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Sensory and Consumer Studies in Plant Breeding: A Guidance for Edamame Development in the U.S.

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Plant breeding is an important discipline to develop food products and improve overall quality, chemical composition, and nutritional value of crops, vegetables, fruits, and nuts, which can be important allies in health promotion. Apples, blueberries, wine grapes, tomatoes, and peanuts are a few examples of food products that were improved in past decades through plant breeding programs in the United States. Recently, edamame (vegetable soybean) has gained special attention from breeders, non-breeder researchers, growers, and consumers, and new edamame varieties are currently being developed for domestic production. As a popular nutritious crop in Asian countries, edamame is increasing in sales and consumption in the United States. Therefore, edamame has great potential to be a profitable alternative crop to replace tobacco farming, whose production and market value have been declining. Until the present date, most published reviews on edamame have focused on its agronomic characteristics. However, understanding consumer expectations, needs, and acceptability for new and improved crops like edamame is vital to guide and sustain their production. It is important that researchers working on plant breeding programs understand and consider the aspects that are relevant for both growers and consumers (e.g., crop productivity, pest and disease resistance, nutritional properties, and sensory attributes). Thus, this review paper aims to integrate available information on sensory quality of edamame and to support its development and production in the United States. This review presents an overview of how sensory evaluation and consumer studies have been used to support plant breeding programs in the development of alternative crops, such as edamame.

Keywords: consumer studies, sensory, plant breeding, food development, edamame, vegetable soybean, *Glycine max* (L.) Merr.

INTRODUCTION

Breeding programs elevate crop productivity and adaptation, which are crucial to expand and sustain the market and industry growth (Gallardo et al., 2018; Padikasan et al., 2018). The development of new food products through plant breeding programs is also an important way to promote human health and dietary improvement as farmers are able to sustainably produce the plant-based products consumers desire and are willing to purchase (Hansson et al., 2018). Breeders' contributions can help improve the nutritional quality of plant-based food products, for example, by increasing the amount of micronutrients (minerals and vitamins) and bioactive compounds (flavonoids, organic acids), modifying fat and oil composition (fatty acid composition), and improving carbohydrate quality (dietary fiber and sugar profile) and protein quality (amino acid profile) (Welch and Graham, 2004; Sands et al., 2009; Patil et al., 2014; Hansson et al., 2018; Padikasan et al., 2018). Over the last decades several food crops have been improved in the United States and Canada through breeding, such as apples (Hampson et al., 2000), blueberries (Gilbert et al., 2015; Gallardo et al., 2018), edamame (Jiang et al., 2018; Carneiro et al., 2020), peanuts (Pattee et al., 2001), and wine grapes (Reynolds et al., 2004). However, in order to succeed, plant breeders must consider both producers' and consumers' current and emerging needs and desires to determine priority traits (Gallardo et al., 2018; Morris and Taylor, 2019). Understanding consumer behavior, needs, and expectations is vital to direct investments and research, and promote sustainable production of new food products. Therefore, interdisciplinary approaches and collaboration among breeders, other agricultural researchers, public health officials, nutritionists, food scientists and technologists, economists, and social and political scientists are important and needed over the next decades (National Academies of Sciences, 2019).

Edamame or vegetable soybean [*Glycine max* (L.) Merr.] is a very popular food in East Asia and is increasing in popularity in the United States (Zhang and Kyei-Boahen, 2007; Carson et al., 2011). In addition to its Japanese name "edamame," vegetable soybeans are also known as "maodou" in China and "poot kong" in Korea (Kumar et al., 2011). Although often available in pods, only edamame beans are edible; they are mostly consumed as a snack, after being cooked in salted boiling water for a short time or roasted like peanuts, and may also be consumed as additions to salads, soups, and stews, stir-fried, or processed sweets and desserts (Sirisomboon et al., 2007; Mebrahtu and Devine, 2008; Sujith Kumar et al., 2011). Due to the need for import, seasonal production, and short harvest period, frozen edamame (in pods or shelled) is more common than fresh edamame in the U.S. market (Montri et al., 2006; Saldivar et al., 2010; Nolen et al., 2016; Wolfe et al., 2018). Asian countries are still the major suppliers of the edamame consumed in the U.S. and since the 1990s China has replaced Taiwan as the major edamame exporter (Wang, 2018; Flores et al., 2019). However, the growing demand for edamame in the U.S. has aroused the interest of breeders, growers, and food processors to produce this vegetable domestically (Xu et al., 2016). Hence, edamame has been suggested as an alternative crop to replace the decreasing tobacco production, for example, in Virginia and Kentucky (Xu et al., 2012; Ogles et al., 2016). Although genetically modified (GM) soybeans are predominant in the U.S. market for feed and oil production, only non-GM edamame has been sold for food consumption. In addition, consumers in the U.S. have reported they are willing to pay significantly more for non-GM edamame (Lee et al., 2018; Wolfe et al., 2018), which emphasizes the importance of breeding programs to increase domestic production and consumption of edamame in the United States.

Edamame quality is comprised of its agronomic characteristics, sensory attributes, and nutritional value. Characteristics for high quality edamame pods are commonly described as bright green with a light pubescence (white to gray), intact, without external defects, a spotless surface, good shape, and must contain two or more beans per pod to be acceptable for sale (Wszelaki et al., 2005; Williams, 2015). Edamame are harvested when the plant is still immature (between reproductive growth stages R6 and R7), seeds have filled 80–90% of the green pod width and still retain around 65% moisture content, with Brix readings (total soluble solids) between 8.5 and 12 (Johnson, 2000; Sujith Kumar et al., 2011; Nolen et al., 2016). Harvesting edamame at the R6 stage brings the benefits of having desired quality attributes, such as intense green color, low concentrations of oligosaccharide and anti-nutrients, and both sucrose content and seed weight at their peak (Xu et al., 2016).

Although the Japanese market is still the largest consumer of edamame (Wang, 2018), the number of consumers who are interested in improving their health by following a better diet has been increasing in the U.S., as well as the demand for soy products and alternative sources of protein (Ogles et al., 2016). Edamame is a nutritious, high-value and easy-to-grow specialty crop, and an appealing product for consumers interested in natural foods, especially when coming from organic production (Montri et al., 2006; Zhang and Kyei-Boahen, 2007). Soy foods like edamame are healthy dietary options for most consumers and are premier choices to versatile vegetarian and vegan diets, because they are rich sources of protein and many other nutrients (Rizzo and Baroni, 2018). The major isoflavones present in edamame (genistein and daidzein), for example, are known for their potent antioxidant property that is associated with the health benefits of soy products (Mebrahtu et al., 2004; Roland et al., 2011). However, the soybean isoflavones are associated with astringency and bitterness, two undesired sensory attributes that can impact acceptability (Roland et al., 2011).

In terms of food composition, the carbohydrate, fat and oil composition, energy density, and micronutrients (minerals and vitamins) contents are important aspects to consider for health-promoting breeding (Hansson et al., 2018). Breeders in the U.S. have worked on the development of new edamame varieties better adapted to the U.S. soil and climate through crossing between adapted U.S. grain varieties and Asian large-seeded varieties (Zhang and Kyei-Boahen, 2007). Asmara, Randolph, and Owens are examples of North American edamame cultivars and their compositions are shown in **Table 1**. Over the last decades, agronomic research studies have been performed in universities across the U.S. to introduce and improve new edamame varieties. However, most of these studies did not include information regarding consumers' perceptions and buying attitudes toward edamame (Flores et al., 2019). Likewise, the few reviews of edamame published until recently have focused exclusively on the agronomic characteristics, despite the importance of understanding consumer data to answer breeding and food production questions. As new breeding programs have started to focus on the improvement of edamame to push for a competitive production in the U.S., this review aimed (1) to combine and summarize the available information regarding consumer preferences and sensory quality of edamame for the U.S. market, and (2) to understand and describe how sensory

TABLE 1 | Edamame bean composition of three North American cultivars on a dry weight basis averaged.

	Asmara[a]	Randolph[b]	Owens[c]
Sucrose	39.6 g g^{-1}	51.8 g g^{-1}	63.0 mg g^{-1}
Protein	430 g kg^{-1}	445 g kg^{-1}	350 g kg^{-1}
Oil	92 g kg^{-1}	(Not informed)	139 g kg^{-1}
Oleic acid	43.3 % of total oil	39.3 % of total oil	45.3 % of total oil

[a]Mebrahtu et al. (2005a); [b]Mebrahtu et al. (2005b); [c]Mebrahtu et al. (2007).

evaluation methods and consumer studies have been used to assist plant breeding programs and to help the development of edamame in the U.S. We also identify some of the challenges and benefits associated with providing sensory and consumer data in the early stages of new food crop development.

SENSORY EVALUATION AND CONSUMER STUDIES IN PLANT BREEDING: IMPORTANCE, METHODS AND CHALLENGES

In plant breeding, the genetic pattern of plants can be modified to address economic importance (Padikasan et al., 2018). For example, Gallardo et al. (2018) reported that quality traits such as firmness, flavor, and shelf life can influence price (premium products), consumer demand and acceptability, machine harvestability, and economic viability of the blueberries industry (Gallardo et al., 2018). Similar association can be made to other fruit and vegetable crops. For edamame, the volatile compound 2-acetyl-1-pyrroline (2AP), characterized by a "popcorn-like" aroma, is an important aroma discriminator for premium characteristics and higher price of edamame and influence its acceptability and consumer preference (Arikit et al., 2011a,b). However, instrumental methods are still not able to completely mimic human sensory responses and perceive food products as humans do (Lawless and Heymann, 2010). Thus, sensory and consumer studies can be used to investigate quality attributes and preferences for different plant cultivars and can be valuable tools to support plant breeders in parent selection as well as selection of new breeding lines and cultivars (Hampson et al., 2000; Suwonsichon, 2019).

Although sensory evaluation has already been employed in plant breeding research worldwide, it is still common that breeding programs often are limited to the tasting results, experiences, and perspectives from only a few experts (frequently the plant breeders) to assist varietal and traits selection (Hampson et al., 2000; Bowen et al., 2019). Application of sensory techniques and/or consumer studies for guiding plant parent selection, or selection of breeding lines and cultivars requires consideration of the intended use of the information. Sensory evaluation methods and consumer studies can be used to understand and/or measure sensory attributes (e.g., appearance, aroma, flavor, texture, mouthfeel) of food products, or how consumers perceive and respond to them. Discrimination tests and descriptive sensory methods typically focus on the characteristics and differences in products, while affective tests (acceptance and preference) focus on consumer response to the product characteristics (Civille and Oftedal, 2012). Descriptive methods [e.g., quantitative descriptive analysis (QDA)] may use fewer people to complete an assessment, but participants must be trained to recognize, identify, and quantify the characteristics they perceive in the varieties. Thus, the low number of participants in descriptive panels, typically between 5 and 20, is justified by their level of calibration (Lawless and Heymann, 2010). By using this approach, differentiation of produce or crop product attributes may be assessed early in the breeding process, possibly with correlation to instrumental analyses of compositional or quality parameters (Morris and Taylor, 2019). This contribution can be highly informative to breeders and assist in guiding the development of breeding lines and cultivars. However, the time investment for training and the need to retain the trained panel members over the study duration or across multiple years of breeding development increases complexity and can be unaffordable (Morris and Taylor, 2019).

Although descriptive sensory analyses can help differentiate varieties, the data-derived information does not suggest that the varieties will be well received by consumers. Wang and Kays (2003) cited the examples of improved strawberry (*Fragaria* × *ananassa* Duch.) and tomato (*Lycopersicon esculentum* Mill.) cultivars that were released to the market without previous validation of consumer acceptability; they have bigger size, longer shelf-life, but do not meet consumer expectations in terms of flavor. Consumer testing is used to estimate the response by untrained product users, purchasers, or those interested in the broad class of products. In order to estimate the public acceptance, a large number of participants are needed and a typical guidance is 75–150 responses per product (Lawless and Heymann, 2010). Product limitations in early stage of breeding programs may limit the use of consumer testing to advanced breeding lines. Therefore, the first step to obtain acceptability information for varietal development is to assure sufficient sample availability for the sensory studies.

Plant breeding programs have commonly applied sensory evaluation and/or consumer testing to investigate which cultivars (or new genotypes) are mostly preferred by consumers and which major sensory characteristics drive these preferences (Hampson et al., 2000). The list of major challenges regarding the development and evaluation of novel fruit and vegetable cultivars includes natural variability, the fact that products cannot be stored for a long time, and different cultivars are not always available at the same period due to different optimal maturation and harvest dates (Jaeger et al., 2003; Bowen et al., 2019). These factors can complicate, for example, the selection and training of panelists for descriptive analysis, which is a sensory method often applied in later stages of breeding programs (to assess flavor of selected varieties, for example). Consumer acceptance and preference mapping are additional sensory analyses that have been applied to support plant breeding programs. These approaches were used, for example, to support development of kiwifruit and apple cultivars in New Zealand and Canada, respectively (Jaeger et al., 2003; Bowen et al., 2019). However, traditional acceptability studies are often difficult to perform or are avoided for routine screening selection in breeding programs due to limitations in resources and sample availability (Hampson et al., 2000). In the two fruit development studies cited above, researchers conducted descriptive sensory analysis prior to investigating product acceptability (Jaeger et al., 2003; Bowen et al., 2019). Statistical approaches (regression and correlation) can also be used to relate instrumental measures and consumer acceptance with descriptive analysis information (Lawless and Heymann, 2010).

The development of a lexicon, a standardized list of descriptors that characterize a food product, is another important application of sensory evaluation methods to support the development of new products, such as new plant cultivars (Suwonsichon, 2019). Lexicons, also called word lists, are important tools applied in descriptive analysis and enable clear and effective communication among different audiences (e.g., scientists, researchers, consumers, breeders, product developers, producers, industry etc.) (Suwonsichon, 2019). In the last decades, lexicons have been developed and used to support improvement and development of food crops worldwide. Talavera-Bianchi et al. (2010), for example, used samples of beet greens, swiss chard, spinach, endive, radicchio, lettuce, mustard greens, pak (bok) choy, turnip greens, cabbage, collard greens, kale, arugula, watercress, cilantro, and parsley to develop a lexicon (32 terms) to describe flavor of fresh leafy vegetables. Likewise, Belisle et al. (2017) developed a lexicon (29 terms) to describe appearance, aroma/flavor, texture, and feeling factors of fresh peach, and Griffin et al. (2017) developed a lexicon (29 terms) to characterize sensory attributes of cashew nuts (feeling factors, flavor, and texture terms). These validated sensory descriptors can be applied, for example, in check-all-the-apply (CATA) lists and surveys (e.g., economic, marketing, and behavioral surveys), which can be used to support varietal screening and selection in breeding programs. For instance, the edamame lexicon developed by Krinsky et al. (2006) was used as the major reference for the CATA list used by consumers in our recent study (Carneiro et al., 2020).

Overall, optimized sensory evaluation methods are desired to evaluate product quality (e.g., flavor and texture) and support breeding selection in early stages of the breeding schemes (Morris and Taylor, 2019). CATA is a fast and simple descriptive methodology that does not require trained panelists. Nevertheless, it requests a minimum of 60–80 participants, who are instructed to select from a list of descriptors the ones in their opinion that best describe the products (Qannari, 2017; Alexi et al., 2018). CATA typically does not measure intensity of attributes, but can show differences in sensory profile (Alexi et al., 2018). It has been combined with traditional hedonic preference tests to support the development of food products such as strawberries in Uruguay (Lado et al., 2010), *Amaranthus* in South Africa (Hiscock et al., 2018), and tomatoes in Mexico (Vela-Hinojosa et al., 2018). Those researchers suggested CATA as a simple and less time-consuming method to evaluate differences among new genotypes and support the breeding selection. The use of CATA and other sensory approaches to access consumer's preferences and acceptability of edamame in the U.S. market are discussed next.

CONSUMER PERCEPTION OF EDAMAME SENSORY QUALITY IN THE U.S.

While breeders focus on in-field appearance criteria (number of beans per pod, color, shape, defects at time of harvest), from the global perspective, consumers, and distributors evaluate edamame quality by its desirable sensory attributes, including appearance (pod and bean), aroma, flavor, and texture (firmness) (Kelley and Sánchez, 2005; Williams, 2015). Additionally, when breeding to develop heathier produce and crop food products and improve nutritional profile of fruits and vegetables, it is important to consider the impact that bioactive compounds might have on flavor (e.g., increase bitterness or astringency) (Civille and Oftedal, 2012; Patil et al., 2014). Nutritional and sensory properties are key motivators for consumers to purchase edamame, which means commercial varieties must have high-quality sensory characteristics in order to be accepted (Kelley and Sánchez, 2005). Nevertheless, only a few research papers published in the last decades show how descriptive sensory and/or consumer methods (affective tests) have been used by researchers in the U.S. to investigate consumer perception of edamame sensory quality (**Table 2**). In a collective manner, these studies investigated a large set of edamame genotypes (cultivars and/or varieties in development) that were grown in the U.S., as well as commercially processed edamame products (in-pod or shelled beans) available in the U.S. market. Understanding which sensory characteristics of edamame are important to growers, processors, and consumers is vital to develop a sustainable domestic production. Therefore, their findings are summarized in the next paragraphs.

In the earliest study presented in **Table 2**, researchers in Colorado reported that American consumers seem to prefer more mature beans, with "buttery" texture and flavor, while Japanese consumers prefer sweeter beans, with crisper texture and flower-like flavor (Johnson et al., 1999). According to the researchers, this preferred "buttery" texture could be obtained through a delay in harvest, but no further information was given about it, nor about how the sensory panels were conducted. Next, researchers in Virginia reported that untrained consumers evaluated sensory attributes (texture, color, beaniness, nuttiness, sweetness, oiliness, and aftertaste) and overall eating quality of 31 edamame genotypes (maturity groups III–VI), and most samples were characterized as color "light green" to "green," texture "slightly resistant" to "resistant," relatively low sweetness and nuttiness, "slightly beany" to "beany," not oily, and pleasant aftertaste (Young et al., 2000). Their color results suggested panelists evaluated the genotypes differently, which illustrated a limitation of the study: the use of untrained panelists to perform a descriptive test (not calibrated before the study). In addition, despite the small number of panelists in the study, which was another limitation, results suggested flavor, and nutrient attributes as the major motivators to purchase edamame. The importance of considering sensory attributes when selecting

TABLE 2 | Sensory studies performed with edamame samples in the United States.

Location	Sensory evaluation	Panelists	Edamame samples	Sensory attributes analyzed	References
Virginia	*Acceptability*; 9-point hedonic scales (1 = "dislike extremely" and 9 = "like extremely")	Screening study *n* = 182 (50–53 per test); validation study *n* = 171 (90 per test) (untrained)	Screening study: 20 edamame genotypes (2 cultivars, Asmara and UA-Kirksey, and 18 advanced breeding lines) grown in Little Rock, AR, Blacksburg and Painter, VA	Overall liking, appearance, aroma, flavor, texture	Carneiro et al., 2020
	Descriptive; 5-point intensity scale (1 = "not sweet," 5= "extremely sweet")	Participants were allowed to participate in one or more tests (screening study: up to 10; validation study: up to 4)	Validation study: 10 edamame genotypes (1 cultivar, UA-Kirksey, and 9 advanced breeding lines) grown in Blacksburg and Painter, VA, Portageville, MO, and Stoneville, MS	Sweetness intensity	
	Descriptive; check-all-that-apply (CATA) question using a list of 15 descriptors			Aroma, flavor, texture	
California	*Acceptability*; 11-point hedonic scales (0 = "Do not like at all" and 10 = "Like extremely")	*n* = 74 (untrained)	Giant Midori, ButterBean, and Kuroshinja varieties, organically grown in Northern California. Same samples were evaluated in both sensory studies	Flavor, texture, appearance, and overall-liking	Flores et al., 2019
	Descriptive; Free choice profiling (FCP) methodology, scale: 0 = "None" to 10 = "Extreme"	*n* = 25 (flavor), *n* = 24 (texture), and *n* = 37 (appearance) (untrained)		Flavor, texture and appearance	
Arkansas	*Acceptability*; 9-point hedonic scales (1 = "dislike extremely" and 9 = "like extremely")	*n* = 117 (untrained)	A genetically modified (GM) and a non-GM soybean cultivar intended for feed and oil production harvested at the edamame stage	Appearance, aroma, flavor, texture, and overall impression	Wolfe et al., 2018
Illinois	Not described; study performed by a vegetable processor	Not described	Fresh pods and seeds of selected edamame genotypes grown at the University of Illinois Vegetable Crop Farm	Appearance (pod size and color, seed color and blemishes), texture, and flavor	Williams, 2015
North Carolina	*Descriptive*; Lexicon development, 0–15-point intensity scale	*n* = 12 (untrained)	Twenty commercial frozen edamame products (brands from China, Taiwan or Japan; shelled and in-pod options) obtained in U.S. grocery stores	Flavor	Krinsky et al., 2006
	Descriptive; Lexicon verification, 0–15-point intensity scale	*n* = 12 (trained)	(1) A subset of the commercial samples used for the lexicon development. (2) Mojo Green variety grown at North Carolina State University research farm (Goldsboro, NC). Samples from a blanching study (100°C for 0, 30, 60, 90, 120, and 180 s)		
Pennsylvania	*Acceptability*; Overall-liking: 9-point hedonic scale (1 = "extremely dislike" and 9 = "like extremely"). Firmness: 7-point "just about right scale" (1 = "much too soft" and 7 = "much too firm")	*n* = 113 (untrained)	Early Hakucho, Green Legend, and Kenko cultivars grown at the Horticulture Research Farm, Russell E. Larson Research Center (Rock Springs, PA)	Overall-liking and firmness	Kelley and Sánchez, 2005
	Preference; Ranking (preference order from "most liked" to "least liked)			Liking	

(Continued)

TABLE 2 | Continued

Location	Sensory evaluation	Panelists	Edamame samples	Sensory attributes analyzed	References
Ohio	*Descriptive*; 9 cm horizontal line scales (from less to more)	$n = 10$ (trained)	Six commercial varieties (Sapporo Midori, White Lion, Early Hakucho, Sayamusume, Misono Green, and Kenko) organically grown at the Ohio Agricultural Research and Development Center (Wooster, OH)	Flavor and texture	Wszelaki et al., 2005
	Acceptability; 9-point hedonic scales (1 = "dislike extremely" and 9 = "like extremely")	$n = 54$ (untrained)		Appearance (pods and beans), aroma, taste, texture, aftertaste, and overall acceptability	
Virginia	*Descriptive*; 5-point scales. Color range: 1 = "yellow green" to 5 = "dark green." Texture range: 1 = "not resistant" to 5 = "extremely resistant." Intensity scale ranges (flavor attributes): from 1 = "not intense" to 5 = "extremely intense." Aftertaste: 1 = "extremely unpleasant "to 5 = "extremely pleasant, "plus a sixth category labeled 6 = "no aftertaste"	$n = 22$ (total) (untrained) Panelists were grouped into 3 panels, A, B, and C, which had 8, 6, and 10 participants, respectively	31 maturity groups III-VI genotypes grown at Randolph Research Farm of Virginia State University (Petersburg, VA)	Color, texture, sweetness, nuttiness, beaniness, oiliness, and aftertaste	Young et al., 2000
	Acceptability; Overall eating quality: 5-point scale (poor, fair, good, very good, and excellent)			Overall eating quality	
Colorado	*Not described*; 10-point scale (1 = "poor, "10 = "excellent")	Not described	Five Japanese edamame cultivars (SE1–SE5) provided by Seedex, Inc. (Longmont, CO), which were grown in Rocky Ford and Ft. Collins, CO, between 1994 and 1998	Texture	Johnson et al., 1999

genotypes for production was acknowledged by the authors, but they did not report how sensory data was used to guide breeders throughout the breeding process (for example, selection criteria or decision tree).

Sensory studies conducted a few years later in Ohio and Pennsylvania used commercial cultivars to assess U.S. consumer acceptability of edamame. Wszelaki et al. (2005) investigated acceptability and sensory characteristics of six commercial cultivars already available to growers and overall consumer acceptability (mean scores) of the edamame cultivars were reported as following: Misono Green = 5.5, Early Hakucho = 5.9, Kenko = 6.1, Sapporo Midori = 6.1, White Lion = 6.1, and Sayamusume = 6.3 (9-point hedonic scale; 9 = "like extremely"). Researchers reported that significant differences in acceptability were only observed in pod appearance and taste of edamame beans. Consumers liked better the pod appearance of Kenko, White Lion, and Sayamusume cultivars and the taste of Sayamusume, Kenko and Sapporo Midori beans. In sequence, sweetness and chewiness were suggested by consumers as the most important attributes to differentiate edamame varieties (Wszelaki et al., 2005). The cultivar Kenko was reported as the sweetest edamame evaluated, but the intensity of its sweetness attribute was not significantly different from cultivar Sapporo Midori. Kelley and Sánchez (2005) also reported a high overall acceptability score for the edamame cultivar Kenko (mean score = 6.84; 9-point hedonic scale). In their study, consumers evaluated overall-liking and firmness of edamame beans of cultivars Kenko, Early Hakucho and Green, then ranked the three cultivars in order of preference. Researchers reported that Kenko was ranked the most preferred edamame and its firmness was rated as just about right. Although the studies of Wszelaki et al. (2005) and Kelley and Sánchez (2005) investigated acceptability and sensory attributes of commercial edamame cultivars not necessarily developed to be grown in the U.S., they offer valuable information that can support parent selection in edamame breeding programs. They also provide initial information to breeders about quality traits of edamame that are desired by consumers in the U.S. and can drive purchase intent.

Sensory and consumer studies that investigated edamame attributes and acceptability in the U.S. mostly used samples of processed edamame products instead of raw edamame. Krinsky et al. (2006) used up to 20 commercial processed (frozen) edamame products for the development and validation of a lexicon that contained 14 terms to describe edamame flavor: "raw bean," "cooked bean," "green complex," "fruity complex," "nutty/almond," "brothy," "sulfur," "salty," "sweet," "sour," "bitter," "astringent," "umami," and "metallic." Samples for the lexicon development consisted of edamame products (in-pod and shelled options) processed in Asian countries and obtained in U.S. grocery stores. For the lexicon verification, participants evaluated two sets of samples: a subset of commercial samples, and a set of shelled edamame (variety Mojo Green) from a blanching study conducted by the researchers. The importance of lexicons to support breeding programs was discussed in the previous section of this review. Although the study performed by Krinsky et al. (2006) was not directly associated to a breeding program, it is the only lexicon for edamame found in the literature. As the lexicon was focused on flavor descriptors, there is still a need for a more complete standardized list of descriptors that includes other edamame attributes, such as texture, mouthfeel and appearance.

Recently, the acceptability of three edamame cultivars (Giant Midori, Kuroshinja, and ButterBean) was investigated as part of a broader organic vegetable research project in California (Flores et al., 2019). Participants rated overall liking, appearance, flavor, and texture of each sample, and Giant Midori was the most liked edamame (overall liking and all sensory attributes), while ButterBean had the lowest sensory scores. Next, a free choice profiling (FCP) descriptive analysis was performed after the acceptability testing; participants (untrained) created their own descriptors to describe appearance, flavor, and texture, then rated each of their descriptors using an intensity scale. Similar descriptors were grouped by researchers for analysis. For appearance, all cultivars were mostly described as small, green, and fuzzy. However, researchers did not clearly describe if the appearance descriptors were associated with edamame pods, beans, or both. Two factors explained flavor variability; the first factor (sweet with minor notes of strong and fresh) was mostly identified with the Giant Midori and Kuroshinja cultivars, and the second one (bland, earthy, and grass) was mostly linked to the ButterBean edamame. Lastly, three factors explained texture variability; the first factor (crunchy, with some firmness and wetness) was mostly associated with Giant Midori edamame; the second factor (chewy, firm, slippery, smooth, squishy) best explained the Kuroshinja cultivar, and the third factor (bumpy, dry, fuzzy, hard, mealy, soft, stringy) was mostly linked to the ButterBean cultivar. As FCP does not request trained sensory panelists, it is a less expensive and quicker descriptive method that can be used, for example, to provide breeders with information about how consumers perceive the sensory attributes of improved varieties, especially in earlier stages.

CATA is another example of a quick descriptive method that does not request trained participants and could be associated with acceptability tests, as previously mentioned in this review. The use of a CATA question to investigate sensory profile of edamame was only reported by Carneiro et al. (2020). In Virginia, consumer studies and sensory evaluation are currently being used to support breeding decisions in a multistate plant-breeding program focused on developing varieties for domestic production (Carneiro et al., 2020). The authors divided their sensory study in two parts: screening study (first year) and validation study (second year). First, 20 edamame genotypes (breeding lines and cultivars) were evaluated by untrained consumers who participated in one or multiple sensory panels. Then, first-year consumer data (overall-liking, appearance, aroma, taste, and texture liking, and CATA descriptor selection) led to the development of a decision tree to assist breeding selection criteria, and the following selection of 10 genotypes for further sensory evaluation (validation study). Researchers also reported the use of penalty analysis to understand the impact of each of the 15 CATA descriptors in edamame acceptability. They suggested "salty" and "sweet" as the main natural sensory attributes of edamame associated with high acceptability scores, while "bitter" was the main attribute associated with lower acceptability scores.

The decision tree developed by Carneiro et al. (2020) illustrated how sensory studies can be used to support breeding selection criteria. The authors reported the tool was developed based on the literature and acceptability scores of selected edamame cultivars (checks). For example, genotypes suggested to continue in the breeding programs should have at least a 5.9 (rounded up) overall-liking mean score and/or at least a 1.8 sweetness intensity mean score. This decision tree included approval of edamame breeding lines whose profile was characterized by at least 4 sensory attributes with high acceptability scores. It supported the selection of most breeding lines chosen for the validation study, as well as the identification of varieties that are strong candidates to be released. Likewise, a previous study performed in Illinois reported how sensory studies helped identify edamame genotypes that were promising genotypes to be grown in the North Central United States (Williams, 2015). Sensory data was obtained by a vegetable processor and the following sensory attributes were evaluated: pod color and size, and seed color, blemishes, texture, and flavor. Details about how the sensory study was performed were reported. Sensory evaluation criteria was an acceptable threshold to the vegetable processor, and the basis for this threshold was only described as acceptable R6 pods and seeds, meaning "two- to three-seed pods, green pods and seeds, seed free of blemishes, a smooth seed texture, and seed with a sweet and/or nutty flavor." Besides an acceptable sensory profile, their selection criteria included emergence ($>$36%), height at R6 ($<$66 cm), and seed mass ($>$20 g 100 seed^{-1}). Both agronomic and sensory criteria supported the selection of 12 edamame genotypes from an initial set of 136 genotypes (Williams, 2015). As there is no standard way to use sensory results to make breeding decisions, the studies above can be used as a reference for future plant breeding programs.

CONSUMER BEHAVIOR AND PURCHASE INTENTION OF EDAMAME IN THE U.S. MARKET

In the mid-Atlantic and Southeast U.S., edamame has been promoted to growers as a profitable alternative or new crop, for example, to replace tobacco (Xu et al., 2012; Ogles et al., 2016). However, when selecting the best cultivar, growers are suggested to consider agronomic aspects of the cultivars, such as yield characteristics, but also consumers' preferences (Ogles et al., 2016). One requirement for varietal success (vegetables, fruits, nuts) is having a market for the new developed crop. Seed and crop producers, as well as food processors, want to know that there will be economic value for growing, distributing, and selling the new varieties in a competitive food market. Estimating consumer interest in and motivation for edamame products through consumer willingness-to-pay (WTP) studies helps provide that information. For instance, Flores et al. (2019) reported that consumers in California showed the highest purchase intent for the edamame cultivar Giant Midori and the lowest for the cultivar ButterBean, which were, respectively, the most and least liked edamame evaluated.

U.S. consumers are willing to pay price premium for non-genetically modified edamame (Wolfe et al., 2018), which suggests breeding programs are vital to develop and sustain the edamame production in the U.S. Wolfe et al. (2018) reported that although no significant difference was observed between preference scores of genetically modified (GM) and non-GM edamame samples, consumers valued more on non-GM-labeled edamame and were willing to pay at least $0.42 more per unit for that information. Based on WTP, unlabeled or GM-labeled products did not provide similar additional value to edamame. In addition, Lee et al. (2018) reported that negative information about GM products affects consumer WTP for edamame more than positive information. The authors suggested it would be difficult to introduce GM edamame in the U.S. market, which reinforced the importance of breeding programs for increasing domestic production of this vegetable.

Furthermore, a deeper understanding of factors that drive consumer purchase intent is important to build a sustainable domestic production. Recently, Carneiro et al. (2020) reported that in both years their sensory study was conducted, ∼50% of the participants answered they consume edamame few times per year, and chose "like the taste" and "for heath reason," respectively, as their main motivations to consume soy products. Previous consumer studies conducted in Pennsylvania also investigated behaviors and attitudes toward edamame to have a better picture of the U.S. market preferences and needs. Kelley and Sánchez (2005) investigated the potential demand for edamame through a telephone survey in the Metro-Philadelphia area. The majority of the participants belonged to the group of potential edamame purchasers and they were more likely to care about the nutritional profile of the products they purchased and consumed. This group was also characterized by the largest number of participants who reported they have included soy or soy-based products in past purchases, and had heard about edamame before the survey. After these participants were informed about edamame origin, health benefits associated with its consumption, and some ways to prepare it, most of them reported their potential to eat edamame as "very likely" or "likely."

A subsequent consumer study performed in supermarkets located in the metropolitan Philadelphia area investigated consumer interest in fresh and in-shell edamame (Montri et al., 2006). Although fresh edamame can be occasionally purchased in farmers markets or groceries stores, most edamame available in the U.S. market is sold as a processed product, typically blanched and frozen stored. Consumers reported same preference to purchase in the future either fresh edamame in-shell only, or both in-shell and shelled. In addition, more than half of the participants reported they were more likely to buy Pennsylvania grown edamame, mostly because they were farmed without the application of pesticides. Among the factors that could possibly affect their decision to purchase a new product, participants ranked friend's recommendation, in-store promotions (sample of product at the supermarket), price, outside advertising (magazine or news article), and product packaging (health benefits stated on package), in this order, as the main factors. In summary, U.S. consumers have expressed that they value the nutritional and sensory profile of edamame and it can drive their purchase decisions. For edamame breeders, the consumer studies presented in this review reinforce the importance of breeding to improve nutritional quality of new varieties for the U.S. market. For domestic edamame growers and processors, this knowledge is important to guide production decisions, such as type of products (in-shell or shelled) and packaging information that are mostly appreciated.

CONCLUSION

Sensory attributes and nutritional value, as well as agronomic characteristics, are important factors to be considered when breeding new cultivars to develop and improve food products, such as edamame. Sensory evaluation and consumer studies provide valuable information to support plant breeders in the selection of genotypes that have more potential for market success, such as desirable product characteristics (e.g., sensory and nutritional profile, shelf life, organic production) for which consumers would be willing to pay more. However, this information is often obtained only in late stages of breeding schemes due to sample limitations, cost, and complexity of traditional sensory methodologies. Releasing improved cultivars of fruits and vegetables without understanding consumers' preferences and expectations increases the risk of market failure. Understanding the available sensory methods (discrimination, descriptive, acceptance, and preference tests) is essential since early planning phases to manage resources and mitigate problems related, for example, to sample quality and limitations. Additionally, we acknowledge the importance of seeking alternatives that can contribute to reduce the cost and complexity to obtain consumer data. Future efforts are needed and encouraged to develop and validate new simple, fast, and optimized sensory methods to support breeding programs. Likewise, future studies aiming to understand the relationship between sensory and analytical data are suggested to support the development of quality evaluation methodologies. Lastly, an interdisciplinary approach that integrates breeders and non-breeder researchers, such as crop scientists, nutritionists, food scientists, and economists, has been proven to be of great value for the development and success of new food crops and is suggested for future breeding programs.

AUTHOR CONTRIBUTIONS

RC drafted the manuscript and edited based on co-author and reviewers' comments. All authors reviewed, edited, and approved draft and submitted versions of the manuscript.

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REFERENCES

Alexi, N., Nanou, E., Lazo, O., Guerrero, L., Grigorakis, K., and Byrne, D. V. (2018). Check-All-That-Apply (CATA) with semi-trained assessors: sensory profiles closer to descriptive analysis or consumer elicited data? *Food Qual. Prefer.* 64, 11–20. doi: 10.1016/j.foodqual.2017.10.009

Arikit, S., Yoshihashi, T., Wanchana, S., Tanya, P., Juwattanasomran, R., Srinives, P., et al. (2011a). A PCR-based marker for a locus conferring aroma in vegetable soybean (*Glycine max* L.). *Theor. Appl. Genet.* 122, 311–316. doi: 10.1007/s00122-010-1446-y

Arikit, S., Yoshihashi, T., Wanchana, S., Uyen, T. T., Huong, N. T. T., Wongpornchai, S., et al. (2011b). Deficiency in the amino aldehyde dehydrogenase encoded by GmAMADH 2, the homologue of rice Os2AP, enhances 2-acetyl-1-pyrroline biosynthesis in soybeans (*Glycine max* L.). *Plant Biotechnol. J.* 9, 75–87. doi: 10.1111/j.1467-7652.2010.00533.x

Belisle, C., Adhikari, K., Chavez, D., and Phan, U. T. X. (2017). Development of a lexicon for flavor and texture of fresh peach cultivars. *J. Sens. Stud.* 32, 1–12. doi: 10.1111/joss.12276

Bowen, A. J., Blake, A., Tureček, J., and Amyotte, B. (2019). External preference mapping: a guide for a consumer-driven approach to apple breeding. *J. Sens. Stud.* 34. doi: 10.1111/joss.12472

Carneiro, R. C. V., Duncan, S. E., O'Keefe, S. F., Yu, D., Huang, H., Yin, Y., et al. (2020). Utilizing consumer perception of edamame to guide new variety development. *Front. Sustain. Food Syst.* [submitted for review in this same special edition]

Carson, L., Freeman, J., Zhou, K., Welbaum, G., and Reiter, M. (2011). Cultivar evaluation and lipid and protein contents of Virginia-grown edamame. *Horttechnology* 1, 131–135. doi: 10.21273/HORTTECH.21.1.131

Civille, G. V., and Oftedal, K. N. (2012). Sensory evaluation techniques—make "good for you" taste "good." *Physiol. Behav.* 107, 598–605. doi: 10.1016/j.physbeh.2012.04.015

Flores, D., Giovanni, M., Kirk, L., and Liles, G. (2019). Capturing and explaining sensory differences among organically grown vegetable-soybean varieties grown in Northern California. *J. Food Sci.* 84, 613–622. doi: 10.1111/1750-3841.14443

Gallardo, R. K., Zhang, Q., Dosset, M., Polashock, J., Rodriguez-Saona, C., Vorsa, N., et al. (2018). Breeding trait priorities of the blueberry industry in the United States and Canada. *HortScience* 53, 1021–1028. doi: 10.21273/HORTSCI12964-18

Gilbert, J. L., Guthart, M. J., Gezan, S. A., De Carvalho, M. P., Schwieterman, M. L., Colquhoun, T. A., et al. (2015). Identifying breeding priorities for blueberry flavor using biochemical, sensory, and genotype by environment analyses. *PLoS ONE* 10:e0138494. doi: 10.1371/journal.pone.0138494

Griffin, L. E., Dean, L. L., and Drake, M. A. (2017). The development of a lexicon for cashew nuts. *J. Sens. Stud.* 32, 1–10. doi: 10.1111/joss.12244

Hampson, C. R., Quamme, H. A., Hall, J. W., Macdonald, R. A., King, M. C., and Cliff, M. A. (2000). Sensory evaluation as a selection tool in apple breeding. *Euphytica* 111, 79–90. doi: 10.1023/A:1003769304778

Hansson, S. O., Åman, P., Becker, W., De Koning, D. J., Lagerkvist, C. J., Larsson, I., et al. (2018). Breeding for public health: a strategy. *Trends Food Sci. Technol.* 80, 131–140. doi: 10.1016/j.tifs.2018.07.023

Hiscock, L., Bothma, C., Hugo, A., Van Biljon, A., and Van Rensburg, W. S. J. (2018). Overall liking and sensory profiling of boiled Amaranthus leaves using the check-all-that-apply question. *CYTA J. Food* 16, 822–830. doi: 10.1080/19476337.2018.1464521

Jaeger, S. R., Rossiter, K. L., Wismer, W. V., and Harker, F. R. (2003). Consumer-driven product development in the kiwifruit industry. *Food Qual. Prefer.* 14, 187–198. doi: 10.1016/S0950-3293(02)00053-8

Jiang, G.-L., Rutto, L. K., Ren, S., Bowen, R. A., Berry, H., and Epps, K. (2018). Genetic analysis of edamame seed composition and trait relationships in soybean lines. *Euphytica* 214, 1–10. doi: 10.1007/s10681-018-2237-9

Johnson, D. (2000). Edamame: westerners develop a taste for Japanese soybean. *Eng. Technol. Sustain. World* 7, 11–12.

Johnson, D., Wang, S., and Suzuki, A. (1999). "Edamame: a vegetable soybean for Colorado," in *Perspectives on New Crops and New Uses*, ed J. Janick (Alexandria, VA: ASHS Press), 385–387. Available online at: https://hort.purdue.edu/newcrop/proceedings1999/pdf/v4-385.pdf (accessed September 3, 2018).

Kelley, K. M., and Sánchez, E. S. (2005). Accessing and understanding consumer awareness of and potential demand for edamame. *HortScience* 40, 1347–1353. doi: 10.21273/HORTSCI.40.5.1347

Krinsky, B. F., Drake, M. A., Civille, G. V., Dean, L. L., Hendrix, K. W., and Sanders, T. H. (2006). The development of a lexicon for frozen vegetable soybeans (edamame). *J. Sens. Stud.* 21, 644–653. doi: 10.1111/j.1745-459X.2006.00088.x

Kumar, V., Rani, A., Goyal, L., Pratap, D., Billore, S. D., and Chauhan, G. S. (2011). Evaluation of vegetable-type soybean for sucrose, taste-related amino acids, and isoflavones contents. *Int. J. Food Prop.* 14, 1142–1151. doi: 10.1080/10942911003592761

Lado, J., Vicente, E., Manzzioni, A., and Ares, G. (2010). Application of a check-all-that-apply question for the evaluation of strawberry cultivars from a breeding program. *J. Sci. Food Agric.* 90, 2268–2275. doi: 10.1002/jsfa.4081

Lawless, H. T., and Heymann, H. (2010). *Sensory Evaluation of Food Principles and Practices, 2nd Edn*. New York, NY: Springer.

Lee, J. Y., Popp, M. P., Wolfe, E. J., Nayga, R. M. Jr., Popp, J. S., et al. (2018). Information and order of information effects on consumers' acceptance and valuation for genetically modified edamame soybean. *PLoS ONE* 13:e0206300. doi: 10.1371/journal.pone.0206300

Mebrahtu, T., and Devine, T. E. (2008). Diallel analysis of sugar composition of 10 vegetable soybean lines. *Plant Breed.* 128, 249–252. doi: 10.1111/j.1439-0523.2008.01561.x

Mebrahtu, T., Devine, T. E., Donald, P., and Abney, T. S. (2005a). Registration of "Asmara" vegetable soybean. *Crop Sci.* 45, 408–409. doi: 10.2135/cropsci2005.0408

Mebrahtu, T., Devine, T. E., Donald, P., and Abney, T. S. (2005b). Registration of "Randolph" vegetable Soybean. *Crop Sci.* 45, 2644–2945. doi: 10.2135/cropsci2005.007

Mebrahtu, T., Devine, T. E., Donald, P. A., and Abney, T. S. (2007). Registration of "Owens" vegetable soybean. *J. Plant Regist.* 1, 95–96. doi: 10.3198/jpr2006.09.0570crc

Mebrahtu, T., Mohamed, A., Wang, C. Y., and Andebrhan, T. (2004). Analysis of isoflavone contents in vegetable soybeans. *Plant Foods Hum. Nutr.* 59, 55–61. doi: 10.1007/s11130-004-0023-4

Montri, D. N., Kelley, K. M., and Sánchez, E. S. (2006). Consumer interest in fresh, in-shell edamame and acceptance of edamame-based patties. *HortScience* 41, 1616–1622. doi: 10.21273/HORTSCI.41.7.1616

Morris, W. L., and Taylor, M. A. (2019). Improving flavor to increase consumption. *Am. J. Potato Res.* 96, 195–200. doi: 10.1007/s12230-018-09702-7

National Academies of Sciences, Engineering and Medicine. (2019). *Science Breakthroughs to Advance Food and Agricultural Research by 2030*. Washington, DC: The National Academies Press.

Nolen, S., Zhang, B., and Kering, M. K. (2016). Increasing fresh edamame bean supply through season extension techniques. *J. Hortic.* 03, 1–5. doi: 10.4172/2376-0354.1000170

Ogles, C. Z., Guertal, E. A., and Weaver, D. B. (2016). Edamame cultivar evaluation in Central Alabama. *Agron. J.* 108, 2371–2378. doi: 10.2134/agronj2016.04.0218

Padikasan, I. A., Chinnannan, K., Kumar, S., and Subramaniyan, G. (2018). "Agricultural biotechnology: engineering plants for improved productivity and quality," in *Omics Technologies and Bio-Engineering. Volume 2: Towards Improving Quality of Life*, eds D. Barh and V. Azevedo (Cambridge, MA: Academic Press), 87–104.

Patil, B. S., Crosby, K., Byrne, D., and Hirschi, K. (2014). The intersection of plant breeding, human health, and nutritional security: lessons learned and future perspectives. *HortScience* 49, 116–127. doi: 10.21273/HORTSCI.49.2.116

Pattee, H. E., Isleib, T. G., Corbet, D. W., Ciesbrecht, F. G., and Cui, Z. (2001). Parent selection in breeding for roasted peanut flavor quality. *Peanut Sci.* 28, 51–58. doi: 10.3146/i0095-3679-28-2-3

Qannari, E. M. (2017). Sensometrics approaches in sensory and consumer research. *Curr. Opin. Food Sci.* 15, 8–13. doi: 10.1016/j.cofs.2017.04.001

Reynolds, A. G., Cliff, M., Wardle, D. A., and King, M. (2004). Evaluation of winegrapes in British Columbia: new cultivars and selections from Germany and Hungary. *Horttechnology* 14, 420–436. doi: 10.21273/HORTTECH.14.3.0420

Rizzo, G., and Baroni, L. (2018). Soy, soy foods and their role in vegetarian diets. *Nutrients* 10:43. doi: 10.3390/nu10010043

Roland, W. S. U., Vincken, J.-P., Gouka, R. J., Van Buren, L., Gruppen, H., and Smit, G. (2011). Soy isoflavones and other isoflavonoids activate the human bitter taste receptors hTAS2R14 and hTAS2R39. *J. Agric. Food Chem.* 59, 11764–11771. doi: 10.1021/jf202816u

Saldivar, X., Wang, Y.-J., Chen, P., and Mauromoustakos, A. (2010). Effects of blanching and storage conditions on soluble sugar contents in vegetable soybean. *LWT Food Sci. Technol.* 43, 1368–1372. doi: 10.1016/j.lwt.2010.04.017

Sands, D. C., Morris, C. E., Dratz, E. A., and Pilgeram, A. L. (2009). Elevating optimal human nutrition to a central goal of plant breeding and production of plant-based foods. *Plant Sci.* 177, 377–389. doi: 10.1016/j.plantsci.2009.07.011

Sirisomboon, P., Pornchaloempong, P., and Romphophak, T. (2007). Physical properties of green soybean: criteria for sorting. *J. Food Eng.* 79, 18–22. doi: 10.1016/j.jfoodeng.2006.01.022

Sujith Kumar, P. V., Basheer, S., Ravi, R., and Thakur, M. S. (2011). Comparative assessment of tea quality by various analytical and sensory methods with emphasis on tea polyphenols. *J. Food Sci. Technol.* 48, 440–446. doi: 10.1007/s13197-010-0178-y

Suwonsichon, S. (2019). The importance of sensory lexicons for research and development of food products. *Foods* 8:27. doi: 10.3390/foods8010027

Talavera-Bianchi, M., Chambers, I. V., E., and Chambers, D. H. (2010). Lexicon to describe flavor of fresh leafy vegetables. *J. Sens. Stud.* 25, 163–183. doi: 10.1111/j.1745-459X.2009.00249.x

Vela-Hinojosa, C., Escalona-Buendía, H. B., Mendoza-Espinoza, J. A., Díaz de León-Sánchez, F., Lobato-Ortíz, R., Rodríguez-Pérez, J. E., et al. (2018). Chemical and sensory analysis of native genotypes and experimental lines of tomato (*Solanum lycopersicum* L.). *Fruits* 73, 60–71. doi: 10.17660/th2018/73.1.7

Wang, K. (2018). East Asian food regimes: Agrarian warriors, edamame beans and spatial topologies of food regimes in East Asia. *J. Peasant Stud.* 45, 739–756. doi: 10.1080/03066150.2017.1324427

Wang, Y., and Kays, S. J. (2003). Analytically directed flavor selection in breeding food crops. *J. Am. Soc. Hortic. Sci.* 128, 711–720. doi: 10.21273/jashs.128.5.0711

Welch, R. M., and Graham, R. D. (2004). Breeding for micronutrients in staple food crops from a human nutrition perspective. *J. Exp. Bot.* 55, 353–364. doi: 10.1093/jxb/erh064

Williams, M. M. (2015). Phenomorphological characterization of vegetable soybean germplasm lines for commercial production. *Crop Sci.* 55, 1274–1279. doi: 10.2135/cropsci2014.10.0690

Wolfe, E., Popp, M., Bazzani, C., Nayga, R. M., Danforth, D., Popp, J., et al. (2018). Consumers' willingness to pay for edamame with a genetically modified label. *Agribusiness* 34, 283–299. doi: 10.1002/agr.21505

Wszelaki, A. L., Delwiche, J. F., Walker, S. D., Liggett, R. E., Miller, S. A., and Kleinhenz, M. D. (2005). Consumer liking and descriptive analysis of six varieties of organically grown edamame-type soybean. *Food Qual. Prefer.* 16, 651–658. doi: 10.1016/J.FOODQUAL.2005.02.001

Xu, Y., Cartier, A., Kibet, D., Jordan, K., Ivy, H., Davis, S., et al. (2016). Physical and nutritional properties of edamame seeds as influenced by stage of development. *J. Food Meas. Charact.* 10, 193–200. doi: 10.1007/s11694-015-9293-9

Xu, Y., Sismour, E., Pao, S., Rutto, L., Grizzard, C., and Ren, S. (2012). Textural and microbiological qualities of vegetable soybean (edamame) affected by blanching and storage conditions. *J. Food Process. Technol.* 3, 1–6. doi: 10.4172/2157-7110.1000165

Young, G., Mebrahtu, T., and Johnson, J. (2000). Acceptability of green soybeans as a vegetable entity. *Plant Foods Hum. Nutr.* 55, 323–333. doi: 10.1023/A:1008164925103

Zhang, L., and Kyei-Boahen, S. (2007). Growth and yield of vegetable soybean (edamame) in Mississippi. *Horttechnology* 17, 26–31. doi: 10.21273/HORTTECH.17.1.26

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