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Review

Vegetable soybean, edamame: Research, production, utilization and analysis of its adoption in Sub-Saharan Africa

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Food and nutritional insecurity constitute a main challenge in most Sub-Sahara African countries. Efforts to provide diets with sufficient nutrients such as proteins, carbohydrates, vitamins and essential minerals should include the introduction of new vegetable and legume crops. Vegetable soybean "edamame", is a nutritious vegetable legume well known and consumed in Asia and America, but underutilized in Africa. This review paper aims at documenting the existing information on edamame and analyzing the potentials for its use in Sub-Saharan Africa. The analysis of the existing literature revealed that vegetable soybean provides great advantages in term of production because of good market value of the fresh pods having a good market value and high demand on both local and international markets. Then, the consumption of edamame can also really contribute to reducing nutritional deficiencies in children and even adults, through its great nutritional content and good health benefits. Therefore, edamame is a good crop to promote in Africa. The promotion of edamame requires many research activities starting from evaluation of agro-ecological adaptation, determination of consumers' preferences and genetic improvement based on farmers, processors and consumers' needs, in order to sustain a seed system for the crop.

Key words: Food security, genetic improvement, seed system, sub-Saharan Africa, vegetable soybean.

INTRODUCTION

Food insecurity is a worldwide problem and the number of undernourished people in the world rose up from 783.7

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million to 820.8 million between 2014 and 2017 (FAO et al., 2018). Africa has the world's highest percentage of undernourishment (Fry, 2018) with the case of Sub-Saharan Africa (SSA) appearing to be at critical level (FAO and ECA, 2018). It carries 92.20% of Africa's undernourished people. In Benin, 71% of population is affected by undernourishment (Fry, 2018), with 51.3% of pre-school children suffering from iron, zinc and vitamin A deficiencies (Muthayya et al., 2013).

Although there are endeavors to fight-off malnutrition, more efforts are needed in most SSA countries (Saltzman et al., 2017). Actions should be more focused on providing sufficient nutrients, such as essential proteins, carbohydrates, vitamins and minerals (Keatinge et al., 2011). Promotion of underutilized vegetables and legume crops and introduction of new vegetable crops with high bioavailability of essential nutrients and vitamins should therefore be envisaged (Dinssa et al., 2016).

It is the trend in SSA to consume fresh legume grain and pods. This is the case with fresh common beans (*Phaseolus vulgaris*) and fresh peas (*Pisum sativum*), widely consumed in East Africa, as well as groundnut (*Arachis hypogaea*) and pigeon peas (*Cajanus Cajan*) which can also be eaten fresh. Leguminous vegetable are nutritious, as they contain up to 90% of water, 50 - 80% of carbohydrates, 15 - 30% of protein, low total lipid and low fat (Vicente, 2009). Fresh green legumes are also good sources of vitamins, minerals, fibers and antioxidants. Nutrients and medicines together are termed as nutraceuticals (Bhattacharya and Malleshi, 2012). Vegetables are rich in nutraceuticals and vegetable soybean is one of the top nutraceutical rich vegetables.

Vegetable soybean refers to soybean varieties having pods and seeds that can be harvested and consumed when they are still fresh and premature. The crop is well known and widely used in Asia and America, but less known in Africa (Chadha and Oluoch, 2004). Edamame can be eaten in salads, put in stews or mixed with rice (Mohamed and Rangappa, 1992). Beyond its nutritional traits, edamame could have medicinal attributes. It is used to purportedly reduce body pains, cure stomach heat, clean bad blood and reduce effects of poisonous drugs (Shurtleff and Aoyagi, 2009).

As a cash crop, and owing to its short cycle, vegetable soybean can be cultivated four to six times in a year, under irrigated cropping system. Edamame can yield up to 10 t/ha of marketable fresh pods. Besides, the leaves are nutritious feed and together with stems provide about 120 kg of nitrogen (N), 18 kg of phosphorus (P_2O_5) and 120 kg of potassium (K_2O) to the soil after decomposition (Shanlnugasundaram et al., 1992). Beyond its richness in micronutrients and vitamins, edamame provides as much macronutrients as grain soybean. For instance, on dry weight basis, 100 g of edamame provides 477 kilocalories, 41.3 g of proteins, 31 g of carbohydrates and 21.9 g of lipids, while 100 g of matured soybean provides 475.4 kilocalories, 40.2 g of proteins, 32.1 g of carbohydrates and 21.6 g of lipids (Takahashi and Ohyama, 2011). According to these authors, edamame contains more vitamins A, C, K and B than grain soybean. Iron, zinc, magnesium, phosphorus, calcium, potassium, sodium, cupper and manganese concentrations of edamame are higher than those of snap peas and green peas (Takahashi and Ohyama, 2011). The nutritional content of edamame makes it a potential provider of many health benefits. For instance, isoflavones or phytoestrogens are soybean polyphenols involved in the regulation of cholesterol, decreasing the risk of cancer, hypertension, osteoporosis and heart diseases (Magee et al., 2012).

There is high research interest for edamame in Asia and America. Research conducted on edamame include agronomic evaluation for yield, yield components and quality traits to check for adaptation (Basavaraja et al., 2005; Duppong and Hatterman-Valenti, 2005; Zhang and Kyei-Boahen, 2007; Zhang et al., 2010; Kumar et al., 2011). Preference analysis, nutritional and anti-nutritional evaluation of edamame varieties were also reported by various authors (Wszelaki et al., 2005; Bhattacharya and Malleshi, 2012; Carson et al., 2011; Carson et al., 2012; Castoldi et al., 2011; Jadhav et al., 2018; Mohamed and Rangappa, 1992; Takahashi and Ohyama, 2011). Furthermore, storage of edamame was also investigated (Saldivar et al., 2010; Xu et al., 2012; Lara et al., 2019). Genetic diversity was assessed with nutritional, morphological and molecular markers (Mimura et al., 2007; Dong et al., 2014; Ramya and Mummigatti, 2015; Williams, 2015; Pooprompan et al., 2006; Jadhav et al., 2018). Moreover, breeding research was done on edamame (Sarutayophat, 2012; Li et al., 2013; Mebrahtu and Devine, 2008; Jiang et al., 2018, 2018a).

In Africa, research on edamame is very scarce. The few reported are from Chadha and Oluoch (2004), who prior to introduction and distribution of edamame accessions in 26 sub-Saharan African countries, conducted evaluation trials on performance to identify suitable lines. Then, Arathoon (2015) evaluated germination rate, influence of seedling rate, effect of dryland conditions and effects of fertilizers on productivity of edamame. Besides, the adaptation and stability of vegetable soybean genotypes has been recently reported in Uganda (Tsindi et al., 2019). Research works pertaining to the nutritional content of edamame grown under tropical conditions have not yet been reported. Optimized storage techniques that suit tropical environments of SSA countries need to be investigated. In addition, consumers' preferences have to be assessed in order to develop suitable edamame varieties for SSA countries.

This paper summarizes the existing information on edamame covering history of edamame, the requirements for its production, seed systems and prospects for its introduction and adoption in Africa.

METHODOLOGY

This review used keywords such as “origin and history of edamame”, “vegetable soybean production”, “conservation and consumption history of edamame”, “Vegetable soybean: characterization and evaluation”, “genetic diversity of vegetable soybean”, “physical, chemical and nutritional characteristics of vegetable soybean”,…, to search for literature in popular web search engines such as Google Scholar, Research Gate, PubMed Central, Science Direct, AGORA and HINARI to get papers related to the topic. Additional literature was obtained from the websites of some International Organizations like World Health Organization (WHO), Food and Agriculture Organization (FAO), Asian Vegetable Research and Development Center (AVRDC) and United States Department of Agriculture (USDA). Online resources were downloaded, organized into categories and summarized to draft the paper.

DESCRIPTION AND HISTORY OF VEGETABLE SOYBEAN “EDAMAME”

Vegetable soybean [*Glycine max* (L.) Merr.] is native to China and domesticated from wild annual *Glycine soja*, similar to commodity soybean (Singh, 2017). It represents a group of large seeded soybean cultivars harvested when the green seeds fill the fresh pods (R6 stage), for use as vegetable (Esler, 2011). Known under various local names, vegetable soybean is called “mao dou’’ in China and ‘’poot kong’’ in Korea (Saldivar et al., 2011). Although the local names vary among Asian countries, the Japanese name “edamame” prevails and is used worldwide. It is pronounced “ay-dah-MAH-may” which can be translated to mean “bean on branch” in Japanese.

Edamame was first reported in 1275, when the Japanese Buddhist Saint Nichiren Shonin wrote a thanking note to a parishioner, as appreciation for his vegetable soybean gift (Shurtleff and Aoyagi, 2009). It was first introduced in America by Charles C. Georgeson and William J. Morse during the world wars when searching for inexpensive source of protein (Shurtleff and Aoyagi, 2009). Though edamame improvement started in 1950 in Taiwan, vegetable soybean became more popular across the world with the creation of AVRDC-World Vegetable Center in 1971. The AVRDC published their first findings titled “immature green soybeans” and started research on mechanical harvesting of edamame in 1985 (Shanlnugasundaram et al., 1992; Sharma and Kshattry, 2013). Besides, this center became a leader on vegetable soybean research and helped to increase its production in Taiwan for exportation mostly to Japan and United States of America (Shurtleff and Aoyagi, 2009).

Assessing its phylogenetic relationship with other tropical legumes, edamame is closely related to many tropical legumes consumed fresh in SSA countries (Figure 1). These legumes are peanut (*A. hypogaea*), cowpea (*Vigna unguiculata,* (L.) Walp) and common bean (*Ph. vuligaris* L.), indicating the potential for adoption of edamame in SSA countries (Dhaliwal, 2017).

MAJOR RESEARCH ON EDAMAME

Many research works have been carried out on edamame across the world, with a very limited range in Sub-Saharan Africa. These works tackled various aspects including evaluation for adaptation and diversity studies, consumers’ preferences and sensorial qualities assessment, nutritional profiling, testing for yield and yield components, breeding and evaluation of production, harvest and post-harvest constraints.

Adaptation and diversity

Diversity study and evaluation for adaptation are the first step to introduction of new crop in an area and for cultivar development. Research on adaptation of vegetable soybean has been extensively done across the world. Adaptation trials conducted in Australia showed low adaptation due to low water availability, as exotic lines require more water compared to local cultivars of commodity soybean (James, 2007). In North Centre of United States, field evaluation of 136 edamame accessions revealed only 12 promising cultivars for commercial production, and most lines exhibited poor seedling establishment (Williams, 2015). In Uganda, twenty one (21) genotypes evaluated in six (06) locations during 2 seasons, revealed that genotype “G10427” is the most adaptable to agro-ecological areas of Uganda (Tsindi et al., 2019). This shows that edamame has a generally poor adaptation in areas where new varieties are being introduced. Hence, it is necessary to conduct evaluation trials to identify adapted varieties prior to search for traits requiring improvement.

Both morphological and molecular tools have been used to assess diversity among edamame cultivars. Agro-morphological characterization of 150 soybean lines, including 136 vegetable soybean accessions was conducted for 3 years in the North-Center USA (Williams, 2015). It was reported that seedling growth, development and green harvest time of vegetable soybean varieties were faster than those of grain soybean lines. Besides, days to R6 ranged from 77 to 93 days after sowing (DAS) in vegetable soybean lines and from 87 to 112 DAS in grain-type varieties. Variations were also observed between 100-seeds weight of vegetable soybeans (23 g – 25 g) which were greater than commodity soybeans (14 g – 15 g). In India, similar research conducted with 12 soybean varieties including 10 edamame genotypes, showed variations for pod filling period, 62 to 72 days in vegetable soybean versus 70 to 73 days in grain soybean (Ramya and Mummigatti, 2015). The authors also found

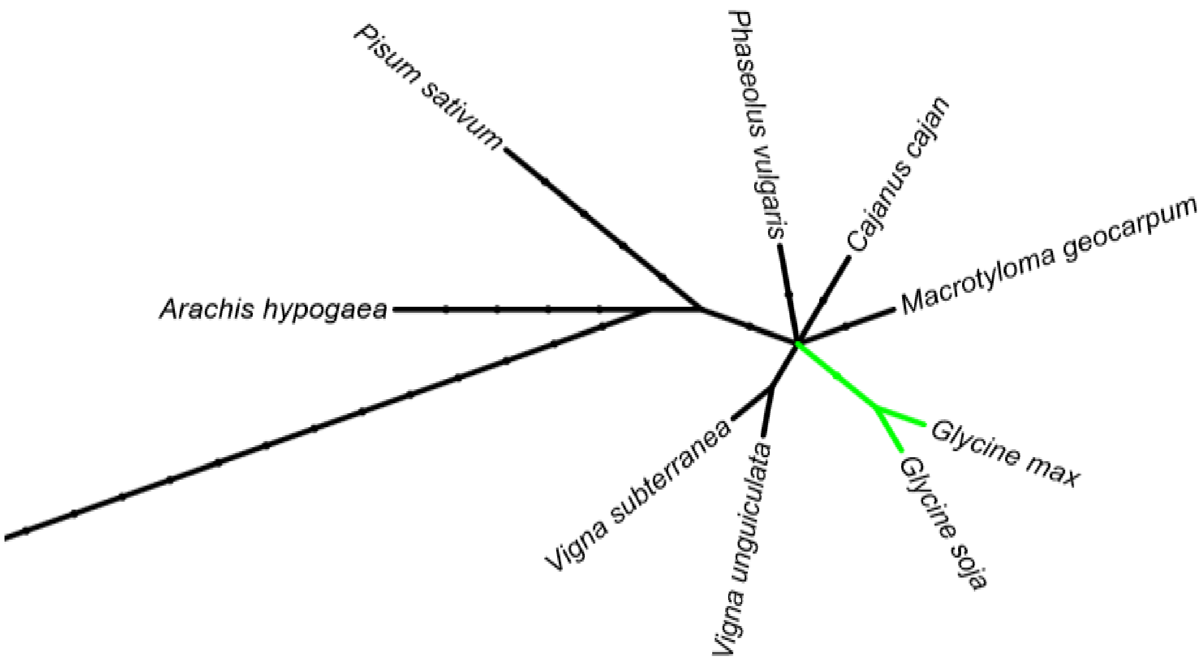

Figure 1. Phylogenetic relationship between soybeans and other tropical legumes (https://itol.embl.de/tree/2131659112773131548664928).

green seed weight of vegetable soybean lines (44.2 g) greater than those of grain soybean accessions (19.2 g). While agro-morphological assessments of edamame varieties have proven useful in understanding the existing germplasm of edamame, molecular analysis of the varieties is important to confirm variation and help depict the underlying genetic factors of those observed variations. Such a study was carried out in China using microsatellites (SSR) markers on 130 soybean accessions obtained from Japan, China and USA. Lower diversity was observed among the 107 Japanese cultivars compared to the 10 cultivars from China (Mimura et al., 2007). Similar work conducted with 53 SSR markers on hundred edamame accessions, including 77 from breeding companies of China, 13 from AVRDC, 8 from Japan and 2 from Thailand, indicated 11 subgroups based on simple agglomerative hierarchical clustering (UPGMA) method and revealed also that the Chinese cultivars were more diverse than those from the other countries (Dong et al., 2014). So, these cultivars got a broader genetic base and could be useful in breeding programs. Diversity among edamame cultivars also hints a variation in nutritional contents. This was shown at Virginia in the United States, where genetic analysis of nutritional contents performed with 86 edamame genotypes showed significant genotypic differences for protein, starch, oil, dietary fiber, stachyose, sucrose and total sugar content among cultivars (Jiang et al., 2018). These authors' findings are indication that, there is potential to select edamame for nutritional traits having great insights to consumers' preferences.

Consumers' preference and sensorial quality

Quality traits and consumers' preference based on sensory attributes have been reported in the major countries where edamame is produced. Authors have identified the most important quality traits for consumers in Australia as large seed size, high sugar content and bright green color (Nguyen, 1998; James, 2005). Researchers at Ohio State University in USA have highlighted a gender dimension in differential consumers' preference. It was pointed out that preference for the taste of bean vary between women and men (Wszelaki et al., 2005). It was also shown that chewiness and sweetness are discriminating quality traits for edamame varieties. Consumers in Quebec (Canada) reported the sweetest taste for "Beer Friend" and "Early Hakucho" varieties (Leblanc et al., 2014). At Ohio State (USA), the variety "Sayamusume" was preferred for its taste and texture while "Kenko" had the most preferred pod appearance and sweetness (Wszelaki et al., 2005). Variety "Sayamusume" was also appreciated for its large seeds at North Dakota (Duppong and Hatterman-Valenti, 2005). Other preferred quality attributes include green bright color of pods and the large seeds with high sugar content in Australia (James, 2007). In India, variety "AGS 406" was preferred because of its good pod appearance and the highest score for pod texture (lack of pubescence), pod color, seed color and seed appearance (Esler, 2011). The brightness of green pods, the sweet and savory taste and the nutritional contents of seeds are other major quality traits (Zeipiņa et al., 2017). Consumers generally dislike the "beany" taste of edamame. As solution to that, researchers at World Vegetable Center suggested the development of varieties with the aroma of fragrant rice expressed by the variety "dadachamame" (Shanmugasundaram and Yan, 2004). Some traits like astringency, bitterness and off-flavors caused by saponins and isoflavins, are found unacceptable by some target consumers in Africa and south Asia (Esler, 2011). However, the use of fertilizers such as N-P-K in 30-80-38 kg/ha formulation together with 10 t/ha chicken manure has been reported to improve the flavor, sweetness and seeds size of edamame (Zeipiņa et al., 2017). Moreover, it was demonstrated that high concentrations of compounds such as glutamic acid, sucrose and alanine enhance flavor in boiled edamame as well as its nutritional contents (Mausda, 1991).

These preferences associated with the qualities may be appreciated differently by various consumers, thereby showing the importance of taking account not only of organoleptic traits, but also nutritive components, during the introduction of a new food crop.

Nutritional content and health benefits

Many authors have assessed nutritional quality of edamame. They mainly focused on macronutrients, micronutrients, antioxidants and isoflavones, with some emphasis on anti-nutrients. For instance, Carson et al. (2011) analyzed five edamame cultivars for protein and lipid contents in Virginia State and reported that the cultivars "Midori Giant", "BeSweet 292" and "BeSweet2001" had high protein contents (36-38%) and low fat contents (13-15%). In India, Jadhav et al. (2018) evaluated 30 soybean genotypes (12 edamame types, 4 mutants and 14 grain soybean cultivars) for nutritional contents. The authors observed ranges of 33.01 to 42.13% for protein, 17.07 to 20.87% for oil and 19.19 to 38.52% for sugar content. These authors ranked the tested cultivars and found "Karune" vegetable type from Bangalore, the mutant "AMS 353" and "Swarna" vegetable type from AVRDC having the highest contents of protein, oil and sugar, in that order. Therefore, these varieties could be useful to feed children in developing world lacking protein in their diets. Additionally, Takahashi and Ohyama (2011) presented in Japan a detailed nutritional content of edamame in comparison with grain soybean, snap peas and green peas. It appears that edamame contains more protein (41.3%) than soybean (35.3%). The same trend was observed in vitamins content, especially for vitamin A between edamame (77.1 µg/100 g) and soybean (1.14 µg/100 g). As for micronutrients, raw edamame has higher iron content (2.7 mg/100 g) than green peas (0.6 - 1.7 mg/100 g), as well as other minerals like zinc, potassium, calcium, magnesium, phosphorus, copper and manganese (Table 1). Therefore, edamame types are more nutritious than grain soybeans and both peas.

Cooking mode of edamame seems to influence bioavailability of micronutrients. Mentreddy et al. (2002) reported that fast cooking ability could reduce flatulence in human and enable doubling bioavailability of iron in edamame. Increase of iron bioavailability after cooking was observed for twenty vegetables including vegetable soybean for which, this content raised from 4 to 9% (Chadha and Oluoch, 2004). Besides, the highest iron (15.72 mg/100 g) was reported at R6 stage for genotype "TAMS-38" and the highest zinc content (5 mg/100) was also found at R6 stage in variety "AMS-73" (Jadhav et al., 2018). Therefore, frequent consumption of fresh edamame can reduce health problems, especially stunting caused by iron and zinc deficiency in diets of SSA children and women of reproductive age (Luo and Xie, 2012), because they have been reported as the most deficient nutrients in diets of SSA countries (Fry, 2018). It would therefore be important to improve iron and zinc contents and their bioavailability in vegetable soybean (Anoma et al., 2014; Akande et al., 2018).

Regarding health benefits of edamame, high isoflavones content and high antioxidant capacity have been reported for some varieties. Isoflavones are phytoestrogens known to prevent prostate, cancer, menauposal symptoms and to raise up good cholesterol rate for the prevention of cardio-vascular diseases (Magee et al., 2012; Carson et al., 2012). Castoldi et al. (2011) reported high isoflavones content (92.62 mg/100 g) in cultivar "JLM024" and low content (22.67 mg/100 g) in cultivar "JLM004" evaluated in Brazil. A high content of isoflavones detected in "Midori Giant" and high antioxidant capacity reported in both cultivars "BeSweet2001" and "BeSweet2015" are indications that vegetable soybean has potential to solve health issues due to food deficiency (Carson et al., 2012). In contrast, some anti-nutrients like phytates, saponins, trypsin inhibitor and lipoxygenase can be found in vegetable soybean. Their high contents in edamame are indicated to be responsible for sour or bitter flavor, decreasing edamame quality (Mentreddy et al., 2002). In a study conducted in Brazil, genotype "JLM030" exhibited low trypsin inhibitor content (13.9 mg/100 g) (Castoldi et al., 2011). Therefore, this variety could be chosen as parent for the development of progenies with lower trypsin inhibitor useful for increasing the bioavailability of micronutrients in vegetable soybean. Cultivars "PI 203399" and "Sooty" screened in Virginia State, exhibited low lipoxygenase activity (Mohamed and Rangappa, 1992). Hence, these varieties would have a better flavor compared to other high yielding varieties.

Table 1. Nutrients content of edamame as compared to other legumes vegetable and grain soybeans per 100 g.

Nutrients \ Products	Edamame (Raw)	Snap peas (Raw pod)	Green peas	Soybean (matured)	Edamame (Dry)***	Soybean (Dry)***
Energy (kcal)	**135**	**43**	**93**	**417**	**477**	**475.38**
Water (g)	71.7	86.6	76.5	12.5	0	0
Protein (g)	11.7	2.9	6.9	35.3	41.3	40.242
Lipid (g)	6.2	0.1	0.4	19	21.9	21.66
Carbohydrate (g)	8.8	9.9	15.3	28.2	31	32.148
Ash (g)	1.6	0.5	0.9	5	5.65	5.7
Minerals						
Na (mg)	1	1	1	1	3.53	1.14
K (mg)	590	160	340	1900	2083	2166
Ca (mg)	58	32	23	240	205	273.6
Mg (mg)	62	21	37	220	219	250.8
P (mg)	170	62	120	580	600	661.2
Fe (mg)	2.7	0.6	1.7	9.4	9.53	10.716
Zn (mg)	1.4	0.4	1.2	3.2	4.94	3.648
Cu (mg)	0.41	0.08	0.19	0.98	1.45	1.1172
Mn (mg)	0.71	0.22	0.48	1.9	2.51	2.166
Vitamins						
A (µg)*	22	34	35	1	77.7	1.14
E (mg)	0.8	0.4	0.1	1.8	2.82	2.052
K (µg)	30	33	27	18	106	20.52
B1 (mg)	0.31	0.13	0.39	0.83	1.09	0.9462
B2 (mg)	0.15	0.09	0.16	0.3	0.53	0.342
Niacin (mg)	1.6	0.7	2.7	2.2	5.65	2.508
B6 (mg)	0.15	0.09	0.15	0.53	0.53	0.6042
B12 (µg)	0	0	0	0	0	0
Folic acid, B9 (µg)	320	53	76	230	1130	262.2
Pantotenic acid (mg)	0.53	0.22	0.63	1.52	1.87	1.7328
C (mg)	27	43	19	Tr.**	95.3	0

*Retinol equivalent; Tr** Trace amount; *** Dry weight base.
Source: Takahashi and Ohyama (2011).

Yield and yield components

Yield and yield components have also been tackled by research in edamame. In general, the reported yields of edamame ranged from 2 to 5 tons per hectare for fresh seeds and 7 to 12 tons per ha for fresh pods with about 72% of water content (Takahashi and Ohyama, 2011). Between 1997 and 2003, researchers at AVRDC evaluated some lines in Africa and showed that varieties “AGS 292”, “AGS 339”, “AGS 329” and “AGS 338” outperformed all others and produced more than 7 tons/ha for fresh pods and 3 to 4 tons per hectare for fresh seeds (Chadha and Oluoch, 2004). Similarly in India, Basavaraja et al. (2005) who evaluated ten edamame cultivars, found the fresh seed yield ranging from 2 to 4.9 t/ha. In addition, similar yield range was observed for fresh seed (4.281 tons/hectare) in Uganda for the most adapted vegetable soybean genotype “G10427” (Tsindi et al., 2019). On the contrary, much higher seed yields of 11.12 tons/ha was recorded in Brazil for the cultivar “JLM010” (Castoldi et al., 2011). Carrying out evaluation trials with five edamame varieties in North Dakota (USA), Duppong and Hatterman-Valenti (2005) reported 7 to 11.3 tons of total marketable pod yield, with “Sayamusume”, a famous variety of the Territorial Seeds Company (USA), exhibiting the highest value. In Quebec, eleven edamame varieties were evaluated, giving pod yields as high as 12 tons/ha for varieties “Miodori Giant” and “Envy” (Leblanc et al., 2014). In Virginia State, Carson et al. (2011) reported cultivar “BS2001” yielding 9.108 t/ha of fresh pods. Much higher yield was reported at Stoneville and Mississippi where fresh pods yields ranging between 20.32 and 29.75 t/ha were recorded for cultivars “GardenSoy 01”, “MidoriGiant”, “Garden Soy 21”, “Moon Cake”, and variety “Mojo Green” (Zhang and Kyei-Boahen, 2007).

Factors that influence yields have also been investigated. Plant height, plant population, number of branches/plant, and number of pods/plant, percentage of marketable pods, shelling percentage and fresh biomass have been reported as components of yield for edamame. Arathoon (2015) observed that agronomic traits such as plant height, plant population, number of branches/plant, and number of pods/plant, percentage of marketable pods and shelling percentage, influence positively beans' yield in edamame production. More recently in the Virginia, an evaluation of 86 soybean breeding lines for yield and agronomic traits revealed significant differences among accessions for plant height, fresh biomass, pods and seeds traits (Jiang et al., 2018). They also found a positive correlation between fresh biomass and seed yield. These traits could be used to breed high yielding genotypes of vegetable soybean.

Breeding research

Breeding activities performed on edamame ranged from inheritance studies through cultivar selection and marker-assisted breeding. For instance, the analysis of combining abilities of ten genotypes at Virginia State University, using full-diallel mating scheme, showed that both general and specific combining abilities as well as reciprocal variance were significant for plant height, 100-pod weight, pod width, pod length and pod thickness (Mebrahtu and Devine, 2008). These authors found a high association of green-pod yield components of parents and their general combining ability effects. Yield and nutritional traits have high heritability in edamame. In Virginia, Jiang et al. (2018a) evaluated 86 soybean breeding lines for yield and agronomic traits and found high broad sense heritability for fresh 100-seed weight (87.96%) and plant height (79.22%). Similarly, high to medium and stable heritability values were observed for protein (79.39%), oil (74.62%), stachyose (68.73%) and fiber (56.95%) contents in edamame varieties (Jiang et al., 2018). These authors found also a broad sense heritability of sugar content negatively correlated with oil and protein contents in edamame cultivars. In India, plant height, number of marketable pods per plant and green pods weight were indicated as good traits to consider for yield improvement (Sarutayophat, 2012). Li et al. (2013) and Ramya and Mummigatti (2015) reported respectively in China and India that plant height, number of branches, leaf area, photosynthetic activity, chlorophyll content, dry matter accumulation and seed characteristics, are some valuable traits to use for selecting high yielding edamame cultivars. Although few in number, marker-assisted breeding has also been implemented in edamame improvement. In 2006, SSR markers Satt132 and Satt431 were found polymorphic to reveal differences among flowering dates in inbred lines. This enabled speed selection of early flowering cultivars in Thailand (Pooprompan et al., 2006). These results showed that the traits related to the growth, yield and nutritional contents of edamame can be improved by using both conventional and molecular breeding tools for increased production.

PRODUCTION REQUIREMENTS AND GROWING SYSTEMS

The share of vegetable soybeans in world soybean production is very low and represents only 2% of total soybean production (Esler, 2011). The crop grows well in tropical warm climates with temperature ranges of 20 - 30ºC daytime and 10 - 15ºC at night (Cheng, 1991). The crop requires short daytime, sandy loam soil or irrigated loam soil having both a neutral pH (Miles and Sonde, 2002). It has short growth cycle, as it is harvested at R6 stage. Although, night temperatures match more temperate climate than tropical warm climate, edamame can be produced in Sub-Saharan Africa including Benin. In countries where bradyrhizobia *(Bradyrhizobium japonicum*) is not native, the application of 10 g of inoculant per kg of seeds enables boosting nitrogen fixation (Agoyi et al., 2017; Zhang et al., 2017), and thus circumventing nodulation failure. Another way to overcome nodulation failure would be the identification of promiscuous vegetable soybean cultivars, as this would enable achieving high yield without requiring the application of inoculant on seeds prior to sowing (Agoyi et al., 2016, 2017, 2018). Plant density plays a key role in productivity of edamame. Konovsky et al. (1994) reported that high planting density especially a short distance between rows decreases the yield and lead to dark pods. A hand planting of 75 cm between rows for a seeding rate of 200,000 seeds per hectare were identified as suitable to get beans yield ranging from 3.62 to 6.66 tons/ha (Arathoon, 2015). In general, about 40 tons/ha of biomass for 10 to 12 tons of fresh pods are produced 65-75 days after sowing (Shanmugasundaram and Yan, 2004). It has been also reported that edamame can be successfully intercropped with maize and okra (Chadha and Oluoch, 2004), with rice, peanut, tobacco and melon (Tsay et al., 1991) and with pigeonpea, cotton, sorghum, sugarcane and peanut (Esler, 2011). The crop is also used as green manure for mulching more successfully than cowpea and for growing leafy vegetables with fewer constraints of leafy vegetables (Chadha and Oluoch, 2004). Edamame' researchers reported seedling rates and fertilizer rates as ways to influence fresh pods/seeds yields. Assessing the effect of seeding rates on yield of fresh edamame in South Africa, Arathoon (2015) demonstrated that seeding rate of around 200,000 seeds per hectare could be adopted to achieve bean yield of 3.62 tons to 6.66 tons/ha. As for fertilizer rates, Potassium (K) and phosphorus (P) are macro elements that cause significant yield increase in edamame. An incorporation of 30 kg/ha of phosphorus and 80 kg/ha of potassium into the soil before planting were recommended to achieve bean dry matter yield of 2 tons per hectare for the cultivar “Lightning”(Arathoon, 2015). Besides, AVRDC suggested an application of 20-30 kg/ha of Nitrogen (N) and 60 kg/ha of P_2O_5 and 80 kg/ha of K_2O as basal dose to incorporate into the soil (Lal et al., 2001). At flowering stage, 20 kg of N + 25 kg of K_2O per hectare are required during the first side dressing and an additional application of 20 kg of N at the beginning of the stage of pods filling is important for seed size improvement. AVRDC also recommended irrigation at 10 - 15 days intervals until the development of pods and especially at flowering and pod filling stages (Lal et al., 2001).

PRODUCTION CONSTRAINTS

Commercialization of edamame requires keeping high quality attributes. Pests and diseases are known to cause significant quality loss. Hence, pests and diseases management are key elements to consider for pods and beans appearance. Some pests have been reported to affect quality of vegetable soybean without reducing significantly the yield, but affect the marketability of pods. The most commonly pests reported in the USA are soybean aphids (Rutledge, 2004), stinkbugs (Hamilton, 2007), leaf hoppers (Williams et al., 2011; Tiroesele et al., 2012), bean leaf beetles (Delate et al., 2003) and defoliating caterpillars (Thrash, 2014). The population of aphids and leafhoppers on the behavior of edamame varieties was separately evaluated in field and laboratory at Minnesota University using 14 edamame varieties, three varieties of aphid susceptible soybean-grain and one variety of aphid resistant soybean-grain (Menger et al., 2018). The trials revealed a higher aphid density on vegetable soybean variety “Hokkaido Black” than on “Agate”, “Kuroshinju” and “Chiba green” varieties. Therefore, the latter varieties could be directly used to decrease aphid damages on edamame or choosen as parents to breed aphid tolerant varieties of vegetable soybean. Leafhoppers damages were also reported. Edamame genotypes were more susceptible to potato leafhoppers than grain-type soybean lines, with “Kuroshinju” and “Midori Giant” being the most sensitive among the tested edamame cultivars (Menger et al., 2018). Grain soybean genotypes showed resistant genes useful for vegetable soybean improvement against potato leafhoppers.

There are also field diseases that constrain vegetable soybean production. The main field diseases are root rot and stem canker. A high susceptibility for *Phytophtora* spp*.* causing root rot disease was found in cultivars “C784” and “Bunya” in Australia (James, 2007)*.* Resistant varieties to stem canker have been identified among edamame cultivars. Various resistance traits against *meridionalis* and *caulivora* pathovars *of Diaporthe (Phomopsis) phaseolorum* were found and reported in variety “Kitanosuzu” among thirty vegetable soybean genotypes evaluated in the wet plain of Argentina (Benavidez et al., 2010). Therefore, “Kitanosuzu” variety can serve as parental line to develop stem canker resistant edamame varieties.

In addition to pests and diseases, weeds were also reported as a major constraint in edamame production (Sharma and Kshattry, 2013). Hand weeding and pre-emergence herbicide application are mainly used for weeds control, but hand weeding depends on the availability of casual labor (Esler, 2011) which might lead to higher cost. Zhang et al. (2017) highlighted the need for more research to address this constraint by developing weed tolerant edamame varieties. Besides, labor shortage during harvesting can lead to significant yield loss during edamame production, as non-timely harvesting causes hardening of pods and seeds, leading to the crop failure. This could be solved by using harvesting equipment recommended for big edamame farms (Cheng, 1991).

Interestingly, some of the constraints pointed out above are minor in Sub Saharan Africa. For instance, the need for labor to manage weeds and harvest fresh pods can easily be met with the jobless young people living in urban and peri-urban areas growing vegetables. This is an advantage for edamame production if introduced and adopted in SSA countries.

HARVEST AND POST-HARVEST HANDLING

In edamame production, harvesting occurs around 35-39 days after flowering. During this stage, the green bright and pubescent pod shows light brown or gray hilum and contains 1 to 3 fresh seeds (Zeipiņa et al., 2017). Harvesting is done at night or daytime but keeping the pods with branch at shade, for long freshness and to maintain the sucrose level in pods (Lal et al., 2001). Pods are then removed from branches and stored in polyethylene bags, precooled and preserved at 0ºC to avoid the loss of vitamin C, freshness, hardening and discoloration (Kaiser and Ernst, 2016). Long term storage consists in maintaining pods or beans in frozen form after blanching. The cold storage of fresh beans and pods proved successful in many countries including Australia (James, 2007), United States (Wszelaki et al., 2005; Pao et al., 2008; Carson et al., 2011; Jiang et al., 2018), Taiwan (Shanlnugasundaram et al., 1992), India (Kumar et al., 2011), Thailand (Sarutayophat, 2012), China (Li et al., 2013; Zhang et al., 2017), Argentina (Benavidez et al., 2010) and Latvian (Zeipiņa et al., 2017). Most authors reported on blanching as pre-treatment before cold storage, with various target advantages. Pao et al. (2008) investigated the effect of frozen edamame on its microbiological quality and indicated that blanching treatment at 98°C for about 60 s eliminates yeasts, molds, coliforms as well as infectious species *Escherichia coli* and *Listeria* spp. Moreover, Xu et al. (2012) demonstrated that blanching for 2.5 min or more at 100°C increases the green color intensity of edamame beans,

Table 2. Distribution of AVRDC' edamame varieties in Africa.

Countries	Number of lines distributed
Mauritania	30
Tanzania	71
South Africa	42
Zambia	15
Ghana	15
Zimbabwe	20
Ethiopia	17
Uganda	28
Swaziland	15
Congo	15
Lesotho	2
Kenya	4
Mozambique	4
Senegal	10
Botswana	15
Liberia	10
Chad	15
Togo	10
R.D Congo	4
SaoTome'e Principe	8
Mali	6
Angola	6
Somalia	2
Sudan	4
Malawi	4
Namibia	4

Source: Chadha and Oluoch (2004).

reduces the activities of yeasts, molds, total bacteria and 98% of peroxidase activities, thus alleviating the toxic effect of peroxide accumulation. Steam blanching of fresh pods has also been reported to retain more soluble sugars in edamame than the storage of edamame pods in open air at 25°C for 8 to 12 days found to be responsible for quick decrease in sucrose content causing the loss of sweet taste (Saldivar et al., 2010; Mozzoni et al., 2009). The use of infrared rays heating is another advanced storage technology for dehydrating and blanching of edamame at 11.06 kW/m^2 for hundred seconds or 2 min, indicating not only to reduce pods hardness and weight (9.5%), but also to improve green color and texture of pods (Lara et al., 2019), for a more profitable market. About post-harvest handling in SSA, as edamame production will begin around urban areas, the pods will be directly sold to consumers in gardens or via vegetables resellers who are used to conserve fresh garden crops like common bean and cabbages in open air. In case of commercial production, the cold storage must also be envisaged for edamame transportation to distant areas where it is not produced yet.

SEED MARKETS, INTRODUCTION AND DISTRIBUTION

Seed markets for edamame are well developed in countries where edamame is adopted and well consumed. Many private and public organizations put interest in the crop and seeds of superior varieties are nicely packed and marketed. In Netherlands, "DutchSoy" representing "Europe Soya" organization is producing and promoting organic edamame with many soybean varieties. In addition to selling planting seeds, the company provides farmers with technical assistance. The firm conducts field trials and research to develop technologies, to supply quality seeds to producers and to provide them with advice on various aspects of non-Genetically Modified edamame production. It also assists them with market strategies and distributes rhizobia to them (Strijk, 2019). In the United Kingdom, commercial production for local market takes place and this has significantly reduced the import needs from Thailand and Taiwan (Shanmugasundaram, 2004). The production of commercial quantities of edamame has been reported in Argentina, Mongolia, New Zealand, and Italia. Other countries like France, Germany, Chile and Britain grow vegetable soybean in home gardens (Konovsky et al., 1994). Vegetable soybean has recently been introduced at Latvia (Zeipiņa et al., 2017). Part of the edamame consumed in Japan and United States is imported from China, Taiwan and Thailand (Keatinge et al., 2011). In Africa, AVRDC has distributed edamame cultivars to about ten thousand smallholder farmers in 26 African countries for trials, utilization and varietal development (Table 2). In Zambia, nutrition kits composed of edamame seeds were distributed to farmers and the initiative was successful as most beneficiary farmers adopted edamame as new crop (Chadha and Oluoch, 2004). In Sudan, about 2,000 households received and grew edamame seeds which were shared with other fellow farmers. Similar case was observed by these authors in Tanzania, where edamame seeds have been distributed to over 2,500 farmers for testing and its utilization was liked. Vegetable soybean has contributed to income generation for farmers in Mauritania. The crop is widely grown and fresh pods are sold at about 2 USD/kg (Chadha and Oluoch, 2004). Some of the 22 others African countries involved in the programme, include Ghana, Senegal, Mali and Togo in West Africa (Table 2). Some African countries like South Africa have adopted vegetable soybean production and agronomic studies of edamame have been reported recently in Kwazulu-Natal (Arathoon, 2015). Seed Company Ltd, an African seed company released one edamame variety in Zimbabwe and is being marketed although the uptake is low. Therefore, more awareness on beneficial effects of edamame production and utilization need to be initiated, especially in countries where no action has been undertaken to introduce and promote edamame.

Table 3. SWOT matrix associated with vegetable soybean potentials in sub-Saharan Africa.

Strength	Weakness
- Favorable growing areas in SSA countries. - Short life cycle and nitrogen fixation. - Few damages of pests and diseases on vegetable soybean seeds yield. - Consumption: Less cooking time, used in various diets (snacks, salads, soups, stews mixed with cereals…). - Nutritious diets for SSA people: Good levels of proteins, carbohydrates; contains few fats and provides ash, fiber, micronutrients and vitamins. - Introduction in Africa: Distribution of lines to 26 sub-Saharan Africa. - Possibility for easy access to germplasm for research with AVRDC, NARO and private Companies (Seeds-Savers-Exchange).	- Little research on the crop in Africa. - Lack of adapted varieties and local seed system for edamame. - Presence of oligosaccharides causing flatulence in human. - Cost of irrigation system for smallholder gardeners. - Imported seeds cost to guarantee a good germplasm each growing season. - Needs of post-harvest logistics.
Opportunity	**Threat**
- High yield potential - Improvement of soil fertility. - Good for intercropping and rotation. - Markets access: local sales in gardens and markets like other vegetables. - Job opportunity for young. - Possibility of exportation. -Improvement of African farmers' income.	- Land pressure especially in suburban areas. - Flooding or drought risks in lowlands. - Development of new pests associated to climate change effects. - High labor cost for production in urban and peri-urban areas.

PERSPECTIVES OF VEGETABLE SOYBEAN ADOPTION IN SUB-SAHARAN AFRICA

Edamame production and utilization show many advantages and have potential to make significant contribution to food security in Sub-Saharan Africa. The crop is easy to grow and Africa's agro-ecological conditions are favorable for its production. Besides, edamame is suitable for intercropping and rotation systems. Due to its short cycle, edamame can be grown at least 4 times a year if water is available and well managed. This would make it a cash crop with quick return for households. Moreover, biomass debris can provide organic matter which increase natural nitrogen for the improvement of soil fertility. The possibility of obtaining germplasm from International Institutes may act as a motivation for edamame production and trigger research on interesting traits and development of seed systems for farmers in Sub-Saharan Africa (Table 3). As solution to fewer interests in production and consumption of edamame in sub-Saharan Africa, participative research work must be implemented, starting from evaluation for yield adaptation and stability, consumers' preferences and sensorial qualities to nutritional contents improvement. Initiatives to promote the crop in SSA countries may also include farmer's field schools that will involve all stakeholders to demonstrate and increase awareness for an effective and efficient use of the technology.

CONCLUSION

This review showed that edamame is well known in many countries across the world, however, the crop has not been thoroughly researched everywhere. East Asia and North America are the top regions where research on edamame has advanced the most. In Sub-Saharan Africa, edamame is still not well known and underutilized, despite the great potential of the crop. This potential illustrated in the SWOT matrix shows the strengths for its production, the opportunity to promote edamame in Africa and the job opportunity this will provide, contributing to reduced youth unemployment. Research gaps observed in Sub-Sahara Africa, especially research needs on adapted varieties and lack of facilities that would help avoid relying on rain-fed edamame production could hinder its introduction in some areas. Interestingly, other constraints that limit edamame production elsewhere in the world are minor in Africa. For instance, urban and peri-urban areas hold enough and cheap labor to effectively handle hand weeding and timely harvesting of edamame.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests

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