Received: 31 May 2019 | Accepted: 21 September 2019 | Published online: 6 February 2020

DOI: 10.1002/agj2.20136

Agronomy Journal

ARTICLE

Agronomic Application of Genetic Resources

Evaluation of edamame genotypes suitable for growing in Florida

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Funding information
Florida Department of Agriculture and Consumer Service, Grant/Award Number: # USADA-AMS-SCBGP-2015; USDA National Institute of Food and Agriculture Hatch, Grant/Award Number: FLA-JAY-005475; Mass Spectrometry Research and Education Center, University of Florida, Grant/Award Number: NIH S10 OD021758-01A1

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Abstract

Edamame, or vegetable soybean, has gained popularity in the United States, likely due to its nutritional quality, purported human health benefits, and flavor. Little information is available about the performance of current edamame cultivars in Florida areas. The objective of this study was to evaluate yield and production potential of edamame genotypes in northern Florida. Nineteen genotypes (based on preliminary study) were selected and planted at two locations (Jay and Citra) to evaluate phenotypic performance, including emergence, plant height, nodes per plant, 100-green seed weight, fresh pod yield, percentage of 1-, 2-, and 3-seeded pods, total lipid concentration, and total protein content. Genotypes and locations showed a significant effect on most of the traits studied. Edamame grown at Jay produced significantly higher yield and 100-green seed weight than the plants grown at Citra. Two early maturing genotypes (PI614832 and PI584470) and one late maturing genotype (PI633424) showed high yield potential, >30 g of 100-green seed weight, and high protein content at Jay. In addition, PI417206 showed the highest 100-green seed weight across locations (50.81 g) and demonstrated moderate yield potential with high protein content and low lipid concentration and may be a suitable candidate for cultivation in different areas in Florida after further evaluation. Number of pods per plant and 100-green seed weight significantly correlated with pod yield, could be considered as selection tool for edamame yield under Florida growing conditions. This study has established a basic knowledge on edamame production for Florida growers and selected lines suitable for the region.

1 | INTRODUCTION

Edamame [*Glycine max* (L.) Merr.], or vegetable soybean, is an immature edible soybean, typically harvested at the reproductive stage 6 (R6) of development (Fehr, Caviness, Burmood, & Pennington, 1971). Edamame is a nutritional food-grade vegetable popular in the global market and has gained widespread acceptance in the United States within the last 30 yr (Johnson, 2000; Shurtleff & Aoyagi, 2009). The demand for edamame has increased in the United States as a healthy snack or vegetable, or as a salad component (Dong, Fu, Yuan, Chen, & Zhu, 2014; Sams, Pantalone, Kopsell, Zivanovic, & Deyton, 2012). Whereas edamame pods or beans are used as human food, the leaves and shoots can be used as forage, like most legumes, and tend to be high in

Abbreviations: MG, maturity group; PSREU, Plant Science Research and Education Unit; WFREC, West Florida Research and Education Center.

protein and low in fiber compared to grasses, which makes edamame excellent forage if harvested properly.

Demand for edamame in the USA was estimated to have a fourfold increase from 2000 to 2008 and predicted to increase at 12 to 15% per year (Cartright & Medders, 2012; Sams et al., 2012). In the USA, between 22,700 to 27,270 Mg of edamame was consumed in 2013, and it was considered the second most important soy food after soymilk (Nuss, 2013; Soyfoods, 2014). The broad acceptance and demand of edamame is increasing in the USA mostly due to its health benefits, including lowering low-density lipoprotein (LDL) cholesterol levels and reducing the risk of cardiovascular disease (Sánchez, Kelley, & Butler, 2005; Wszelaki et al., 2005). It is one the few plant-based foods which contain all the essential amino acids and certain antioxidants such as isoflavones (Velasquez & Bhathena, 2007; Wang & Murphy, 1994). In the past few years, some food companies, with the help of public universities, have begun production of edamame in the states of Arkansas, Washington, North Carolina, Kentucky, Illinois, Virginia, and Pennsylvania (Carson, Freeman, Zhou, Welbaum, & Reiter, 2011; Lumpkin, Konovsky, Larson, & McClary, 1993; Ogles, Guertal, & Weaver, 2016; Rao, Bhagsari, & Mohamed, 2002; University of Kentucky Extension, 2013; Williams, 2015; Wszelaki et al., 2005). The growing demand has attracted plant breeders and food industries to find suitable varieties for production in different regions of the USA. Currently, edamame for US consumption is imported as well as grown domestically. It was estimated that 97% of edamame is imported from China into the USA (Roseboro, 2012). The primary production areas for edamame in the USA are on the West Coast and Upper Midwest; however, most frozen edamame is imported from China (Shurtleff & Aoyagi, 2009). Therefore, food processers and packagers seek local sources to fill the expanding need.

Previous studies on edamame production and variety selection are limited. Some previous studies were conducted to find suitable edamame varieties for different growing areas in the USA including North Dakota, Illinois, Virginia, Alabama, Mississippi, and Georgia (Duppong & Hatterman-Valenti, 2005; Hunsberger et al., 2007; Ogles et al., 2016; Williams, Herman, & Nelson, 2012). Soybean maturity groups (MGs) are mainly governed by latitude and are important to soybean cultivar development (Board & Hall, 1984). It is important that cultivars are adapted to the latitude in which produced. For instance, cultivars adapted to long daylengths (e.g., MGs II or III) will present premature blooming when grown under the shorter daylengths in the south (Board & Hall, 1984). Although lower yield was observed in edamame in some areas, but the magnitude of lower yield could potentially be contributed to the evaluation of genotypes in different environments where they are not adapted (Cregan & Hartwig, 1984). In a study, Rao et al. (2002) evaluated 12 edamame genotypes collected from Japan and China in a 4-yr study

Core Ideas

- Edamame could be a high value crop for Florida fresh food market.
- There is no information is available on production, processing, and specific varieties adapted for the Florida environment.
- Ninety-three edamame genotypes with diverse origin were evaluated in central and northern Florida.
- Four edamame genotypes showed relatively high yield potential, high green seed weight and adaptation.
- The present study established a basic knowledge on the production of edamame for Florida growers and selected lines suitable for the region.

at Fort Valley, Georgia. They reported mean fresh pod and seed yields of 18.5 and 9.6 Mg ha^{-1}, respectively. Seed oil and protein contents ranged from 130.7 to 155.8 and 333.2 to 386.0 g kg^{-1}, respectively. Duppong and Hatterman-Valenti (2005) reported a 6471 to 11,341 kg ha^{-1} total marketable fresh pod yield of five vegetable soybean cultivars in Prosper, North Dakota. They also found significant differences for the percentage of 1-, 2-, and 3-seeded pods among five cultivars. Zhang and Kyei-Boahen (2007) evaluated seven cultivars in a 2-yr field study in the Mississippi Delta. Fresh pod yield ranged from 4535 to 21,430 kg ha^{-1}. Morphological characteristics of plant height, nodes per plant, and pods per plant varied between 17 and 145 cm, 7.5 to 25.8, and 29.9 to 76, respectively. The authors also concluded that the estimated net returns could be more than twice the returns from growing the regular commodity soybean using the Mississippi State Budget Generator as a guide. Carson et al. (2011) compared five edamame cultivars in Painter, Virginia and reported a fresh pod yield from 5607 to 8430 kg ha^{-1}. In their study, the 100-seed weight ranged from 47.5 to 68 g. Lipid concentration varied between 12.9 and 18.3 g 100 g^{-1} whereas protein concentration ranged from 36.1 to 39.5 g 100 g^{-1}. Ogles et al. (2016) evaluated 11 cultivars and reported a total fresh pod yield from 2592 to 15,960 kg ha^{-1} in Central Alabama. Their study also indicated a varied emergence rate among genotypes and the percentage of 2- or 3-seeded pods ranged from 65 to 91%. However, the performance of edamame production in the US MG VIII regions (north and north-central Florida) is unknown.

Research has demonstrated that the consumer demand for locally grown food is rapidly increasing in Florida (Hodges, Stevens, & Wysocki, 2016). Edamame is a potential source for locally grown food to meet the demand of fresh food for Florida consumers. Due to climatic conditions and soil types in Florida, edamame can be grown and sold by the growers as a high value crop in the local fresh food market. Edamame may diversify crop production for Florida producers as well and may increase income of small farmers. The University of Kentucky Extension (2013) showed that the profit potential of edamame could be $4,940 to $5,434 per hectare of land with hand harvesting and management on the fresh, wholesale market. The same report projected that production using a mechanical harvester with direct local market access could likely result even in higher profit. Despite being a high value crop, there are only few edamame producers in Florida, likely due to lack of information on production, processing, and specific varieties adapted for the Florida environment. Based on the increasing demand of consumption in the past decade in the USA, there will be need for increase in production of edamame to meet future demand. Because of high market value, the findings of the present research might motivate growers toward edamame cultivation in Florida. In conjunction with edamame related studies in Alabama (Ogles et al., 2016) and Georgia (Rao et al., 2002), this research provides information regarding genotype selection for the southern USA. The goal of this study was to investigate the feasibility of edamame production for growers of Florida. The specific objectives were: (i) to evaluate the yield and production potential of the edamame genotypes in Florida, (ii) to assess the associations between fresh pod yield and other phenotypic traits, and (iii) to evaluate selected cultivars for nutritional content.

2 | MATERIALS AND METHODS

In 2016, 80 soybean genotypes (74 edamame and 6 maturity checks) were collected from the USDA Soybean Germplasm Collection, Urbana, Illinois, while 19 edamame genotypes were collected from the Asian Vegetable Research and Development Center (AVRDC), Tainan, Taiwan. For genotypes collected from the USDA Soybean Germplasm Collection, the GRIN database was used and the genotypes with seed weight >20 g per 100-seed at the R8 reproductive stage were selected for the study. The maturity groups (MGs) of the edamame genotypes collected from the USDA Soybean Germplasm Collection ranged from MGs III–VIII. The 99 genotypes (including maturity checks) were planted for evaluation at the Plant Science Research and Education Unit (PSREU) in Citra, FL (north central Florida; 29°24′ N, 82°10′ W), while 80 genotypes were planted at the West Florida Research and Education Center (WFREC) in Jay, FL (northwest Florida; 30°46′ N, 87°8′ W). Nineteen genotypes (including one maturity check, PI614832, that showed >30 g per 100-green seed weight) were selected based on their field performance, phenotype, and predicted maturity group range (Table 1) for evaluation in the following year (2017) in a replicated yield trial at the same two locations. Inoculated seeds, using TerraMax Dry Soybean Inoculant (contains two strains of *Bradyrhizobium Japonicum*), were planted with a cone planter at the rate of 18 seeds m^{-2} on 3 May and 6 July of 2017 at PSREU and WFREC, respectively. The planting at WFREC was delayed due to excessive rain during May and June 2017. The experiment was planted in a randomized complete block design with three replications with four-row (3.05 m length and 3.66 m width) plots and a row spacing of 0.914 m. Plots at the PSREU were planted 3.8 cm deep on a loamy sand soil (Tavares sand, hyperthermic, uncoated Typic Quartzipsamments; 97% sand, 1% silt, and 2% clay) with a history of cotton and corn cultivation. Fertilizer was broadcasted at the rate of 130 kg P_2O_5 ha^{-1}, 140 kg K_2O ha^{-1}, and 24 kg S ha^{-1} at planting. Pendimethalin at the rate of 1065 g a.i. ha^{-1} was applied right after planting prior to emergence. The post plant herbicide, clethodim, at the rate of 124 g a.i. ha^{-1} was applied about 60 d after emergence. Post plant fungicide, Quadris Top, at the rate of 0.98 kg ha^{-1} was applied three times to control foliar diseases. Plots at the WFREC were planted 1.3 cm deep on a field with a history of cotton, corn, and sesame rotation on an Orangeburg sandy loam 0 to 2% slopes (fine-loamy, kaolinitic, thermic Typic Kandiudults) consisting of 77% sand, 14% silt, and 9% clay. Two weeks after planting, 115 kg P_2O_5 ha^{-1}, 127 kg K_2O ha^{-1}, and 24 kg S ha^{-1} were applied. Considering a heavier soil texture at the WFREC and the need for adequate weed control, a pre-emergence application of pendimethalin at 1065 g a.i. ha^{-1} and metribuzin at 315 g a.i. ha^{-1} was made immediately after planting. Post-emergence weed control was achieved using a tank mix of bentazon at 841 g a.i. ha^{-1} and chlorimuron ethyl at 35 g a.i. ha^{-1}. Three fungicide applications were made 32, 49, and 66 d after planting using pyraclostrobin at 146 g a.i. ha^{-1}, pyraclostrobin at 146 g a.i. ha^{-1}, and azoxystrobin at 182 g a.i. ha^{-1}, respectively, were applied to control foliar diseases. Plots were irrigated as needed. Weather data, including average temperature (60 cm above canopy) and precipitation, were retrieved from Florida Automated Weather Network (FAWN) and the National Oceanic and Atmosphere Administration (NOAA) for each location (Figures 1 and 2).

2.1 Phenological, morphological and yield related traits

Percentage emergence data was calculated after 3 wk of planting from the middle two rows by comparing the number of emerged seedlings to the number of seeds planted [Percentage of emergence (%) = 100 × plants m^2/seeds m^2]. Reproductive stage 1 (R1; beginning of flowering) and reproductive stage 6 (R6; green bean stage) was calculated from days to planting to 50% of plants in a plot at R1 and R6 stages, respectively. At the R6 stage, five consecutive plants in the

TABLE 1 Plant introduction numbers, seed sources, names, predicted maturity, and emergence at both locations for each genotype evaluated in this study: the Plant Science Research and Education Unit (PSREU) in Citra, FL, and the West Florida Research and Education Center (WFREC) in Jay, FL

PI[a] number/AGS[b] number	Origin	Name	Predicted maturity	Emergence at PSREU	Emergence at WFREC
				%	
PI548587	United States	Kin	III	67	51
PI614832	Nebraska, USA	NE3400	III	85	70
PI642768	United States	Ohio FG5	III	71	47
PI584470	United States	Ohio FG2	III	72	47
PI584469	United States	Ohio FG1	III	61	41
PI089162	North Korea	Hawante	III	28	30
PI662960	United States	Gardensoy 41	IV	77	60
PI662961	United States	Gardensoy 42	IV	83	64
PI662962	United States	Gardensoy 43	IV	73	62
PI423980	Japan	Tsurunoko	V	85	67
PI398401	South Korea		V	74	57
PI662963	United States	Gardensoy 51	V	61	41
PI633049	United States	Asmara	VI	74	51
AGS357	AVRDC, Taiwan		VI	80	63
PI633424	United States	Randolph	VI	76	61
AGS358	AVRDC, Taiwan		VII	70	50
AGS378	AVRDC, Taiwan		VII	86	64
AGS383	AVRDC, Taiwan		VII	81	68
PI417206	Japan		VII	70	47
LSM ± SE[c]				72.3 ± 13	54.7 ± 11

[a]Plant introduction number (source: http://www.ars-grin.gov).
[b]Asian Vegetable Research and Development Centre accession number.
[c]Least squares means ± standard error.

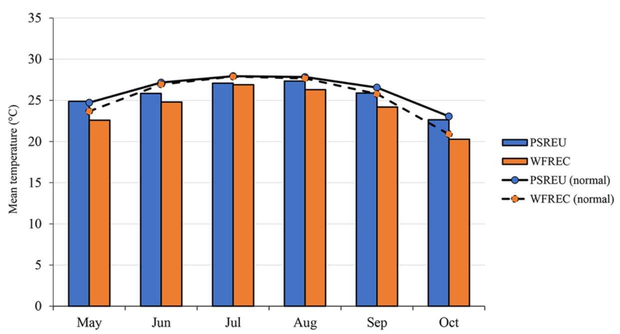

FIGURE 1 Monthly mean air temperature (60 cm) during May-October 2017 with 30-yr average at the Plant Science Research and Education Unit (PSREU) in Citra, FL, and the West Florida Research and Education Center (WFREC) in Jay, FL. Mean temperature was from Florida Automated Weather Network and National Weather Service (FAWN); 30-year monthly average was from NOAA National Centers for Environmental Information

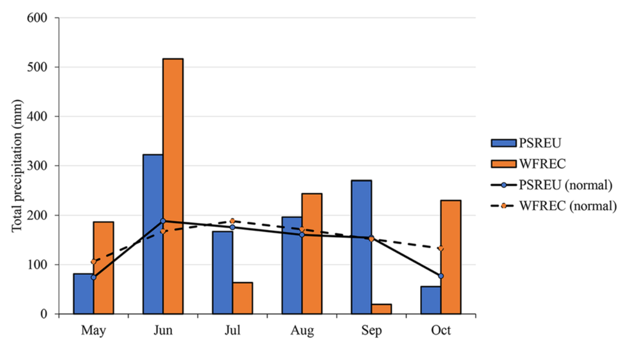

FIGURE 2 Monthly total precipitation during May-October 2017 with 30-yr average at the Plant Science Research and Education Unit (PSREU) in Citra, FL, and the West Florida Research and Education Center (WFREC) in Jay, FL. Mean temperature was from Florida Automated Weather Network and National Weather Service (FAWN); 30-year monthly average was from NOAA National Centers for Environmental Information

two middle rows were hand-harvested by clipping off whole plants above the soil and counting the number of nodes per plant, the number of harvestable pods per plant, the number of 1-, 2-, and 3-seeded pods, fresh pod weight, and green seed weight. These pods were calculated back into the final yield. Yield data were obtained by multiplying harvestable fresh pod weight per plant by the final plant stand [Fresh pod yield (kg ha^{-1}) = final plant stand ha^{-1} × fresh pod weight plant^{-1}].

Plant height was measured from soil level to plant apex at the R6 stage. After recording of fresh weight of the pods with seeds, 200 fresh pods were randomly selected and shelled, and 100 green seeds randomly selected to record 100-green seed weight. All pod yield and seed weight data were expressed on fresh weight basis. A random sample of fresh green seeds harvested at the R6 stage was dried at 60°C for 7 d and ground to a fine powder and stored at −20°C for quality analysis.

2.2 Protein and lipid estimation

The total protein analysis was performed at the Forage Evaluation Support Laboratory at the University of Florida. For nitrogen analysis, samples were digested by using a modified aluminum block digestion procedure of Gallaher, Weldon, and Futral (1975). A 0.25-g fine powder (1-mm sieve) subsample was placed in a 75 ml digestion tube. A digestion mixture of 1.5 g 9:1 K_2SO_4:$CuSO_4$, 4.5 ml of neat sulfuric acid, and 2.0 ml of hydrogen peroxide (30%) were added to each tube. Tubes were set in a digestion block (120-tube Martin Machine Magnum Series, Ivesdale, Illinois) and digested at 375°C for 4 h. Heat was applied until the digest turned clear green in color. Tubes were cooled overnight before adding deionized water until the digest turned light blue. Nitrogen in the digestate was determined by semiautomated colorimetry using an Alpkem Rapidflow Analyzer II according to the Association of Analytical Communities (AOAC) approved Method No. 506–77A (Hambleton, 1977). The absorbance of the ammonia-salicylate complex was measured at 660 nm. The concentration of ammonia complex was determined using colorimete and recorded as a peak on a printer. Peak heights were compared to known standards and converted into percentage N in solution. The percentage N was multiplied by 6.25 to estimate total protein (Hambleton, 1977).

The estimation of total lipid concentration was performed at the Mass Spectrometry Research and Education Center at the University of Florida using the sulfo-phospho-vanillin assay (Knight, Anderson, & Rawle, 1972). All lipids and samples were handled using glass pipettes (Nichipet ECO from Sigma-Aldrich), glass lined micro well plates (WebSeal Plate + 96-Well Glass-Coated Microplates from Thermo Fisher Scientific, Waltham, Massachusetts), and Teflon-covered vials. Lipids from 10 mg of ground seed (1-mm sieve) subsamples were extracted using the Bligh and Dyer extraction method (Bligh & Dyer, 1959). Standard lipid stocks of soy extract standard (Avanti Lipids, Alabaster AL) were prepared using 100 mg ml^{-1} in 4:1 chloroform/methanol. They were stored at a temperature of −20°C until further use. A calibration curve was prepared using this mixture as the stock solution. The calibration curve consisted of concentrations ranging from 0 to 100 μg μl^{-1} and was prepared in a 2:1 ratio of chloroform/methanol. Ten microliters of each calibration standard and sample extracts in triplicate were added to glass coated wells in a 96 well plate. The samples were evaporated to dryness by placing the plate on a heating block at 95°C. One hundred microliters of sulfuric acid (95%) was added to the wells and heated at 95°C for 20 min. Absorbance was measured using colorimetry (Molecular Devices, SpectraMax Plus 384 Microplate Reader) at 540 nm. Fifty microliters of 1.2 mg ml^{-1} vanillin solution in 60% phosphoric acid was added to each well and incubated in the dark for 10 min. The final color change was measured at 540 nm. The sulpho-phospho-vanillin results were determined by the difference between the post-vanillin and pre-vanillin absorbance readings.

2.3 Statistical analysis

Analysis of variance (ANOVA) was performed with genotype and location as a fixed effects and block as random effect in the following linear mixed model:

$$Y_{ijk} = \mu + G_i + B_{j(k)} + L_k + GL_{ik} + e_{ijk}$$

where Y_{ijk} was the observed value; μ was the general genotype mean; G_i was the genotypic effect (i = 1 to 19); L_k was the environment effect (k = 1 to 2); $B_{j(k)}$ was the block effect (j = 1 to 3) within the kth location; GL_{ik} was the ith genotype by kth location interaction effect; and e_{ijk} was the random error. Phenotypic performance of each genotype was represented by least squares means (LSM) for each trait. Broad sense heritability (H^2) was calculated using the following formula, $H^2 = (\sigma^2_G)/(\sigma^2_G + \sigma^2_{GL/l} + \sigma^2_{E/lr})$, where σ^2_G, $\sigma^2_{GL/l}$, and $\sigma^2_{E/lr}$ were variances due to genotype, genotype × location, and error, respectively; and E and r were the number of locations and replications (Babar, van Ginkel, Reynolds, Prasad, & Klatt, 2007). Comparison of population means was calculated using Tukey's Post-Hoc test for the traits with a significant difference (P = .05) among genotype at both locations. Means were determined for all traits at each location and used for pairwise Pearson correlation analyses. Data analysis, including ANOVA, means separation, and correlation analyses, were performed using R (R Development Core Team, 2018).

3 | RESULTS AND DISCUSSION

3.1 Location and weather

In general, PSREU had higher temperatures than WFREC (Figure 1). Unusually high precipitation occurred during June at both locations, and low precipitation was observed in July and September at WFREC (Figure 2). In June, precipitation was higher at WFREC compared to PSREU. In September, PSREU had higher precipitation than WFREC and the 30-yr average. Overall, PSREU had consistently higher temperatures than WFREC throughout the growing season, whereas WFREC had more precipitation than PSREU. Additionally, two locations had different soil types, where the WFREC had a heavier soil texture than PSREU.

3.2 Genotype selection

There are no recommended edamame varieties for Florida growing conditions. An evaluation of edamame genotypes from different origins and maturity groups in 2016 showed that most of these genotypes were unsuitable for growing under Florida conditions. Of the 99 genotypes tested in 2016, the nineteen genotypes selected had moderate to high yield potential with varying maturity adaptations, acceptable phenotype, disease tolerance, emergence and survival.

3.3 Emergence

Emergence was significantly higher at PSREU (72.3% ± 13) than WFREC (54.7% ± 11) (mean ± SE) (Table 1). Genotype PI612157 had the highest emergence percentage (86%). The poorest emergence was found in genotype PI089162 (28%) at PSREU. At WFREC, PI648270, and PI089162 exhibited the highest (67%) and the lowest (30%) emergence, respectively. Emergence was lower than expected at both locations. It is likely that heavy rainfall and high temperature after planting may have contributed to lower emergence, particularly at WFREC. In addition, the application of metribuzin PRE could potentially explain lower emergence at the WFREC as soybean is sensitive to metribuzin (Barrentine, Edwards, & Hartwig, 1976). Previous studies also reported difficulties in establishing adequate emergence of edamame under different environmental conditions (Duppong & Hatterman-Valenti, 2005; Rao et al., 2002; Sánchez et al., 2005). Emergence was highly variable among genotypes, which corroborate studies by Duppong and Haterman-Valenti (2005), Sánchez et al. (2005), and Hunsberger et al. (2007). Though overall emergence percentage was low in the present study, the selected genotypes had higher average emergence than results previously reported by Williams (2015).

3.4 Genotype, location, interactions, and broad-sense heritability

Significant phenotypic differences existed among genotypes for all traits measured (Table 2). The location effect was significant for emergence, days to R1 and R6, height, number

TABLE 2 Analysis of variance and broad sense heritability (H^2) for physiological, yield component and quality traits of 19 vegetable soybean genotypes

	df	Emergence	Days to R1 stage	Days to R6 stage	Height at R6	Number of nodes plant^{-1} at R6	Number of pods plant^{-1} at R6	1-seeded pods	2-seeded pods	3-seeded pods	100-green seed	Fresh pod yield at R6	Total lipid concentration	Total protein content
Genotype	18	0.0817**†	209**	1241**	401**	26.4**	4326**	2260**	82828**	15638**	409**	2178846**	5.4**	10.5**
Location	1	0.8842**	473**	5600**	7184**	2.2	25404**	24034**	1240214**	227558 **	8052**	8481663**	5.8	3.9
Genotype × Location	18	0.0958	44.8**	444**	54**	2.6*	238.3	1390**	52578**	11311**	73**	1764400**	1.4	20.1*
H^2		92%	79%	64%	86%	90%	94%	39%	37%	28%	82%	65%	69%	19%

*Significant at the .05 level.

**Significant at the .01 level.

of pods per plant, 1-, 2-, 3-seeded pods, 100-green seed weight, and fresh pod yield at R6, but not for the number of nodes per plant, total lipid concentration, and protein content. Genotype-location interactions were significant for all variables except for emergence, number of pods per plant, and total lipid concentration (Table 2). Differences in weather patterns and soil composition and genotype adaptation might be major factors for creating significant differences in genotypic performance in two different locations in the present study. Therefore, care should be taken to select edamame genotypes which are suitable for the specific growing regions.

Broad sense heritability of analyzed traits ranged from 19% (total protein) to 94% (number of pods per plant). Notably, the percentage of 1-, 2-, and 3-seeded pods showed lower heritability (39, 37, and 28%, respectively) compared to other yield components (Table 2), indicating that these traits were highly influenced by environment. Moderate to high broad-sense heritability was observed for the number of pods per plant (94%), 100-green seed weight (93%), and fresh pod yield at R6 (65%). Seed weight heritability of edamame was reported between 50 to 88% by other authors (Basavaraja, Naidu, & Salimath, 2005; Jiang, Rutto, & Ren, 2018; Orf et al., 1999; Tinius, Burton, & Carter, 1991). The present study demonstrated high heritability for 100-green seed weight (93%), indicating that genetic gains for green seed weight, which is one of the most important traits for the commercialization of edamame, can be made. Pod yield is a complex trait and highly influenced by environment, so a low to moderate heritability is expected. Variable heritability of edamame fresh pod yield, ranging from 22.9 to 82.3%, has been reported (Basavaraja et al., 2005; Jiang et al., 2018), within the range of heritability (65%) found in the present study. This indicates that care must be taken to reduce environmental variation and human error during edamame evaluation for fresh pod yield at R6. The heritability estimates for pod yield, 100-green seed weight and number of pods per plant demonstrate that those traits can be used as selection parameters for increased productivity under north Florida environments.

3.5 Phenological and morphological traits

Means separation among genotypes showed significant differences for days to R1 and R6, plant height, and nodes per plant (Table 3). In general, plants at PSREU showed later maturity, shorter height, and fewer nodes than plants at WFREC (Table 3), likely due to the later planting date at WFREC. As expected, genotypes from early maturity groups (MG III-V) reached R1 and R6 stage earlier than late maturity groups (MG VI-VII) at both locations, and showed shorter height than late maturing genotypes, demonstrating that reported maturity classifications from these seed sources were likely correct. AGS378 and AGS383 were the latest maturing and tallest genotypes, respectively, whereas PI1662963 and PI1662962 were the earliest and shortest genotypes, respectively. The number of nodes per plant was not associated with maturity group. PI089162 showed the greatest number of nodes per plant whereas PI1633424 had the lowest number of nodes. Overall, shorter plants were observed compared to results reported by Ogles et al. (2016) in Alabama, but taller than plant heights reported by Zhang and Kyei-Boahen (2007) in Mississippi. In addition to decreased lodging susceptibility, Zandonadi, Coolong, and Pfeiffer (2010) indicated that shorter plants presented higher harvest efficiency compared to taller plants. Genotypic morphology, such as plant height and number of nodes per plant, was likely affected by differences in genetic background (Mebrahtu & Devine, 2008), corroborating findings of the present study.

Although all genotypes were harvested at R6, limited photoperiodic conditions could affect the performance of early maturity genotypes (Board & Settimi, 1986). Optimal edamame harvesting timing is critical to achieve peak texture and flavor (Johnson, 2000; Mbuvi & Litchfield, 1995; Wszelaki et al., 2005), and timeliness of harvest influences yield and quality. Crop developmental time affects quality properties such as color, texture, and seed size in edamame (Mbuvi & Litchfield, 1995), and maximum sweetness is achieved 1 mo after flowering when pods are plump and bright green (Zhang & Kyei-Boahen, 2007). Studies have suggested that since quality traits do not peak at the same time for all genotypes, edamame harvest timing is optimal when pods are green with fully developed immature green seeds (Mbuvi & Litchfield, 1995; Shanmugasundaram, Cheng, Huang, & Yan, 1991), corresponding with the R6 development stage. Thus, the determination of the R6 stage is critical to ensure quality and yield of edamame.

3.6 Yield component traits

The number of pods per plant ranged from 34.9 (PI662962) to 135.9 (AGS357) at WFREC and 20.9 (PI642768) to 109.7 (AGS357) at PSREU (Table 4). Plants at WFREC produced significantly more pods per plant (85.5) than at PSREU (55.6) (Table 4). In general, late maturing genotypes produced more pods per plant than early maturing genotypes. These were similar results to those demonstrated by Ogles et al. (2016) in their study in central Alabama. Four genotypes belonging to late maturity groups (PI633049, AGS357, AGS358, and AGS378) generated over 100 pods per plant at R6 (Table 4). The lower number of pods per plant in early maturing genotypes could potentially be due to less vegetative growth prior to entering the reproductive growth stage, resulting in premature blooming due to suboptimal photoperiod conditions (Ogles et al., 2016). Reduced vegetative growth is expected

TABLE 3 Least squares means for physiological traits of 19 vegetable soybean genotypes at the Plant Science Research and Education Unit (PSREU) in Citra, FL, and the West Florida Research and Education Center (WFREC) in Jay, FL. (MSD, minimum significant difference according to Tukey's Post-Hoc test)

	Days to R1			Days to R6			Height at R6			No. nodes plant^{-1} at R6		
	WFREC	PSREU	Combined	WFREC	PSREU	Combined	WFREC	PSREU	Combined	WFREC	PSREU	Combined
PI number	d (Julian)						cm					
PI548587	35.7	38.3	37.0	84.0	75.0	79.5	52.1	45.1	48.6	15.8	15.3	15.6
PI614832	35.3	38.3	36.8	74.0	84.0	79.0	65.2	45.0	55.1	14.6	14.7	14.7
PI642768	36.3	38.0	37.2	81.0	86.0	83.5	61.8	42.5	52.2	13.4	12.3	12.9
PI584470	35.0	44.0	39.5	84.0	92.0	88.0	58.4	49.9	54.2	12.9	12.0	12.5
PI584469	34.0	32.7	33.3	88.0	86.0	87.0	57.9	40.9	49.5	14.0	11.7	12.9
PI089162	36.3	42.3	39.3	88.0	79.0	83.5	50.4	35.8	43.1	17.2	18.4	17.8
PI662960	35.7	43.3	39.5	85.0	84.0	84.5	54.6	45.2	49.9	17.1	17.2	17.2
PI662961	40.0	46.3	43.2	84.0	84.0	84.0	56.5	33.8	45.2	11.6	10.5	11.0
PI662962	34.7	37.0	35.8	68.0	77.0	72.5	41.5	28.8	35.2	12.4	10.5	11.5
PI423980	40.7	50.3	45.5	91.0	92.0	91.5	59.7	41.9	50.8	11.5	12.9	12.2
PI398401	42.0	43.0	42.5	80.0	92.0	85.8	65.8	38.1	51.9	11.8	11.3	11.6
PI662963	34.0	37.7	35.8	68.0	75.0	71.5	48.3	26.9	37.6	12.0	9.2	10.6
PI633049	42.0	52.3	47.2	91.0	114.0	102.5	61.4	51.0	56.2	13.3	13.4	13.4
AGS357	39.0	48.3	43.7	91.0	114.0	102.5	63.1	39.6	51.4	11.2	9.7	10.4
PI633424	42.7	50.3	46.5	88.0	120.0	104.0	54.6	36.9	45.7	9.7	10.9	10.3
AGS358	42.0	53.0	47.5	91.0	139.0	115.0	63.9	54.2	59.1	11.1	12.8	11.9
AGS378	43.3	67.3	55.3	98.0	139.0	118.5	67.3	58.5	62.8	12.7	14.4	13.6
AGS383	46.7	55.0	50.8	98.0	127.0	112.5	72.8	60.3	66.6	12.5	12.8	12.6
PI417206	45.0	51.0	48.0	88.0	127.0	107.5	73.2	52.5	62.9	13.0	12.3	12.7
MSD	9.4[a]	6.0[b]	2.5[a]	1.58[b]	14.2[a]	9.1[b]	3.9[a]	2.5[b]				
Mean	38.9	45.7	42.3	85.3	99.3	92.3	59.4	43.5	51.5	13.0	12.7	12.9

[a]Minimum significant difference between genotypes within both sites.
[b]Minimum significant difference between genotypes across both sites.

to reduce photosynthetic area required for developing pods, seeds, seed weight and quality (Board & Hall, 1984).

It is recommended that >90% of pods contain two or three seeds for a cultivar to be competitive in the market (Konovsky, Lumpkin, & Mcclary, 1994). Overall, the percentage of 1-, 2-, and 3-seeded pods ranged from 6% (PI548587) to 28% (PI089162), 28% (PI662960) to 83% (AGS357), and 6% (AGS357) to 65% (PI548587 and PI662960), respectively. The percentages of 2- or 3- seeded pods were greater than the percentage of 1-seeded pods in all genotypes. Genotypes in the present study generally produced more 2-seeded pods than 3- or 1-seeded pods, except PI548587 and PI662960, which produced more 3-seeded pods than 2-seeded pods. Genotypes PI548587P, PI662960, PI662961, PI423980, PI398401, PI633424, AGS358, and AGS383 produced >90% of 2- and 3-seeded pods. These genotypes may have commercial potential in Florida when other commercial standards (like seed weight and quality) are met. Previous studies demonstrated that the proportions of 2 or 3-seeded pods is dependent on genetic and environmental factors (Ogles et al., 2016; Tischner, Allphin, Chase, Org, & Lark, 2003; Vega, Andrade, Sadras, Uhart, & Valentinuz, 2001). Genetic differences for the percentages of 2- or 3- seeded pods could potentially be used for further genetic improvement of this trait for commercial purposes. Late maturing genotypes had a higher percentage of 2-seeded pods compared to early maturing genotypes corroborating results by Ogles et al. (2016). Early maturing genotypes bloom prematurely when exposed to suboptimal photoperiod, reducing overall photosynthetic capacity, and ultimately reducing seed weight and seed number due to limited assimilate supply to developing pods and seeds (Board & Hall, 1984; Kantolic & Slafer, 2001). Early maturing genotypes had a higher percentage of 3-seeded pods than late maturing genotypes. This was also demonstrated by the significant negative correlation between the percentage of 3-seeded pods with days to R6. Despite being self-pollinating, poor seed setting in soybean is caused by abiotic stresses such as excessive temperature, drought stress, and plant competition (Epler & Staggenborg, 2008; Holshouser, 2009). Since the later maturing genotypes in our study were exposed to excessive heat stress over an extended period, this may have caused seed abortion resulting in fewer 3-seeded pods. Based

TABLE 4 Least squares means for yield component traits of 19 vegetable soybean genotypes at the Plant Science Research and Education Unit (PSREU) in Citra, FL, and the West Florida Research and Education Center (WFREC) in Jay, FL. (MSD, minimum significant difference according to Tukey's Post-Hoc test)

	Number of pods plant^{-1} at R6			One-seeded pods			Two-seeded pods			Three-seeded pods		
				WFREC	PSREU	Combined	WFREC	PSREU	Combined	WFREC	PSREU	Combined
PI number	WFREC	PSREU	Combined	%								
PI548587	78.2	40.2	59.2	6	5	6	33	26	29	61	70	65
PI614832	66.7	40.2	53.4	20	29	24	50	49	50	30	22	26
PI642768	61.4	20.5	40.9	14	17	15	55	56	56	31	27	29
PI584470	72.4	29.4	50.9	14	17	15	58	58	58	29	25	27
PI584469	63.9	20.9	42.4	14	14	14	61	59	60	25	28	26
PI089162	87.0	59.6	73.3	28	29	28	57	61	59	15	11	13
PI662960	83.7	37.5	60.6	8	5	7	29	28	28	63	67	65
PI662961	87.6	56.2	71.9	9	6	8	52	54	53	40	40	40
PI662962	34.9	31.8	33.4	14	12	13	56	64	60	30	25	27
PI423980	93.5	58.8	76.1	13	3	8	62	57	59	25	40	32
PI398401	99.9	60.5	80.2	9	8	8	62	71	67	29	21	25
PI662963	41.6	36.1	38.8	10	10	10	64	69	67	26	20	23
PI633049	121.1	92.4	106.7	15	9	12	73	75	74	12	16	14
AGS357	135.9	109.7	122.8	15	6	11	79	87	83	6	7	6
PI633424	76.6	46.6	61.6	7	5	6	76	72	74	16	23	20
AGS358	126.1	97.2	111.7	11	2	7	63	56	60	25	42	34
AGS378	112.7	99.1	105.8	16	5	11	75	75	75	9	19	14
AGS383	116.7	73.4	95.1	13	4	8	76	83	80	12	12	12
PI417206	64.3	46.9	55.6	32	17	25	64	75	70	4	8	6
MSD	42.3[a]	27.1[b]	11[a]	7[b]	15[a]	9[b]	16[a]	10[b]				
Mean	85.5	55.6	70.6	14	11	12	60	62	61	26	27	27

[a]Minimum significant difference between genotypes within both sites.
[b]Minimum significant difference between genotypes across both sites.

on the findings of the present study, it may be more desirable to have predominantly 2-seeded pods if a late maturity genotype is selected for commercial cultivation in north Florida.

3.7 Fresh pod yield and seed weight

On average, fresh pod yield at WFREC was double that of PSREU (8182 and 4033 kg ha^{-1}, respectively) despite lower emergence (Table 5). Genotypes AGS358 (9305 kg ha^{-1}) and AGS357 (8421 kg ha^{-1}) ranked 1 and 2, respectively, considering performance across locations. At WFREC, fresh pod yield ranged from 4256 (PI662962) to 11,828 (PI633424) kg ha^{-1} while at PSREU the range was 1457 (PI584469) to 8348 (AGS358) kg ha^{-1}. The average yield was comparable to the fresh pod yield of edamame reported by Zhang and Kyei-Boahen (2007) in Mississippi (7085 kg ha^{-1}), Carson et al. (2011) in Virginia (5829 kg ha^{-1}), and Jiang et al. (2018) in Virginia (6950 kg ha^{-1}). However, fresh pod yield was lower than the yield reported by Ogles et al. (2016) in central Alabama (10,226 to 15,966 kg ha^{-1}) and Rao et al. (2002) in Georgia (14,600 to 22,000 kg ha^{-1}). High temperatures (>30°C) have a negative effect on the development of soybean reproductive stages (Bouslama & Schapaugh, 1984; Gibson & Mullen, 1996; Hatfield et al., 2011). It is common in northwest and north-central Florida for temperature to reach over 35°C (21 d at PSREU and 8 d at WFREC in 2017). This may have contributed to both an overall lower yield and yield components in the current experiment compared to studies in Georgia and Alabama. Heat tolerance should be considered during cultivar selection for Florida. Average fresh pod yield at WFREC was higher than the yield reported by Carson et al. (2011), Zhang and Kyei-Boahen (2007), and Jiang et al. (2018), and is similar to the yield reported by Ogles et al. (2016). The overall lower fresh pod yield at PSREU compared to WFREC could likely be attributed to the differences in soil types (PSREU has more sand type soil) and to the environmental factors such as higher temperature and precipitation during the early and late growth stages, and to management practices. The present study indicates that cultivation of edamame in north central Florida will likely

TABLE 5 Least squares means for yield and quality traits of 19 vegetable soybean genotypes at the Plant Science Research and Education Unit (PSREU) in Citra, FL, and the West Florida Research and Education Center (WFREC) in Jay, FL. (MSD, minimum significant difference according to Tukey's Post-Hoc test)

	Fresh pod yield at R6			100-green seed weight			Total lipid concentration			Total protein		
	WFREC	PSREU	Combined	WFREC	PSREU	Combined	WFREC	PSREU	Combined	WFREC	PSREU	Combined
PI number	kg ha^{-1}			g			mg ml^{-1}			g 100 g^{-1}		
PI548587	6034	2899	4467	21.46	13.14	17.29	2.68	2.52	2.60	38.78	42.30	40.54
PI614832	9387	3192	6289	31.38	15.00	23.19	1.86	3.00	2.43	40.86	44.26	42.56
PI642768	7097	1675	4386	34.57	12.23	23.40	2.03	3.25	2.64	39.52	40.43	39.98
PI584470	8246	3218	5732	42.58	18.27	30.42	2.83	6.26	4.54	39.96	42.34	41.15
PI584469	4761	1457	3109	33.43	16.49	24.95	5.92	5.44	5.68	37.80	40.84	39.32
PI089162	5153	2079	3616	32.00	20.40	26.20	2.45	3.06	2.76	41.01	41.48	41.25
PI662960	8178	3378	5778	21.84	12.83	17.34	1.91	3.07	2.49	37.26	41.65	39.46
PI662961	7892	3828	5860	28.28	9.37	18.82	1.95	2.11	2.03	40.30	38.25	39.28
PI662962	4256	3333	3794	32.30	14.40	23.35	1.7.0	2.81	2.25	40.26	44.29	42.28
PI423980	11678	4098	7888	23.63	8.13	15.88	1.69	2.74	2.21	42.58	36.07	39.32
PI398401	8951	4772	6862	28.24	11.00	19.62	1.66	2.49	2.07	41.89	36.11	39.00
PI662963	4452	2817	3635	31.45	12.43	21.94	1.88	1.94	1.91	42.12	40.88	41.50
PI633049	9975	4924	7449	23.23	9.33	16.28	1.83	2.00	1.92	42.82	40.69	41.75
AGS357	11017	5826	8421	23.73	5.40	14.57	1.82	2.07	1.95	41.03	35.76	38.40
PI633424	11828	3231	7529	33.74	7.87	20.81	2.71	2.49	2.60	43.88	38.88	41.38
AGS358	10262	8348	9305	24.14	15.00	19.57	1.82	2.20	2.01	39.87	40.95	40.41
AGS378	7100	6890	6995	21.43	10.13	15.78	1.92	2.71	2.32	44.92	40.00	42.46
AGS383	10083	4413	7248	18.39	9.77	14.08	3.53	2.07	2.80	40.62	36.81	38.71
PI417206	9107	6252	7680	69.02	32.60	50.81	2.21	3.65	2.93	42.17	40.26	41.22
MSD	4355[a]	2788[b]	11.53[a]	7.38[b]	1.82[a]	1.42[b]	5.87[a]	3.76[b]				
Mean	8182	4033	6108	30.25	13.36	21.81	2.34	2.94	2.64	40.93	40.12	40.52

[a]Minimum significant difference between genotypes within both sites.
[b]Minimum significant difference between genotypes across both sites.

require not only more intensive management practices, but also genotype selection for greater heat tolerance. Although there was a significant genotype x location interaction for fresh pod yield, high yielding genotypes including PI1417206, AGS358, and AG357 performed consistently at both locations.

In general, later maturing genotypes demonstrated more fresh pod yield than early ones. Five genotypes had yields greater than 10,000 kg ha^{-1} at WFREC including PI423980 (11,678 kg ha^{-1}), AGS357 (11,017 kg ha^{-1}), PI633424 (11,828 kg ha^{-1}), AGS358 (10,262 kg ha^{-1}), and AGS383 (10,083 kg ha^{-1}). All these genotypes are classified in maturity group V-VII. At PSREU, the maturity of top four pod yielding genotypes, AGS357 (5826 kg ha^{-1}), AGS358 (8348 kg ha^{-1}), AGS378 (6890 kg ha^{-1}), and PI417206 (6252 kg ha^{-1}), also ranged between VI-VII. Since early maturing soybean normally requires longer daylengths than later maturing genotypes, it is expected that most of the late maturity genotypes would have greater yield, confirmed by this and previous studies (Duppong & Hatterman-Valenti, 2005; Ogles et al., 2016). In addition, late maturing genotypes have more vegetative growth duration and bloom numbers, and more photosynthetically active green area which helps to produce more assimilates for higher pod numbers and growing seeds. At PSREU, the highest yield was 8348 kg ha^{-1} (AGS358), indicating that this genotype yielded well across locations. Four edamame genotypes (PI662960, Gardensay 42; PI662963, Gardensoy 51; PI633049, Randolph; PI633049, Asmara) were also studied by Ogles et al. (2016) and Jiang et al. (2018). Ogles et al. (2016) reported a pod yield of 15,000 and 14,000 kg ha^{-1} for Gardensoy 51 and Gardensoy 42, respectively. However, those two genotypes yielded considerably lower in our study, with Gardensoy 51 at 3635 kg ha^{-1} across two locations (4452 kg ha^{-1} at WFREC) and Gardensoy 42 averaging 5860 kg ha^{-1} across two locations (7892 kg ha^{-1} at WFREC). On the contrary, Randolph (7529 kg ha^{-1} average and 11,828 kg ha^{-1} at WFREC) and Asmara (7449 kg ha^{-1} average and 9975 kg ha^{-1} at WFREC) yielded higher than reports by Jiang et al. (2018) in Virginia (Randolph, 6420 kg ha^{-1} and Asmara, 6935 kg ha^{-1}). These results indicate that some of the edamame genotypes studied in previous research might not be suitable for growing in

Florida conditions due to differences in soil types (such as sandy soil) or differences in environmental conditions (such as high temperatures during blooming and grain filling). Thus, the results of the present study is important as it provide basic information on edamame genotypes for growing under Florida conditions.

Green seed weight is one of the most important characteristics for commercial edamame production. A seed weight of >30 g per 100-green seed is one of the most important characteristics of marketable edamame (Konovsky et al., 1994). Therefore, selection of edamame genotypes with high seed weight is a necessary objective. Hundred-green seed weight showed high variability among genotypes, ranging from 18.39 (AGS383) to 69.02 g (PI417206) at WFREC and 5.40 (AGS357) to 32.60 g (PI417206) at PSREU (Table 5). Overall, genotypes produced higher seed weight at WFREC (30.25) than PSREU (13.36). Considering different maturity classes, in general, early maturing genotypes showed higher 100-green seed weight compared to late maturing genotypes at both locations, except genotype PI1417206, a late maturing genotype with the highest 100-green seed weight among all the genotypes studied at both locations (Table 5). The higher 100-green seed weight in early maturing genotypes than late maturing genotypes could be attributed to high temperature stress during the latter part of the growing season (Figure 1) while early maturing genotypes avoided extreme heat stress during grain fill. Among all genotypes, PI614832, PI642768, PI584470, PI584469, PI089162, PI662962, PI662963, PI633424, and PI417206 produced >30 g per 100-green seed weight at WFREC. Among these genotypes, PI614832, PI633424, and PI584470 showed relatively high yield with seed weight more than 30 g at WFREC, but not at PSREU, which indicates that these three genotypes could be potentially fit for the northwest region of Florida. Genotype PI417206 had >30 g per 100-green seed weight and relatively high yield at both locations, even though it experienced high heat conditions at PSREU. Thus, PI417206 has broader adaptation and can be considered for growing different areas in Florida. PI417206 had a relatively low number of pods per plant compared to other genotypes at both locations despite having a relatively high yield. The result indicates that seed weight is a major yield contributing trait in our study. The increase in seed weight is a major factor in overall yield increases in edamame as it is in other crops, such as wheat (Osman & Mahmoud, 1981) and corn (Muneeb, Shahbazb, & Yasirc, 2013). Additionally, it is anticipated that these genetics (PI614832, PI633424, PI584470, and PI417206) may be exploited to develop edamame genotypes with both high yield and seed weight traits for Florida. By contrast, genotypes AGS358 and AGS357 had high yield and pods per plant but low seed weight, so may not be suitable to meet the edamame market standard.

3.8 Quality traits

Plants at PSREU had higher total lipid concentration than plants at WFREC whereas the total protein content was not significantly different between two locations (Tables 1 and 5). Genotype PI584469 showed the highest total lipid concentration (5.68 mg ml^{-1}) followed by PI1417206 (2.93 mg ml^{-1}), and PI662963 had the lowest concentration (1.91 mg ml^{-1}). The total protein content was not different among genotypes between two locations (Table 5). According to Brar and Carter (1993), fresh green soybeans should have a combination of low oil and relatively high protein content. Overall, total protein content was higher than that reported by Carson et al. (2011) and Rao et al. (2002). The highest yielding genotype, AGS358, showed lower protein content and lipid concentration than most of the genotypes studied. Several high yielding genotypes identified for northwest or north-central Florida include PI614832, PI584470, PI633424, and PI417206. These had lower total lipid concentration and higher protein content than reported by Carson et al. (2011) and Rao et al. (2002), suggesting that these genotypes are potential candidates for north Florida. Additionally, the identified high yielding genotypes in the present study could be a potential source for making further genetic improvement through breeding for yield, seed weight, pod number and quality traits.

3.9 Correlations among yield components

Fresh pod yield was positively correlated with days to R1 and R6, plant height, pods per plant, and 100-green seed weight at both locations (Table 6). Among the percentage of 1-, 2-, and 3-seeded pods, percentage of 2-seeded pods were significantly correlated with total fresh pod yield at PSREU, but not at WFREC; however, 3-seeded pods showed significant negative correlation with fresh pod yield at WFREC. Percentage of 1-seeded pods were not correlated with fresh pod weight at either location. Percentage of 2-seeded pods showed positive correlation with days to R1 and R6, and pods per plant, but negative correlation with the number of nodes per plant at R6 at both locations. The percentage of 2-seeded pods showed a strong negative correlation with 3-seeded pods at both locations. However, the percentage of 2-seeded pods was positively correlated with days to R1 and R6 at both locations, while the percentage of 1- and 3-seeded pods had negative or no correlation with days to R1 and R6. This may suggest that these genotypes were not able to produce more 3-seeded pods under the conditions of this study. Since the number of seeds per pod showed low heritability in our study, it could signify a complex trait highly influenced by environmental conditions. The correlations between percentages of 1- and 3-seeded pods with other traits were not consistent at either location. Since the number of pods per plant showed high

TABLE 6 Pearson correlation coefficients (*r*) and significance (*p*) among physiological, yield component and quality traits of 19 vegetable soybean genotypes at the Plant Science Research and Education Unit (PSREU) in Citra, FL, and the West Florida Research and Education Center (WFREC) in Jay, FL

	Location	Days to R1	Days to R6	Height at R6	Number of nodes plant^{-1} at R6	Number of pods plant^{-1} at R6	1-seeded pods	2-seeded pods	3-seeded pods	100-green seed weight
Days to R1 stage	WFREC									
	PSREU									
Days to R6 stage	WFREC	0.56***†								
	PSREU	0.82***								
Height at R6 (cm)	WFREC	0.50***	0.53***							
	PSREU	0.61***	0.68***							
Number of nodes plant^{-1} at R6	WFREC	−0.37**	−0.04	−0.15						
	PSREU	0.07	−0.09	0.37**						
Number of pods plant^{-1} at R6	WFREC	0.45***	0.7***	0.49***	−0.04					
	PSREU	0.71***	0.67***	0.43***	0.05					
1-seeded pods	WFREC	0.11	0.12	0.19	0.24	−0.09				
	PSREU	−0.41**	−0.37**	−0.17	0.29*	−0.38**				
2-seeded pods	WFREC	0.50***	0.39**	0.35**	−0.53***	0.40**	0.16			
	PSREU	0.43***	0.54***	0.10	−0.48***	0.47***	−0.12			
3-seeded pods	WFREC	−0.47***	−0.38**	−0.38**	0.34*	−0.30*	−0.56***	−0.91***		
	PSREU	−0.19	−0.32*	0.02	0.29*	−0.24	−0.4**	−0.87***		
100-green seed weight (g)	WFREC	−0.01	−0.20	0.18	−0.02	−0.42**	0.57***	0.07	−0.29*	
	PSREU	−0.18	0.03	0.15	0.24	−0.30*	0.49***	−0.09	−0.16	
Fresh pod yield at R6 (kg ha^{-1})	WFREC	0.32*	0.26*	0.53***	−0.1	0.41**	0.2	0.22	−0.27*	0.49***
	PSREU	0.54***	0.60***	0.41**	0.15	0.74***	−0.18	0.28*	−0.17	0.31*

*Significant at the .05 level.
**Significant at the .01 level.
***Significant at the .001 level.

heritability, field selection for the number of pods per plant could be a promising tool to identify suitable edamame genotypes for Florida. Hundred-green seed weight showed a strong positive correlation with 1-seeded pods, but was not correlated with 2- and 3-seeded pods except at WFREC where 100-green seed weight showed a significant negative correlation with 3-seeded pods. Hundred-green seed weight also showed a negative correlation with the number of pods per plant. The number of pods per plant showed a strong positive correlation with days to R1 and R6 and plant height. Among yield components, pods per plant, 2-seeded pods, and 100-green seed weight were the major contributor to fresh pod yield. In addition, 2-seeded pods showed a strong positive correlation with pods per plant, indicating that the selection of genotypes with a higher number of 2-seeded pods per plant may yield well without sacrificing seed weight. The number of pods per plant and seed weight had a negative correlation, confirming results from previous studies (Johnson, Robinson, & Comstock, 1955; Pandey & Torrie, 1973).

4 | CONCLUSIONS

Edamame has generated considerable interest in recent years, and Florida producers could benefit from the growing consumer awareness of this crop. However, there is no information available for variety selection and management for Florida growers. The present research establishes a basic knowledge of edamame germplasm suitable for Florida growers. It appears that northwest Florida may be better suited for edamame production than north-central Florida because of reduced exposure to extreme temperatures, heavier soil types, etc. Based on fresh pod yield, 100-green seed weight, pods per plant, 2- and 3-seeded pods, maturity, and quality, two early maturing genotypes, PI614832 and PI584470, and one late maturing genotype, PI633424, could potentially be grown in north Florida. The late maturing genotype, PI417206, performed well in both northwest and north-central Florida. However, high yielding lines observed in this study should be further evaluated in commercial scale yield trials before considered as marketable varieties. Also, there is a need to evaluate more germplasm for Florida, especially under central Florida environments.

ACKNOWLEDGMENTS

This research was funded by the Florida Department of Agriculture and Consumer Service (grant # USADA-AMS-SCBGP-2015) and by the USDA National Institute of Food and Agriculture Hatch project FLA-JAY-005475. The authors acknowledge the contribution of Mass Spectrometry Research and Education Center, University of Florida with funding from NIH S10 OD021758-01A1. We also acknowledge the contribution of the Department of Agronomy for providing facilities for this research. We are grateful to Moo Brown and Porcha Phillips for their tireless effort in the field.

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How to cite this article: Guo J, Rahman A, Mulvaney MJ, et al. Evaluation of edamame genotypes suitable for growing in Florida. *Agronomy Journal*. 2020;112:693–707. https://doi.org/10.1002/agj2.20136