Variety Trials

Cultivar Evaluation and Lipid and Protein Contents of Virginia-grown Edamame

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ADDITIONAL INDEX WORDS. soybean, yield, *Glycine max*

SUMMARY. Few studies have compared the growth and yield of commercial edamame (*Glycine max*) cultivars in the mid-Atlantic United States. This study determined yield potential, yield components, and lipid and protein contents of five edamame cultivars [BeSweet 292 (BS292), BeSweet 2015 (BS2015), BeSweet 2001 (BS2001), Midori Giant (MG), and Sunrise (SR)] grown in Painter, VA, during 2008 and 2009. Pod yield ranged between 5002 and 7521 lb/acre. There were no differences in total yield among 'MG', 'BS292', or 'SR'. 'BS2015' had the lowest yield, while the yield of 'BS2001' was not different from other cultivars tested. Percent marketable pods ranged from 74.3% to 85.6%, with no differences among cultivars. 'SR' had the greatest average seed weight in 2008 and 'BS2001' had the smallest; intermediate was 'MG', 'BS292', and 'BS2001', although 'MG' was not different from 'SR'. 'MG' had the greatest average seed weight in 2009; there were no differences among the remaining cultivars. The cultivar lipid content was numerically lower in 2009 than in 2008 for all five cultivars. 'BS292' and 'BS2001' had the least and greatest protein concentrations with 36.1% and 38.3% in 2008, respectively. In 2009, 'MG' and 'SR' had the least and greatest protein concentrations with 35.7% and 39.5%, respectively. Edamame appears to be a viable alternative crop for Virginia with yields similar to snap beans (*Phaseolus vulgaris*). 'MG', 'BS292', and 'SR' produced consistently high yields and quality and are viable cultivar choices for the mid-Atlantic United States.

Edamame, or vegetable soybean, is a group of special cultivars of soybean harvested green at the R6 stage of development,

or ≈80% pod fill, and used as a vegetable (Fehr et al., 1971). When harvested at the R6 stage, the flavor of

edamame is nutty, sweet, buttery, beany, and superior in flavor to agronomic soybeans (Wszelaki et al., 2005). Consumers of edamame prefer bright green pods, two or more beans per pod, and large seed size (Montri et al., 2006). Edamame is eaten steamed in the pod as an appetizer, hulled as a side dish, or in salads or stir fry (Konovsky et al., 1994).

Edamame is a popular vegetable in Asian countries and is becoming increasingly popular in the United States. The increase in popularity can be attributed to the beneficial phytonutrients, high protein contents, increased consumer awareness, and taste of edamame (Duppong and Hatterman-Valenti, 2005; Zhang and Kyei-Boahen, 2007). The value of edamame purchased in the United States increased from \$18 million in 2003 to \$41 million in 2009 (Bernick, 2009; Soyatech, 2010).

Agronomic soybeans have high lipid content and are commonly used as an industrial source of oil. However, high oil content gives edamame an undesirable flavor (Konovsky et al., 1994; Wszelaki et al., 2005; Young et al., 2000). According to Hymowitz et al. (1972), agronomic soybeans' lipid content ranges from 145 to 230 g·kg⁻¹ at dry maturity. Rao et al. (2002) reported edamame having between 130 and 156 g·kg⁻¹ lipids at the R6 stage of development. These numbers agree with the data of Sikka et al. (1978), who reported that vegetable soybeans contain less fat than agronomic cultivars of soybeans. Hymowitz et al. (1972) reported that soybeans contain between 33.1% and 49.2% protein on a dry weight basis. Similarly, Hartwig and Kline (1991) reported averages of 39.8% and 46.9% protein for high and low oil soybean cultivars, respectively. Sikka et al. (1978) showed that edamame contains

We thank Ursula Deitch and Hengjian Wang for their assistance in completing this research.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.01	%	g·g ⁻¹	100
10	%	g·kg ⁻¹	0.1
1	%	g/100 g	1
0.4047	acre(s)	ha	2.4711
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
28.3495	oz	g	0.0353
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

similar amounts of protein to agroeconomic soybeans.

Edamame reportedly grows well in the United States, but most is imported despite its growing popularity (Duppong and Hatterman-Valenti, 2005; Rao et al., 2002; Sanchez et al., 2005; Zhang and Kyei-Boahen, 2007). Although edamame cultivars have been bred for Virginia, few reports have evaluated commercially available cultivar yield potential in the mid-Atlantic United States (Bhardwaj et al., 1996; Sciarappa et al., 2007). Virginia and the mid-Atlantic United States have a robust snap bean industry that may be able to incorporate edamame production because of the similarities in culture, growth, yield, and equipment needed. Growing edamame in Virginia may help replace some of the 18,700 acres of tobacco (*Nicotiana tabacum*) production lost during the past decade [U.S. Department of Agriculture (USDA), 2009]. Bernick (2009) reported net returns of \$600–\$750 per acre for edamame grown for the Sweet Bean Company in Medina, OH. Ernst and Woods (2001) reported less favorable returns of \$259 per acre with a break-even cost of production of ≈\$1 per pound for hand-harvested edamame. The purpose of this study was to determine suitable cultivars for cultivation in Virginia and other areas of the mid-Atlantic United States based on yield, yield components, and quality.

Material and methods

On 7 May 2008 and 22 May 2009, five commercially available cultivars were planted in Painter, VA, on Bojac sandy loam soil (Thermic Typic Hapludults) in a randomized complete block design (USDA, 2002). In both 2008 and 2009, three cultivars (BS292, BS2015, and BS2001) were obtained from Rupp Seed Co. (Wauseon, OH) and two cultivars (MG and SR) were obtained from Wannamaker Seed Co. (St. Matthews, SC). These cultivars were selected because they are readily available and of a maturity group suitable for Virginia. Experimental plots, replicated four times, consisted of two rows 25 ft long with between-row spacing of 3.0 ft and planted at four seeds per foot. Soil samples were taken to plow depth (6 inches) on a grid pattern across the entire research area. The sample was mixed, air dried, and analyzed using

Mehlich-1 extractant for nutrients and Mehlich buffer for pH (Mullins and Heckendorn, 2009). Soil fertility and lime recommendations were based on Virginia Cooperative Extension recommendations for soybean (Maguire and Heckendorn, 2010). Overall, only phosphorus was necessary and was applied using a drop spreader for even distribution using 22 lb/acre triple super phosphate (0N–20.1P–0K). A preemergence application of *s*-metolachlor (Dual Magnum; Syngenta Crop Protection, Greensboro, NC) was made at a rate of 1.0 lb/acre during both experiment years for weed management. Post-emergence weeds were managed by applications of bentazon (Basagran; BASF Corp, Research Triangle Park, NC) and fomesafen (Reflex; Syngenta Crop Protection) at rates of 0.75 and 0.25 lb/acre, respectively, during both experiment years. In-season applications of insecticides were made as needed to control lepidopteran and hemipteran pests. Overhead irrigation was applied both years when signs of water stress were present, then periodically thereafter until the next rainfall.

At harvest on 8 Aug. 2008 and 20 Aug. 2009 (89 and 90 d after planting, respectively), plant height was measured, a plant maturity rating was given, and a subsample of bean pods was collected and frozen for later analysis. The five edamame cultivars were once-over destructively harvested and did not mature at the same time, so a maturity rating was assigned to each. The maturity rating ranged from one to five. Five described plants with mature pods beyond the R6 stage of development, and one described plants with all leaves green with many immature pods at the top of the plant containing small, unmarketable seeds. Mean plant height was calculated from three random measurements per plot, which were taken from the ground to the top of the canopy. Edamame pods were harvested using a single row mechanical harvester (Pixall BH100; Oxbo International, Byron, NY). Total yield data were obtained from a single row in each of the four replications. A 100-pod subsample was taken and the pods containing one, two, or three beans were counted and weighed to determine percent marketable pods. Pods containing two or more large-sized beans were considered marketable. Flat pods, one seeded pods, and

those with poor appearance were considered unmarketable. Beans were shelled and the weight of 100 seeds was recorded. Harvest efficiency was calculated by hand harvesting pods from 20 mechanically harvested plants and comparing the pods of five unharvested plants using the following equation: $[(\text{number of pods on 20 harvested plants} \div 20) \div (\text{number of pods on five unharvested plants} \div 5) \times 100]$.

Frozen shelled beans were placed in a freeze dryer and dried to a constant weight. Dry beans were milled to pass through a 20-mesh sieve. Ground beans were placed in airtight bags and stored in a freezer at -20°C until analysis. Lipid content was measured using ether extraction [method 922.06 (AOAC International, 2000)]. Extraction cups, filter paper, and thimbles were dried for 30 min at 90°C and cooled in desiccators. A 2-g sample was weighed on Whatman no. 4 filter paper (Whatman International, Maidstone, United Kingdom), folded, placed in the thimble, and extracted in 50 to 70 mL of petroleum ether (Soxtec System HT 1045 and 1043; FOSS Tecator, Eden Prairie, MN). The samples were boiled for 2 h and rinsed for 1 h, and the ether was evaporated from the cups for 30 min before removing the cups from the extractor and allowing them to cool in desiccators for 30 min. Cup weights were taken and the percent lipids was calculated as follows: $[(\text{weight of the cup with lipids} - \text{weight of the dry cup}) \div \text{weight of the sample extracted} \times 100]$.

Protein content was determined using a modified Kjeldahl method [method 920.87 (AOAC International, 2000)]. A 1-g sample was placed on Whatman no. 541 no-nitrogen filter paper, folded, and placed in a digestion tube. Kelmate 'N Kjeldahl Digestion Mixtures (EMD Chemicals, Gibbstown, NJ), 20 mL of 36 N sulfuric acid, and 3.0 mL of hydrogen peroxide (30%) was added to each tube. Tubes were digested at 350°C until frothing slowed, then the block heater was adjusted to 410°C . The heating continued for an additional 30 min once the digest turned clear blue in color. Tubes were allowed to cool for 10 min before adding 50 mL of distilled water. The digestion tube was placed into the receiver of a prepared Rapid Still II (Labconco Corp., Kansas City, MO) along with a receiving

flask containing 25 mL of boric acid solution containing methyl red and bromocresol green. The Rapid Still was pre-filled with a solution of sodium hydroxide–sodium thiosulfate and a boiling flask with distilled water. The tube was placed in the unit and 75 mL of sodium hydroxide–sodium thiosulfate solution was added. Steam drove the nitrogen gas into the receiving flask. The receiving flask was titrated with 0.2 N hydrochloric acid (HCl) until the green color turned to clear. The percent nitrogen was calculated using the following equation: $[(\text{volume of HCl to titrate the sample} - \text{volume of HCl to titrate the blank}) \times 1.4007 \times 0.2] \div (\text{weight of glycine} \times 18.65)$. The Kjeldahl digestion was ran in duplicate for each cultivar.

Analysis of variance (ANOVA), means separation, and correlation analysis were performed using the fit model platform in JMP (version 8.0; SAS Institute, Cary, NC). Cultivar and year were considered main effects, and cultivar $\times$ year was an interaction effect. Arcsine transformed percentage data were used in the ANOVA procedure. After transformation, data were found to be normal by Shapiro–Wilk test ($P = 0.846$). Blocks were considered random effects. Means were separated using Tukey's honestly significant difference test ($P \leq 0.05$). Correlation analysis was performed among plant height and yield, percent marketable pods, average seed size, and harvest efficiency.

Results

There were no interactions between year and cultivar in terms of yield ($P = 0.080$) or percent marketable pods ($P = 0.73$), and so the respective data were combined over years for each cultivar. There were significant interactions between year and cultivar with respect to average seed weight ($P = 0.003$), harvest efficiency ($P = 0.006$), plant height ($P = 0.0135$), lipid concentration ($P \leq 0.0001$), and protein concentration ($P \leq 0.001$). For effects with significant interactions, data are presented separately by year.

Yield of pods ranged between 5002 and 7521 lb/acre (Table 1). 'MG', 'BS292', and 'SR' yields were similar and significantly greater than 'BS2015'. 'BS2001' was not significantly different from other cultivars, with a yield of 6076 lb/acre.

Percent marketable pods ranged from 74.3% to 85.6% (Table 1). There were no significant differences among cultivars.

The range of 100-seed weights in 2008 was from 50.1 to 71.0 g/100 seeds (Table 1). 'SR' had a mean seed weight of 71.0 g/100 seeds, which was greater than all cultivars except 'MG'. 'BS2015' had the lowest seed weight at 50.1 g/100 seeds. 'MG' was not different from 'BS292', 'BS2001', or 'SR'. In 2009, weights ranged from 47.5 to 68.0 g/100 seeds. 'MG' had the highest seed weight in 2009 at 68.0 g/100 seeds, and seed weight of all other cultivars were similar to each other.

Overall, with the exception of 'MG', harvest efficiency was numerically greater in 2008 than in 2009 (Table 2). There were no significant differences among harvest efficiencies in 2008, which ranged from 90.2% to 95.9%. In 2009, the harvest efficiency ranged from 82.3% for 'BS292' to 95.4% for 'MG'. 'MG' had significantly greater harvest efficiency than both 'BS292' and 'BS2001', but not 'BS2015' or 'SR'.

In 2008, 'SR' received a maturity rating of 5.0 because it matured ≈ 5

d earlier than other cultivars (Table 2). However, in 2009, 'SR' was rated 3.25 and was less mature than 'MG' and 'BS292', which were rated 4.75 and 3.75, respectively. 'BS2015' and 'BS2001' were the least mature cultivars in both years. Statistical analysis was not performed on these data.

In 2008, 'BS2015' had an average plant height of 24.4 inches and was significantly taller than all other cultivars, which were similar in height (Table 2). In 2009, 'SR' had an average plant height of 26.4 inches and was significantly taller than 'BS292', 'MG', and 'BS2001'. 'BS2015' had an average plant height of 23.3 inches, which was similar to all other cultivars.

There was no correlation among average plant height and yield ($R^2 = 0.048$), percent marketable pods ($R^2 = 0.0052$), average seed size ($R^2 = 0.0008$), or harvest efficiency ($R^2 = 0.0087$).

In 2008, the lipid content of the edamame cultivars ranged from 14.0 to 18.3 g/100 g (Table 3). 'SR' and 'MG' had the greatest lipid contents of any cultivars. They were followed in descending order by 'BS292', 'BS2001', and 'BS2015', with lipid contents of 16.3, 14.5, and 14.0 g/100 g,

Table 1. Yield, marketable pods, and average seed weight of five edamame cultivars grown in Painter, VA, during 2008 and 2009.

Cultivar	Yield (lb/acre) ^z	Marketable pods (%)	Seed wt (g/100 seeds) ^z	
			2008	2009
Midori Giant	7,521 a ^y	80.4 NS	66.2 ab	68.0 a
BeSweet 292	7,082 a	78.5	62.4 b	54.8 b
Sunrise	6,987 a	85.6	71.0 a	54.3 b
BeSweet 2001	6,076 ab	74.3	61.3 b	52.5 b
BeSweet 2015	5,002 b	80.6	50.1 c	47.5 b

^z1 lb/acre = 1.1209 kg·ha⁻¹, 1 g = 0.0353 oz.

^yNumbers followed by the same letter, within a column, are not significantly different at $P \leq 0.05$ by Tukey's honestly significant difference test; NS = not significantly different.

Table 2. Harvest efficiency, maturity rating, and average plant height of five edamame cultivars grown in Painter, VA, in 2008 and 2009.

Cultivar	Harvest efficiency (%)		Maturity rating (1–5 scale) ^z		Avg plant ht (inches) ^y	
	2008	2009	2008	2009	2008	2009
BeSweet 292	95.9 NS ^x	82.3 b	4.25	3.75	20.8 b	20.8 b
BeSweet 2015	95.6	87.3 ab	2.0	2.75	24.4 a	23.3 ab
Sunrise	94.1	88.8 ab	5.0	3.25	21.5 b	26.4 a
Midori Giant	90.2	95.4 a	3.5	4.75	18.3 b	19.4 b
BeSweet 2001	90.7	84.5 b	3.0	1.75	20.3 b	20.4 b

^z5 = leaves starting to turn yellow and full size seeds, 1 = all green leaves with some pods at the top of the plant having less than full size seeds; scores are the average of four observations; no statistics were conducted on these ratings.

^y1 inch = 2.54 cm.

^xNumbers followed by the same letter, within column, are not significantly different at $P \leq 0.05$ by Tukey's honestly significant difference test; NS = not significantly different.

Table 3. Lipid and protein content of five edamame cultivars grown during 2008 and 2009 in Painter, VA.

Cultivar	Lipids (g/100 g) ^a		Protein (g/100 g)	
	2008	2009	2008	2009
Sunrise	18.3 a ^y	15.3 a	36.3 ab	39.5 a
Midori Giant	17.7 a	14.6 b	36.5 ab	35.7 b
BeSweet 292	16.3 b	13.4 c	36.1 b	36.8 b
BeSweet 2001	14.5 c	13.1 cd	38.3 a	37.0 b
BeSweet 2015	14.0 d	12.9 d	37.6 ab	37.1 ab

^a1 g/100 g = 1%.^yMeans are to be compared within column. Numbers followed by the same letter are not significantly different at $P \leq 0.05$ by Tukey's honestly significant difference test.

respectively. In 2009, the lipid contents ranged from 12.9 to 15.3 g/100 g. 'SR' had the greatest lipid content of 15.3 g/100 g followed by 'MG' at 14.6 g/100 g. 'BS292' had a lipid content of 13.4 g/100 g, which was greater than 'BS2015' with 12.9 g/100 g, but neither was different from 'BS2001'.

In 2008, 'BS292' had lower protein content than 'BS2001' (Table 3). 'BS2001' had protein content of 38.3 g/100 g, which was similar to 'MG', 'SR', and 'BS2015' at 36.5, 36.3, and 37.6 g/100 g, respectively, which were similar to 'BS292'. 'SR' had the highest protein content in 2009 at 39.5 g/100 g, which was significantly greater than all but 'BS2015' at 37.1 g/100 g. 'BS292', 'MG', and 'BS2001' were similar to 'BS 2015' in 2009.

Discussion

The objective of this study was to evaluate potential yield and yield components of commercially available edamame cultivars in Virginia. The five edamame cultivars yielded between 5002 and 7521 lb/acre, which are comparable to the snap bean yields of 3620 to 7600 lb/acre obtained on Virginia's Eastern Shore by Phillips et al. (2002). When compared with other edamame studies from Georgia and North Dakota, the yields obtained were less than previously published, although narrower between-row spacings of 0.76 m and 24 inch rows were used in Georgia and North Dakota, respectively (Duppong and Hatterman-Valenti, 2005; Rao et al., 2002). Narrower row spacings may have increased cultivar yields (Costa et al., 1980).

The percent marketable pods did not vary among cultivars. The percent marketable pods ranged from 74.3% to 85.6%, which was higher than the percent salable yield reported by Johnson (1999), which ranged from 45.5% to 68.3% salable, although Johnson

(1999) never fully explained what salable yield was beyond "discarding defective bean pods." Timing of edamame harvest is a critical factor in determining consumer acceptability and marketability. The harvest window for best edamame quality is only a few days depending on the cultivar and environmental conditions. In this study, all cultivars were harvested at one time and not based on the maturity of individual cultivars. Harvesting in this manner may result in some cultivars reaching beyond peak maturity and others not reaching peak maturity. Maturity may have affected the number of marketable pods per plant for some cultivars because a higher percentage of pods may have been immature or over mature at harvest. However, there were no differences among unmarketable pods among cultivars as the percentage of unmarketable pods was similar for all cultivars. Soybean is a self pollinated crop, but a poor seed set can be caused by environmental stresses such as excessive temperature, competition, and drought stress (Epler and Staggenborg, 2008; Holshouser, 2009). Plant spacing was relatively wide, so soybean plant-to-plant competition was not the cause of poor pollination. However, there were weed problems that shaded plants and increased competition for water and mineral resources. The edamame was irrigated as needed; however, visual signs of drought stress were often present before irrigation took place. Drought stress is likely the cause for the relatively low marketable yield reported.

In this study, cultivar and year interacted significantly with average seed size but not percent marketable pods. The difference in seed size is most likely a function of relative maturity at harvest and genetics. According to Hanway and Weber (1971), soybean

seeds can accumulate 98.6 kg·ha⁻¹ of dry matter per day. 'BS292', 'SR', and 'BS2001' were slightly less mature at harvest in 2009 than in 2008, which allowed less time for seed fill (Table 2) and would account for the seed size difference between years. 'MG' was more mature at harvest in 2009 than in 2008 and numerically had a larger seed size. Genetics determines the ultimate seed size, and although all these cultivars are considered large seeded, there were differences in seed size among cultivars within the same year. There were also differences among cultivars within the same year in relation to maturity. Soybean flowers based on critical night length, which varies among cultivars. The different maturities may be advantageous if several cultivars were planted at once but with different harvest dates.

Most of the pods left on the soybean plants after harvest were at the bottom of the plant and not removed by the harvester reel. Smith et al. (1961) reported that losses could be expected in agronomic soybean if pods were set lower than 13 to 15 cm above the soil because pods would be below the cutter bar of the combine. Beaver and Johnson (1981) and Costa et al. (1980) reported that narrower rows increased lowest pod height in soybean. Planting in row widths narrower than those used in this study may raise the lowest pod height and increase the harvest efficiency of edamame using a snap bean harvester.

There were differences in lipid content among cultivars, with SR having the highest lipid content in both years followed by 'MG', 'BS292', 'BS2001', and 'BS2015'. According to Rotundo and Westgate (2009), warmer temperatures during seed fill, which starts ≈ 2 weeks after flowering, decreased lipid content. Data from a weather station in Painter, VA, showed that the average air temperature was 0.47 °C higher during seed fill in 2009 than in 2008 (unpublished weather data). Also, before harvest in 2009, weed competition, which can cause both water and shading stress, was a problem. Water stress during seed fill may reduce soybean oil content by $\approx 25\%$ when compared with a well-watered control (Rotundo and Westgate, 2009). Agronomic soybeans contain between 145 and 230 g·kg⁻¹ lipids, and edamame contains between 130 and 156 g·kg⁻¹ lipids (Hymowitz

et al., 1972; Rao et al., 2002). The beans measured in this study contained between 140 and 183 g·kg⁻¹ in 2008 and between 129 and 153 g·kg⁻¹ in 2009, which is similar to the contents reported in the both studies by Hymowitz et al. (1972) and Rao et al. (2002).

‘SR’ had a year-to-year difference in protein content of 3.2%, the only cultivar to have a difference of greater than 1.3%. Hymowitz et al. (1972) found a negative correlation between protein and oil concentration. With the reduced lipid contents, the protein contents should have been greater in 2009, and this was the case for two of the five cultivars. Agronomic soybeans contain between 33.1% and 49.2% protein (Hymowitz et al., 1972). Our results agree with Sikka et al. (1978), who reported that edamame and agronomic soybeans contain similar amounts of protein.

With yields similar to snap beans, edamame appears to be a viable alternative crop for Virginia from a productivity standpoint. Protein and lipid contents of the cultivars measured were similar to those reported for both agronomic and edamame cultivars. All cultivars tested were acceptable for commercial production in Virginia. Cultivars MG, BS292, and SR each performed well in terms of total yield.

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