 2014). Most of the 240 growers responding to the survey indicated they were marketing their specialty crops locally and directly to consumers. In addition, lettuce and leafy green vegetables were often identified as key crop groups for direct marketing strategies. This project targets one of the most important greenhouse crops for direct marketers: lettuce. Production of lettuce during the summer in Florida normally ceases in fields and greenhouses due to extreme heat

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and humidity. Recent advances in technologies for greenhouse hydroponic production systems and heat tolerant cultivars may make it possible for lettuce crops to be grown through the summer and early fall season in Florida.

The hydroponic production system used in this trial was nutrient film technique (NFT), which is the predominant hydroponic system used for lettuce, and the most water-conserving production system available for lettuce. An NFT system consists of plastic or other lightweight channels, gutters, or tubes, with compartments in each container holding transplants, while a thin film of nutrient solution trickles over the bare roots of each plant. The nutrient solution is initially stored in a reservoir, pumped out into these channels which are held at a slight downward angle, drained down to a catchment system, then filtered or aerated and cycled back to the reservoir for reuse. Temperatures for NFT solutions during the summer in Florida will often be over 90 °F, causing lower oxygen levels and increase the risk of diseases such as Pythium root rot. In addition, tip burn, a physiological disorder related to poor calcium nutrition in the expanding leaves, is the most limiting disorder in lettuce during very high temperatures. Lettuce grown under very high temperatures often has a bitter taste and makes the product unmarketable. A nutrient solution chiller was used for this study to maintain solution temperatures below 85 °F during the day and near 72 °F at night. Reducing the solution temperature will increase plant health and reduce disease incidence.

Fifteen lettuce cultivars were chosen for this study based on their potential tolerance to high temperatures and resistance to tip burn. The trial included an industry standard ('Rex') and one additional bibb lettuce cultivar purchased from our local market for taste test comparison. A new lettuce category, Salanova type, was recently introduced by Johnny's Selected Seeds. Initial observations with Salanova lettuce varieties indicate they are more tolerant to high temperatures and tip burn. This trial included eight Salanova cultivars including: 'Green Butter', 'Red Butter', 'Green Sweetcrisp', Red Sweetcrisp', 'Green Oakleaf', 'Red Oakleaf', 'Green Incised', and 'Red Incised'. The industry standard butterhead variety, 'Rex', is known to have a high tolerance to tip burn and was used as the industry standard cultivar. Summercrisp or Batavian lettuces are also known for their heat tolerance and were represented in this trial.

Materials and Methods

The research was conducted at the Suwannee Valley Agricultural Extension Center near Live Oak, FL, in a passively ventilated greenhouse (30 x 60 ft.) having a roof consisting of two layers of clear polyethylene. The greenhouse has an automated ridge vent and roll-up side walls to facilitate ventilation. The greenhouse was covered with Aluminet (50% shade level), the standard in high-performing shading material from Signature Supply, Lakeland, FL.

Nutrient film technique is a water-culture technique that uses no media other than the transplant production cube, rockwool (Fig. 1), in this trial. Plants were grown with roots contained in a plastic channel (Crop King, Lodi, OH). The pH of the nutrient solution was set at 5.8 and the electrical conductivity (EC) was set at 1.2 decisiemens per meter. The nutrient solution provided approximately 120 ppm N, 50 ppm P, 200 ppm K, 48 ppm Mg, 220 ppm Ca, 60 ppm S, 3.5 ppm Fe, 0.3 ppm Cu, 1.3 ppm Mn, 0.3 ppm Zn, 0.7 ppm B, and 0.05 ppm Mo (Hochmuth and Hochmuth, 1990). An electric nutrient solution chiller was attached

Fig. 1. Lettuce cultivar transplants grown in rockwool cubes.

to the NFT nutrient reservoir (Fig. 2) and set to 72 °F, which kept the solution in the holding tank at or near 72 °F during the night hours, but temperatures during the day reached as high as 85 °F for a short period in the afternoon. The nutrient solution continuously circulated through the system.

There were 15 cultivars of lettuce grown on the site in the trial and two standard bibb lettuce heads were obtained from a local grocery store and added to the 15 grown on the site for the taste testing portion of the study. Lettuce plants were grown in channels in a randomized complete-block design with 3 replications (Fig. 3). Plants were spaced 6 inches apart in the channels with 5 plants per plot. The trial was conducted in early summer and duplicated at the end of the summer. Trial #1, plants were transplanted into the NFT channels 15 July 2015 and harvested on 11 Aug. 2015 Trial #2, plants were transplanted into NFT channels on 15 Sept. 2015 and harvested on 19 Oct. 2015 (Fig. 4). Lettuce marketable and unmarketable heads were recorded.

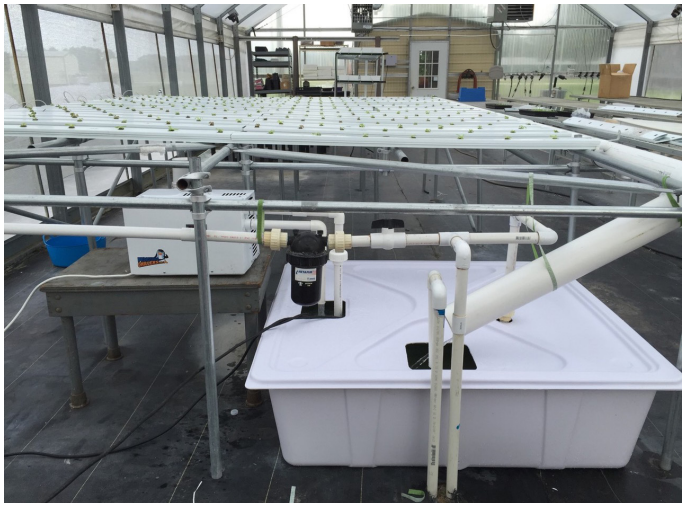

Fig. 2. Nutrient film technique system with solution chiller.

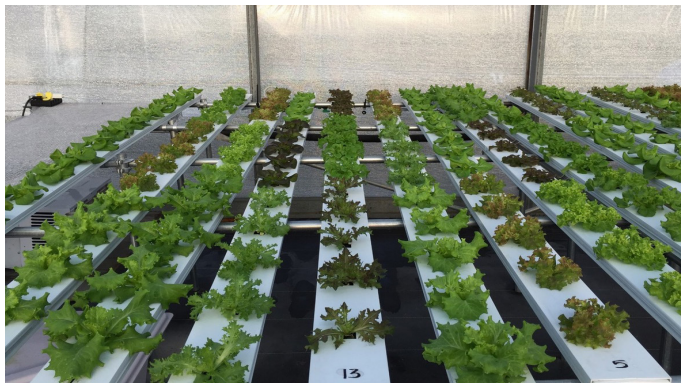

Fig. 3. Lettuce cultivar trial early in growing cycle.

Fig. 4. Lettuce cultivar trial at harvest stage.

Lettuce plant ratings for tip burn, bolting, head density, wilting and favorability were recorded. Ratings were on a scale from 0–5, where 0 = none and 5 = severe for tip burn, bolting, head density, and wilting; and for favorability 0 = not favorable, 5 = favorable. Lettuce plant height was also recorded but is not presented in this report. Insect pests and diseases were monitored using a weekly scouting program.

Data for the production phase of this trial were analyzed using mixed models procedures as implemented with Planting Time, Cultivar and Plating Time × Cultivar as fixed effects and Block (Time) as a random effect. The proportion of marketable yield was analyzed using Generalized Linear Mixed Models procedures with a binomial distribution function. In both cases, we used SAS PROC GLIMMIX. The means separation test was the least significant difference.

Lettuce bitterness evaluation was completed following the standard procedures described in detail by Simonne et al. (2002). In brief, experienced panelists tasted each coded lettuce variety for bitterness in comparison with a standard of a caffeine solution and used a scale of 0–15, where 0 = no bitterness and 15 = highly bitter (Fig. 5). The taste test sessions were conducted at each harvest time. The consistency of rating was confirmed by presenting the same sample twice with different coding every time a taste test was conducted. In addition, a standard variety of lettuce which is available at the market was added to the samples. To simplify the results, the average scores were further grouped into three categories of low (L, < 3.3), medium (M, 3.3–6.6), or high bitterness (H, > 6.6). Bitterness scores were analyzed using the SPSS one-way ANOVA with Duncan's multiple range

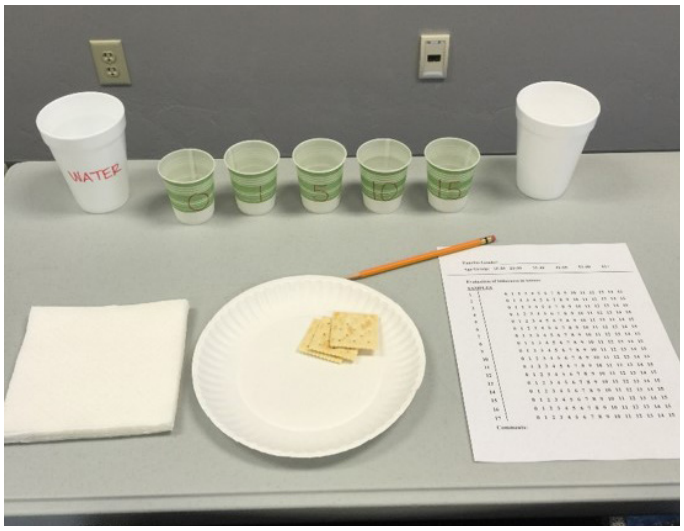

Fig. 5. Bitterness taste test station.

for mean separation.

Results and Discussion

Percentage of marketable heads. This trial was established using the cultivar, 'Rex', as the standard comparative cultivar for hot season culture. Several cultivars were similar to 'Rex' in percentage of harvested heads in the marketable category (Table 1). For the first harvest date (11 Aug.), cultivars with similar percentage of marketable heads to 'Rex' included: 'Flandria', 'Frank', 'Green Butter', 'Green Incised', 'Green Oakleaf', 'Muir', 'Red Oakleaf', and 'Red Sweetcrisp'. For harvests during 19 Oct., the percentage of marketable heads was lower overall, mostly due to bolting. 'Rex', however, had 100% of the heads in the trial graded as marketable. Similar percentages of marketable heads on 19 Oct. were found in 'Flandria', 'Frank', 'Green Butter', and 'Red Oakleaf'. Poor performing cultivars

Table 1. Percentage of marketable heads per plot of lettuce for summer production in a shaded vented greenhouse using nutrient film technique with chilled nutrient solution in Live Oak, FL.

	Marketable heads (%)	
Cultivar	11 Aug. 2015	19 Oct. 2015
Anntonet	30 bc	55 bcd
Flandria	100 a	60 abcd
Frank	100 a	75 abc
Green Butter	90 a	75 abc
Green Incised	75 a	35 cde
Green Oakleaf	85 a	5 e
Green Sweetcrisp	15 bc	5 e
Ilema	35 b	25 de
Muir	100 a	40 cde
Red Butter	30 bc	50 bcd
Red Incised	25 bc	20 de
Red Oakleaf	100 a	85 ab
Red Sweetcrisp	85 a	40 cde
Rex	80 a	100 a
Starfighter	0 c	5 e
SE[y]	14.6	17.0

[y]Standard error.

Table 2. Average head density rating of lettuce cultivars for summer production in a shaded vented greenhouse using nutrient film technique with chilled nutrient solution in Live Oak, FL.

	Head density rating[z]	
Cultivar	11 Aug. 2015	19 Oct. 2015
Anntonet	2.0 ef	2.8 cde
Flandria	3.5 bc	3.5 abc
Frank	3.5 bc	4.8 a
Green Butter	2.8 d	3.3 bcd
Green Incised	2.8 d	2.0 def
Green Oakleaf	4.2 a	4.3 ab
Green Sweetcrisp	0.5 h	0.3 g
Ilema	2.0 ef	1.8 ef
Muir	3.0 cd	3.3 bcd
Red Butter	2.5 de	4.3 ab
Red Incised	1.5 fg	0.8 fg
Red Oakleaf	2.8 d	4.7 a
Red Sweetcrisp	1.3 g	2.8 cde
Rex	3.7 ab	4.8 a
Starfighter	0.5 h	2.0 def
SE[y]	0.24	0.52

[z]Density rating scale 0–5, where 0 = open/loose, 5 = closed/dense.
[y]Standard error.

Table 3. Average bolting rating of lettuce for summer production in a shaded vented greenhouse using nutrient film technique with chilled nutrient solution in Live Oak, FL.

	Average bolting rating[z]	
Cultivar	11 Aug. 2015	19 Oct. 2015
Anntonet	3.0 de	3.8 abc
Flandria	1.5 fg	2.0 def
Frank	0.7 g	1.3 ef
Green Butter	0.7 g	1.3 ef
Green Incised	2.5 de	4.0 abc
Green Oakleaf	1.5 fg	3.5 abcd
Green Sweetcrisp	4.5 ab	5.0 a
Ilema	3.2 cd	4.5 ab
Muir	1.2 g	3.5 abcd
Red Butter	3.2 cd	2.8 cde
Red Incised	4.0 bc	4.5 ab
Red Oakleaf	1.2 g	2.0 def
Red Sweetcrisp	2.2 ef	3.3 bcd
Rex	1.0 g	1.0 f
Starfighter	5.0 a	5.0 a
SE[y]	0.47	0.64

[z]Lettuce bolting rating 0–5, where 0 = open/loose, 5 = closed/dense.
[y]Standard error.

for percentage of marketable heads in both trials included: 'Anntonet', 'Green Sweetcrisp', 'Ilena', 'Red Butter', 'Red Incised', and 'Starfighter'.

Head density ratings. Heads within a plot were rated for the density of the heads using the following rating scale: 0–5, where 0 = open/loose heads, and 5 = closed/dense compact heads (Table 2). This rating is provided as a relative comparison of the natural composition of the cultivar's head. Some cultivars normally have a loose or dense head. More dense heads were typically found in 'Green Oakleaf', 'Rex', and 'Frank'. Loose and open head habit was typically found in 'Starfighter', 'Green Sweetcrisp', 'Red Sweetcrisp', 'Red Incised', and 'Ilena'.

Susceptibility to bolting. Bolting, the development of a flowering or seed head, is a common negative characteristic of greenhouse lettuce, especially during high temperatures. Overall, higher levels of bolting were found in the second trial (19 Oct. harvest). This trial could have been harvested a couple of days earlier, which would have reduced the overall bolting ratings on 19 Oct. (Table 3). However, the October harvest date was not unusually delayed. 'Starfighter' was especially susceptible to bolting in both trials. Other cultivars with relatively high susceptibility to bolting included: 'Anntonet', 'Green Incised', 'Green Sweetcrisp', 'Ilena', 'Red Butter', 'Red Incised', and 'Red Sweetcrisp'. Those cultivars typically tolerant to bolting in both trials included: 'Flandria', 'Frank', 'Green Butter', 'Red Oakleaf', and 'Rex'.

Susceptibility to tip burn. Tip burn is caused by insufficient calcium levels in developing leaves. Tip burn may occur even if adequate calcium levels are in the nutrient solution. During very high temperatures, tip burn in lettuce can be more likely to express and cultivars vary greatly in susceptibility to tip burn. Tolerance to tip burn is one of the most important characteristics in greenhouse lettuce cultivar selection, especially during periods of consistently high temperatures. Tip burn ratings were assigned based on a 0–5 scale, where 0 = no tip burn detected, 5 = severe tip burn on all heads. More tip burn was detected during the first trial and is summarized here (Table 4). During the first trial, harvested on 11 Aug., highest levels of tip burn were found in ''Red Butter' and 'Starfighter'. All other cultivars had little or no tip burn detected during the first trial and no significant differences were found in the remaining cultivars. During the second trial, overall low levels of tip burn were observed, however, the highest levels of tip burn were observed in 'Green Butter', 'Anntonet', and 'Red Sweetcrisp'. No tip burn was observed in any other cultivars during the second trial. The low incidence of tip burn was very encouraging and likely due to good cultivar selections for testing in this trial.

Table 4. Average tip burn rating of lettuce for summer production in a shaded vented greenhouse using Nutrient Film Technique with chilled nutrient solution in Live Oak, FL.

	Average tip burn rating[z]	
Cultivar	11 Aug. 2015	19 Oct. 2015
Anntonet	1.0 b	0.3 ab
Flandria	0.0 b	0.0 b
Frank	0.0 b	0.0 b
Green Butter	1.0 b	0.5 a
Green Incised	0.0 b	0.0 b
Green Oakleaf	0.5 b	0.0 b
Green Sweetcrisp	0.0 b	0.0 b
Ilema	0.5 b	0.0 b
Muir	0.0 b	0.0 b
Red Butter	2.3 a	0.0 b
Red Incised	0.0 b	0.0 b
Red Oakleaf	0.0 b	0.0 b
Red Sweetcrisp	0.0 b	0.3 ab
Rex	1.0 b	0.0 b
Starfighter	2.5 a	0.0 b
SE[y]	0.41	0.12

[z]Tip burn rating scale 0–5, where 0 = none 5 = severe.
[y]Standard error.

Susceptibility to Wilting. Certain cultivars were susceptible to moderate to severe wilting during daytime hours, especially

Table 5. Average wilt rating of lettuce cultivars for summer production in a shaded vented greenhouse using Nutrient Film Technique with chilled nutrient solution in Live Oak, FL.

	Average wilt rating[z]	
Cultivar	11 Aug. 2015	19 Oct. 2015
Anntonet	0.8 C	0.0 a
Flandria	0.0 E	0.0 a
Frank	0.0 E	0.0 a
Green Butter	0.0 E	0.0 a
Green Incised	0.3 De	0.0 a
Green Oakleaf	0.0 E	0.0 a
Green Sweetcrisp	3.0 B	0.0 a
Ilema	0.5 Cd	0.0 a
Muir	0.0 E	0.0 a
Red Butter	0.0 E	0.0 a
Red Incised	0.8 C	0.0 a
Red Oakleaf	0.3 De	0.0 a
Red Sweetcrisp	3.8 A	0.0 a
Rex	0.0 E	0.0 a
Starfighter	0.3 De	0.0 a
SE[y]	0.17	0.0 a

[z]Wilt rating scale 0–5,where 0 = none, 5 = severe.
[y]Standard error.

Table 7. Bitterness grouping of lettuce varieties.

	Bitterness grouping	
Cultivar	12 Aug. 2015	10 Oct. 2015
Rex	M	L
Frank	M	M
Flandria	M	M
Ilema	H	M
Anntonet	H	L
Muir	L	L
Starfighter	M	L
Green Incised	H	M
Red Incised	H	M
Green Butter	M	M
Red Butter	L	M
Green Sweetcrisp	M	M
Red Sweetcrisp	M	L
Green Oakleaf	M	L
Red Oakleaf	L	M
Rex (repeated)	M	M
Control Bib	L	L

[z]Bitterness grouping was based as follows: Low (L) = mean bitterness score of < 3.3; Medium (M)= mean bitterness score of 3.3 < Mean < 6.6, and High (H) = mean bitterness score of >6.6.

during the hottest periods of the day. No wilting was observed in the second trial reported here (Table 5). 'Red Sweetcrisp' and 'Green Sweetcrisp' were very susceptible to wilting in the first trial. Several cultivars had no wilting detected during the first trial, including: 'Flandria', 'Frank', 'Green Butter', 'Green Oakleaf', 'Muir', 'Red Butter', and 'Rex'.

Overall favorability of harvested product rating. During harvest, four people rated the plots for overall favorable appearance at the time of harvest, coming to a consensus rating (Table 6). Favorability rating scale was 0–5, where 0 = not favorable and 5 = very favorable. Overall favorability of the harvested heads was not always consistent between the two trials. However, consistently high favorability ratings were found for 'Flandria', 'Frank', 'Green Butter', 'Muir', 'Red Butter', 'Red Oakleaf', and 'Rex'. Consistently low favorability was found for 'Green Sweetcrisp', 'Ilena', 'Red Incised', and 'Starfighter'.

Table 6. Average favorability of harvested heads of lettuce cultivars for summer production in a shaded vented greenhouse using Nutrient Film Technique with chilled nutrient solution in Live Oak Florida.

	Average favorability rating[z]	
Cultivar	11 Aug. 2015	19 Oct. 2015
Anntonet	2.9 cd	3.1 bcd
Flandria	4.7 ab	3.6 ab
Frank	4.9 A	4.1 ab
Green Butter	4.4 ab	3.8 ab
Green Incised	3.8 bc	1.9 de
Green Oakleaf	4.4 ab	1.9 de
Green Sweetcrisp	1.4 ef	0.5 f
Ilema	2.6 D	2.2 cde
Muir	4.9 A	3.2 Bcd
Red Butter	3.0 cd	3.7 Ab
Red Incised	2.3 de	1.1 Ef
Red Oakleaf	4.3 ab	4.2 Ab
Red Sweetcrisp	2.6 D	3.5 Abc
Rex	4.1 ab	4.7 A
Starfighter	0.7 F	1.9 De
SE[y]	0.44	0.54

[z]Favorability rating based on overall appearance of the lettuce plant. Favorability rating 0–5, where 0 = not favorable, 5 = very favorable.
[y]Standard error.

Bitterness scores. Bitterness grouping for each cultivar and growing time is provided in Table 7. Overall, only four cultivars of lettuce received scores higher than 6.6, and they were Ilema (7.7), Anntonet (8.7), Green (7.1) and Red Incised (7.6). The high bitterness scores only occur during the first harvest in August, while the highest bitterness score during the October harvest was only up to 4.5, which is within the grouping of low and medium. The result reveal that with right variety and growing condition in North Florida, bitterness scores of lettuces could be within the acceptable level.

Conclusions

This trial was conducted to evaluate the performance of several lettuce cultivars grown in an NFT system in the hottest months of the year in North Florida (July–September). This trial implemented a few cultural practices to potentially reduce stress and improve quality. Those practices included deploying a 50% Aluminet shade material on the top and west side of the greenhouse and using a nutrient solution chiller to reduce solution temperatures.

The standard cultivar used by greenhouse growers during the summer months is typically 'Rex', so all other cultivars were compared to 'Rex' as the standard. The results of this trial indicate that several cultivars produced very acceptable quality and marketable heads like the quality seen in 'Rex'. The cultural practices implemented also show evidence of helping to improve the culture of lettuce grown during the summer months of Florida in a greenhouse. Inside air temperatures typically peaked at over 110 °F daily during Trial 1 and over 95 to 100 °F during Trial 2. The results were surprisingly successful for producing

high quality lettuce heads in several cultivars. The overall top performers from a greenhouse production standpoint were: 'Flandria', 'Frank', 'Green Butter', 'Muir', 'Red Oakleaf', and 'Rex'. In terms of low bitterness, 'Muir' was equal in rating to the store-bought bibb lettuce. Those cultivars rated as medium or low bitterness in the taste test included: 'Muir', 'Rex', 'Red Butter', 'Red Sweetcrisp', 'Starfighter', 'Green Oakleaf', and 'Red Oakleaf'. Those cultivars performing well in both production quality and taste included: 'Muir', 'Rex', 'Green Oakleaf', and 'Red Oakleaf'.

These results indicate that lettuce can be grown year-round in greenhouses using hydroponic techniques and deploying the innovative use of shading systems and nutrient solution chillers. Several cultivars were proven to be excellent performers both in greenhouse production and in taste testing for quality parameters.

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