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Edamame: A Nutritious Vegetable Crop

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Edamame, also called *mao dou* in China, is a large-seeded (seed dry wt. >250 mg/seed) green vegetable soybean [*Glycine max* (L.) Merr., Fabaceae] cooked and served in pods as snack-like peanuts (*Arachis hypogaea*) (Shurtleff 2001). In Asia, where edamame is an important vegetable (Fig. 1), farmers harvest stems with fresh green pods before full maturity when pods are fully filled, nearly 80% matured, and just before turning yellow (Shanmugasundaram et al. 1991). This stage corresponds to the R6 stage of soybean development (Fehr et al. 1971). Vegetable soybean was known in China for its nutritional and medicinal values and was consumed as a vegetable as early as second century BCE (Shanmugasundaram 2001). Vegetable soybean has been reported to be better tasting and suitable for human consumption than grain soybean (Weber 1956). Edamame has a sweet, nutty flavor and can be eaten as snack either boiled in salt water or roasted like peanut seed. Fresh or frozen vegetable soybean can be cooked just like sweet peas (*Pisum sativum* L.) or lima beans (*Phaseolus limensis* L.), either stir fried or added to stews and soups. Edamame is highly nutritious and rich in phytochemicals beneficial to the human being (Masuda 1991) and is therefore, considered a nutraceutical or a functional food crop (Messina 2001).

ECONOMIC IMPORTANCE

In the US, edamame is currently becoming more popular along the West Coast than in the southeast. Shelled edamame seed are now available as frozen fresh vegetable or mixed in stir-fry vegetable mix in a few grocery chain stores and oriental food stores along the west coast (Fig. 2) and some midwestern states in the US. Johnson et al. (1999) estimated that approximately 13,000 ha of edamame crop is required to meet the demand for fresh or frozen edamame niche markets in the US. Frozen edamame imports into US increased from about 300 to 500 tonnes (t) per year in 1980s to about 10,000 t in 2000 (Lin 2001). Taiwan and China are major suppliers of frozen edamame to the United States. The increasing popularity of soybean as a nutraceutical is currently driving the demand for this vegetable and it is estimated that by the year 2005, US could be importing about 25,000 t of edamame a year (Lin 2001). The current edamame imports are valued at more than $9 million. The recent approval of soybean protein extract as dietary supplement by the FDA has further increased the demand for soyfoods. Green pods and products made out of fresh seed are in great demand in most Asian countries, particularly Japan (Shanmugasundaram 2001).

Fig. 1. Edamame vendor in China. Photo courtesy of T.A. Lumpkin (Shurtleff and Lumpkin 2001).

FUNCTIONAL FOOD CROP

Soyfoods rich in isoflavones, proteins, and certain oligosaccharides have been reported to be associated with several health benefits to human beings. Clinical studies have shown that isoflavones in soybean proteins reduce blood serum cholesterol levels and thus, reduce the risk of cardiovascular diseases in hu-

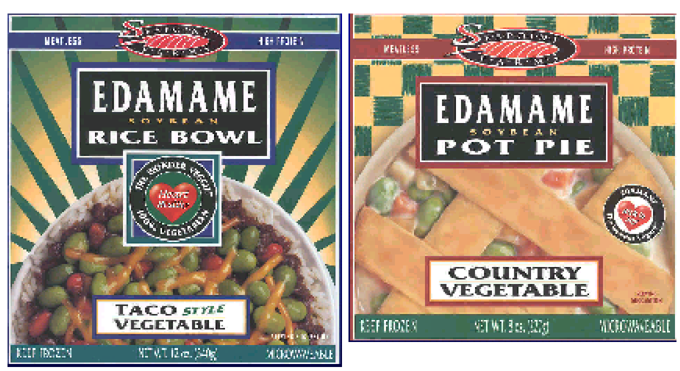

Fig. 2. Two out of several edamame products available in the US. Photo courtesy of T.A. Lumpkin (Shurtleff and Lumpkin 2001).

man beings (Wiseman et al. 2000). Soybean isoflavones have reportedly increased HDL cholesterol (considered good cholesterol) and lowered LDL cholesterol (Potter 1998). Soybean isoflavones have also been shown to prevent some forms of cancer, alleviate diabetes, increase bone density, and reduce osteoporosis (Messina 2001). Due to these well-publicized nutraceutical benefits of soybean, it is likely that the demand for soyfoods will continue to increase over the long term.

NUTRITIONAL COMPOSITION

Fresh vegetable soybean seed has 35% to 38% protein (dry weight basis) and 5% to 7% lipid on fresh weight basis. Monounsaturated fatty acids constitute a greater fraction of lipids in fresh green seeds (Johnson et al. 1999), which makes vegetable soybean a nutritious snack. Soybean is one of the few natural sources of isoflavones (78 to 220 µg/g dried seed depending upon isoflavone type) and tocopherols (vitamin E) which range from 84 to 128 µg/g dried seed (Mohamed et al. 2001).

Proximate analysis of seed nutritional composition of edamame in Colorado, US (Johnson et al. 1999), and Japan (Masuda 1991) indicated that edamame have superior nutritional content than green peas. The calorific value (energy) of vegetable soybean is about 6 times that of green peas. The vegetable soybean contains 60% more Ca, and twice the P and K of green peas. The Na and carotene content of vegetable soybean is about one-third that of green peas and has similar quantities of iron, vitamins B_1 and B_2. Vegetable soybean is rich in ascorbic acid but low in niacin (Masuda 1991).

QUALITY CHARACTERISTICS THAT INFLUENCE MARKETABILITY OF EDAMAME

Edamame marketability is determined by physical and organoleptic properties (Masuda 1991; Shanmugasundaram et al. 1991). Quality characteristics vary according to genotype, time of harvesting, crop growth stage at harvest, and environment (Mbuvi and Litchfield 1995). The time of harvesting is a critical factor in determining consumer acceptability and marketability of fresh vegetable soybeans (Mbuvi and Litchfield 1995). The optimum time for harvesting fresh vegetable soybean to combine the best product quality with maximum yield is a function of a dynamic relationship between maturity, yield, and quality parameters, just as in other vegetable crops (Lee 1989). Quality properties such as color, texture, and seed size of vegetable soybean are a function of development time (Mbuvi and Litchfield 1995). Since these quality parameters do not peak at the same time, it is necessary to compromise time of harvest of green beans. Shanmugasundaram et al. (1991) reported that the optimum time for harvesting green beans was when the pods are still green, immature, and tight with fully developed immature green seeds. This stage coincides with the R6 stage of soybean development (Fehr et al. 1971). Thus, R6 stage is very critical for ensuring bean yield and quality. Among physical characteristics appearance and size of fresh pods and seeds are important. Pods bright green in color with gray pubescence and approximately ≥5.0 cm in length and ≥1.4 cm in width with two or more bright green seeds having light buff or gray hila are considered important for fetching high prices (Shanmugasundaram et al. 1991). A combination of ascorbic acid, sucrose, glutamic acid, and alanine make edamame tasty. Whereas *cis*-jasmone, and (Z)-3-hexenyl-acetate have been reported to confer desirable flavor (Masuda 1991). The amount of protein, lipid, fiber, sucrose, ascorbic acid, essential amino acids, vitamins, and minerals determine nutritional value of vegetable soybeans.

Anti-nutritional factors that could decrease marketability of edamame include phytate, trypsin inhibitor, saponins, isoflavons, and certain oligosaccharides. Phytate, calcium-magnesium-potassium salt of inositol hexaphosphoric acid which is commonly known as phytic acid occurs in bean (*Phaseolus vulgaris* L.) and soybean (Mebrahtu et al. 1997). Phytate is the main source of phosphorus in soybean seed and is known to form complexes with phosphorus, proteins, and minerals such as Ca, Mg, Zn, and Fe (Reddy et al. 1982). This reduces the bioavailability of these minerals, affect seed germination and seedling growth, and cause deficiencies in nonruminant animals. Significant varietal differences in the accumulation of phytic acid in soybean seed have been reported. Trypsin inhibitors bind proteins and reduce protein efficiency ratio. However, heating process such as blanching, eliminate most the activities of these inhibitors.

Saponins and isoflavons cause sour or bitter flavor. Current research indicates that these are important phytochemicals associated with soybean health benefits to humans. Stachyose and raffinose could cause flatulence and abdominal discomfort.

AGRONOMIC IMPORTANCE

Development of improved soybean cultivars for soyfoods offers potential for expanding the domestic and international soybean market. The US farmers, particularly organic vegetable producers will have another vegetable crop to choose to extend crop rotations, supplement farm income, and spread risk. As a legume crop, vegetable soybean is a low input, soil enriching crop that could help farmer minimize insect and disease buildup as well. In the US, specialty soybean is a niche market commodity that fetch a premium ranging from $18 to $589/t above the market price of commodity soybean (Carter and Wilson 1998). Limited consumer base and lack of suitable cultivars are some of the factors limiting vegetable soybean production in the US. Currently, edamame cultivars that produce high pod yields and also high amount of biomass are being developed through breeding at the Asian Vegetable Research and Development Center, Taiwan. These cultivars serve dual purposes of pod production and as a green manure crop to replenish soil nutrient levels including nitrogen, soil organic matter and improve soil structure and sustainability (Shanmugasundaram 2001). Edamame, due to their short duration (99 to 120 d for MG V-VII), fit well into existing crop rotation patterns. Dual purpose varieties serve as main summer crop and enable farmers to turn in green crop residue as green manure before planting crops next spring.

In the US, three general groups of soybean were recognized based on their end-uses—commercial grain (for oil and source of protein in animal feeds), forage, and vegetable (Morse and Carter 1952). In the early 1950s, vegetable soybean production in the US was limited to home gardens, canners, and frozen food processors (Weber 1956). Research into edamame production has been reported from a few universities in the US, Iowa State University, University of Illinois, Urbana, Champaign, Washington State University, University of Hawaii, Colorado State University, and University of Delaware. A few large-seeded soybean varieties particularly suited for vegetable purposes have been released by some of these universities (Shurtliff and Aoyagi 1991; Lumpkin et al. 1992; Shanmugasundaram 1996). A chronology of vegetable soybean has recently been published (Shurtleff and Lumpkin 2001).

In the US, MGs I through III have been reported to be suitable for production in Washington, Oregon, Colorado, and Montana (Konovsky, 1996; Johnson et al. 1999). In the southeastern US, maturity groups V through VIII have been found to be suitable for production (Rao and Bhagsari 1998). As part of a multi-institutional regional soybean research project (RR7) entitled *"Improvement of soybean for food uses"* sponsored by the Association of Research Directors of 1890 Institutions with funding from USDA/CSREES, a four-year study was conducted to evaluate the yield potential of several Asian edamame genotypes at the Agricultural Research Station, Fort Valley State University, Georgia. The results of the 4-year study are discussed in the following sections.

Agronomic Performance in Georgia

In this project, six edamame cultivars from Japan: 'Akiyoshi' (MG V), 'Houjaku' (MG VI), 'Shangrao Wan Qingsi' (MG V), 'Tambagura' (MG VII), 'Tomahomare' (MG V), and 'Tousan-122' (MG V); four plant introductions also from Japan: PI 181565 (MG VII), PI 200506 (MG VII), PI 416981 (MG V), and PI 417427 (MG VI); two edamame cultivars from China: 'Mian Yan' (MG V) and 'Guanyun Da Hei Dun' (MG V); and two US elite soybean cultivars: 'Ware' (IV) and 'Hutcheson' (MG V) were planted May/June 1995–1998 in randomized complete block design with four replications. Each plot comprised four rows, 6 m long and 0.75 m apart. At the R6 stage (Fehr et al. 1971), plants from 0.5 m row length from middle rows were harvested to determine fresh pod and seed yield and yield components, and fresh seed nutritional traits. Crop management was as per recommendations for soybean. Fresh green seeds were analyzed for protein, oil, glucose, and phytate contents as per procedures described by Mohamed et al. (1986, 1995). Data were subjected to statistical analysis using PROC MIXED procedures of SAS (2000) using Year and Year × Cultivar as random effects. Year × Cultivar was used to test differences among cultivars.

Fresh Pod Yield

The fresh pod yields ranged from 14.6 for 'Ware' to 22 t/ha for 'Tambagura'. The genotypic differences were significant at the 5% level of probability. The six Japanese cultivars produced a mean fresh green pod yield of 19.7 t/ha compared to 18.0 and 16.3 t/ha by the Chinese and American cultivars, respectively. The PI lines produced a mean fresh pod yield of 18.0 t/ha. Thus, the Japanese cultivars and PIs with an average yield of about 19.0 t/ha out-yielded the American and Chinese cultivars by 14.3% and 5.3%, respectively. The green pod yield of 'Tambagura', PI 181565, 'Tomahomare', and 'Shangrao Wan Qingsi' was in excess of 20 t/ha (Fig. 3). The fresh green pod yield of the rest of the genotypes did not differ significantly. The pod yield of the genotypes tested in this study were considerably higher than those reported for vegetable soybean breeding lines in Taiwan (Shanmugasundaram et al. 1991). In this study the mean pod yield ranged from 15 to 22 t/ha compared to 10 to 13, 6 to 9, and 6 to 10 t/ha during spring, summer, and autumn seasons, respectively. This could perhaps be due to the differences in maturity groups. In Taiwan, cultivars (e.g., 'Blueside') of MG V are planted (T.E. Carter, Jr., pers. commun.), whereas in this study, the two highest yielding cultivars were of MG VII. Konovsky et al. (1996) evaluated 36 edamame genotypes comprising 32 Japanese, 3 US, and one Taiwanese for heritability of yield and quality traits in Washington and reported gross yields ranging from 11.2 to 13.6 t/ha and net yields of around 7.2 to 8.4 t/ha. Similarly in Colorado, Johnson et al. (1999) reported green bean gross yields ranging from 2.2 to 10.2 t/ha.

Fresh Seed Yield

The genotypes produced fresh green seed yield which ranged from 7.3 for 'Ware' to 11.6 t/ha for 'Tomahomare'. 'Ware' produced a significantly lower green seed yield than 'Tomahomare', 'Shangrao Wan Qingsi', PI 181565, and 'Tambagura', but was similar to the rest of the genotypes. ' Tomahomare', PI 181565, 'Tambagura', 'Shangrao Wan Qingsi', 'Hutcheson', and 'Akiyoshi' had mean green seed yield of 10 t/ha or more. The genotypic mean for seed yield was 9.6 t/ha. Variations in the mean green seed yield between genotypes could be attributed to variation among yield components. 'Hutcheson' produced greater number of fresh green pods and seeds/m^2 which contributed to its high fresh green seed yield. In 'Tambagura' it was mainly the seed fresh weight that resulted in higher fresh pod weight and green seed yields. In 'Guanyun Da Hei Dun', 'Tomahomare', and 'Shangrao Wan Qingsi' it was a combination of number of green pods and seeds/m^2 and green seed fresh weight that was responsible for higher green seed yield than many of the genotypes. 'Ware', 'Tousan-122', and 'Mian Yan' which had relatively fewer pods and seeds, and lighter seeds also had lower green seed yields.

The fresh green pod yields in this study need to be viewed with caution since they have been extrapolated from a small sample area of 0.38 m^2. If small sample size were to be accounted for by reducing the total yield by 25%, the fresh green pod and seed yields obtained in this study still tend to be higher than those reported for edamame cultivars (MGs 1- III) grown in Washington (Konovsky et al. 1996) and Colorado (Johnson et al. 1999). Thus, the maturity group of the cultivar appeared to be an important determinant of yield of edamame.

Seed Nutritional Traits

The seed protein and oil content ranged from 33.3% and 38.6% (dry weight basis) and 5.0% to 6.9% (fresh weight basis), respectively. The protein content of 'Akiyoshi' was significantly higher than 'Tousan-122' and 'Houjaku'. 'Tousan-122' had a significantly lower protein content than most other genotypes except 'Hutcheson', PI 200506, and 'Akiyoshi'. 'Hutcheson' had a significantly greater oil content than 'Houjaku', 'Mian Yan', 'Ware', 'Tousan-122', 'Shangrao Wan Qingsi', and PI 181565. The oil content of the beans on fresh weight basis was only one-third that (18%–20%) found in mature dry soybean seed (Rao et al. 1998).

The Japanese cultivars appeared to have a slightly higher protein and a lower oil content than some of the PI lines and the two American cultivars. A wide range of genetic variability among soybean accessions has been reported. The protein content of matured dry soybean seed could range from 36%–50% (Clarke and Wiseman 2000).

Fig. 3. Fresh edamame pods from 'Shangrao Wan Qingsi', Fort Valley, Georgia.

In this study, the mean protein content of the fresh immature seeds was 36%, which was more than 86% of that of matured soybean seed. The combination of low oil content and the relatively high protein content of fresh green soybean seeds makes them particularly desirable to the health conscious people seeking low fat, high protein snacks.

Sugar ranged from 6.0% to 7.4% during the four-year study and was similar to that reported for edamame grown in Taiwan (Tsou and Hong 1991). ‘Hutcheson’ had a significantly higher sugar content than ‘Guanyun Da Hei Dun’, PI 181565, ‘Akiyoshi’, PI 417427, ‘Tomahomare’, and ‘Mian Yan’. Whereas, ‘Guanyun Da Hei Dun had a significantly lower sugar content than ‘Tousan-122’, ‘Ware’, PI 416981, ‘Hutcheson’, ‘Tambagura’, and ‘Shangrao Wan Qingsi’, but was similar to the rest of the genotypes. Although, ‘Hutcheson’ had a higher seed sucrose content than many genotypes, it does not qualify as a vegetable soybean since it has small seeds and does not possess pod and seed physical traits that characterize vegetable soybean (Shanmugasundaram et al. 1991). Besides, it has a stronger beany flavor and taste than vegetable soybean cultivars. The total soluble sugar content of the fresh green beans is an important nutritional trait that directly influences the organoleptic properties of edamame and determines consumer acceptability (Masuda 1991).

In this study, the mean phytate content was 1.26% and ranged from 1.08% to 1.39%. ‘Tambagura’ and ‘Haujaku’ had relatively lower phytate content than ‘Akiyoshi’, PI 200506, ‘Guanyun Da Hei Dun’, ‘Tomahomare’, and ‘Mian Yan’. The rest of the genotypes did not differ significantly. The phytate content of the genotypes studied here were considerably lower than those reported for several vegetable soybean genotypes harvested at R6 stage in Virginia (Mebrahtu et al. 1997) and for food grade soybean cultivars, ‘Amsoy’ and ‘Vinton’/’Vinton 81’ (Schaefer and Love 1992).

The moisture content of fresh green seeds ranged from 53.9% to 56.1%, but the differences between genotypes were not significant. Seed moisture content is another critical factor that affects time of harvest since it is an integral part of organoleptic characteristics of vegetable soybean. Seed moisture content also influences the shelf/storage life of vegetable soybeans. The methods of storage also affect the seed moisture content and thus, the quality of fresh vegetable soybean (Shanmugasundaram and Yan 2001).

EDAMAME PREPARATION

Edamame beans inside the pod are eaten, just like peanuts. When ready to prepare, remove the pods from the plant. Boil a pot of water with or without a pinch of salt, add the pods and cook for 3 to 5 minutes, place the pods in ice cold water for a minute or two. Drain and serve cold. As a snack, use thumb and forefinger to squeeze beans from pod; eat out of hand. For a vegetable side dish, toss beans with a bit of olive oil and a sprinkle of salt. Use cooked beans to add texture and give a protein boost to salad or mixed vegetables. Edamame are a good addition to stir-fry. Add to vegetable soups—homemade, canned or dried. Make soymilk or further process into ice cream, tofu, dips, etc., from fresh green seeds.

SUMMARY

In summary, most edamame cultivars and some of the PI lines of Japanese origin tested in this study, appeared to be suitable for production in the southeastern US. The American cultivars ‘Ware’ and ‘Hutcheson’ were of maturity groups IV and V, respectively, and therefore flowered earlier than the Japanese cultivars before achieving full canopy closure. This characteristic appeared to be a major reason for inferior performance of these cultivars relative to the Japanese cultivars. The genotypes tested in this study produced a mean fresh green pod yield of 18.5 t/ha and fresh green seed yield of 9.6 t/ha. The pod and seed yields of Japanese cultivars and PIs were similar to or better than that of the adapted cultivar, ‘Hutcheson’. ‘Tambagura’, ‘Tomahomare’, ‘Shangrao Wan Qingsi’, and PI 181565 with fresh green pod yield of more than 20 t/ha and fresh green seed yield greater than 10 t/ha appeared to be suitable for commercial production in the southeastern US. This study has not only helped identify several potential high yielding edamame cultivars for production to cater to the needs of soyfood industry, it also provided valuable information for further improvement of soybean for food uses through classical breeding combined with modern molecular biological approaches.

Lumpkin and Konovsky (1991) and Carter (1987) have discussed the need for addressing several problems associated with large-seeded vegetable soybean. Some of these problems, such as poor germination, uneven plant stands, a greater susceptibility to stink bugs [*Nezara viridula* (L.) and *Euschitus servus* (Say)], and year to year fluctuations in phenology and quality parameters, were also observed in this study. Poor germination could be minimized by planting seeds into moist seed beds as opposed to the application of irrigation after planting. Research aimed at identification of phytochemicals responsible for off-flavor and improving vegetable soybean flavor by either eliminating off-flavor causing oligosaccharrides through conventional and/or molecular marker assisted breeding or through improved processing and storage procedures is in progress in Asia (Kitamura 1995) and to a limited extent on other food-grade soybean in the US (Davies et al. 1987). There is a need for concerted breeding efforts to develop nutritious, high yielding edamame cultivars with acceptable flavor for the American consumer. Currently, edamame production in the US is confined to small-acreage mainly aimed at niche markets. Edamame harvesting is time specific, laborious and time consuming. The Asian Vegetable Research and Development Center in Taiwan has developed machinery for planting, harvesting, and separation of pods from stems with efficiency around 93%–95% (Shanmugasundaram and Yan 2001). Such machinery may be adapted to US conditions with little or no modifications.

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