Nutritional composition of mungbean and soybean sprouts compared to their adult growth stage

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Short version of title

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ABSTRACT

This study determined the level of phytonutrients in mungbean and soybean sprouts compared to mature mungbean grain and vegetable soybean. The comparison included landraces and improved mungbean and soybean varieties to assess the effect of breeding on the phytonutrient content of both crops. Sprouting mungbean enhanced vitamin C content 2.7-fold compared to mature mungbean grain. Relatively old mungbean accessions were superior in protein, calcium (Ca), iron (Fe), zinc (Zn), carotenoid and vitamin C content compared to improved mungbean lines at the fully mature stage. With regards to nutritional value, the vegetable soybean stage was superior to soybean sprouts in terms of content of protein (14% increase), Zn (45%), Ca (72%), and Fe (151%). Isoflavones, reported to have beneficial effects on human health, are found in high concentrations in soybean sprouts and could easily provide the recommended anticarcinogenic dose range from 1.5 to 2.0 mg/kg of body weight per day.

Keywords: Mungbean, Soybean, Sprouts, Vegetable soybean, Mungbean grain, Phytonutrients

Chemical compounds studied in this article

Caffeic acid (PubChem CID: 689043; chlorogenic acid (PubChem CID: 1794427; kaempferol (PubChem CID: 5280863); luteolin (PubChem CID: 5280445); lutein (PubChem CID: 5281243); violaxanthin (PubChem CID: 448438); neoxanthin (PubChem CID: 5281247); α-carotene (PubChem CID: 4369188); β-carotene (PubChem CID: 5280489)

1. **Introduction**

The regular intake of nutritious food such as non-starchy vegetables, fruit, legumes, nuts, fish, etc. reduces the risk of diet-related diseases like obesity, diabetes, cardiovascular disease, hypertension, stroke, and cancers that are escalating worldwide due to increased consumption of fast food with high trans fat content and high caloric density, and sweetened beverages (Hurt, Kulisek, Buchanan, & McClave, 2010; Mozaffarian, 2016). Apart from these behavioral changes in food consumption, climate change, especially rising carbon dioxide (CO_2) levels, is threatening human nutrition. Global climate models predict a gradual increase in atmospheric CO_2 concentration from the current level of ~400 ppm to as much as 700 ppm by 2100 (IPCC, 2014). At global CO_2 levels of 550 ppm, expected to be reached in the next 40-60 years, many of the food crops for human nutrition will have decreased nutritional value when compared with the same plants grown under present CO_2 levels (Myers et al., 2014). According to Meyers and coworkers (2014), elevated CO_2 resulted in significant decreases of iron (Fe) and zinc (Zn) in grains and legumes that follow the C3 photosynthetic pathway. These crops represent major dietary sources of these elements for a large portion of the population in developing countries.

There is also evidence that past breeding efforts, usually geared towards enhancing yield and appearance of produce, led to a decline in nutritional value of modern cultivars. This is supported by a review study conducted on 48 garden crops based on USDA food composition data, which revealed a statistically significant decline of six nutrients—protein, calcium (Ca), phosphorus (P), Fe, riboflavin and ascorbic acid—between 1950 and 1999 (Davis, Epp, & Riordan, 2004). It is likely that these changes were caused by the replacement of older, more nutritious cultivars with modern ones. Similar trends have been observed in wheat (Fan et al., 2008) and potato tubers (White et al., 2009). These observations inspired

Unilever to assemble a scientific consortium to identify ‘pre-domesticated’ varieties of crops (mainly fruit and vegetables) that have not been touched by breeders and could be used to develop the next generation of nutrient-rich food and beverages (Unilever, 2012). Vegetable genebanks like the one maintained by the World Vegetable Center (WorldVeg) harbor many landraces, farmer selections and crop wild relatives, which have hardly undergone any breeding and could be explored for the generation of nutrient-rich food.

Phytonutrient levels in plants vary according to the growth stage. There is some decrease in phytonutrients from the seedling (sprout/microgreen) to the fully grown stage as shown in lettuce (Pinto, Almeida, Aguiar, & Ferreira, 2015), brassicas (Sun et al., 2013), broccoli (Guo, Yang, Wang, Guo, & Gu, 2014), a range of different beans (Nakamura, Kaihara, Yoshii, Tsumura, Ishimitsu, & Tonogai, 2001), and amaranth (Ebert, Wu, & Yang, 2015). Germination of seeds has been reported to enhance the nutritive value of legumes by activating enzymes that reduce or eliminate anti-nutritional factors (Bau, Villaume, Nicolas, & Mejean, 1997) and has been found to be quite effective in reducing phytic acid, stachyose and raffinose in mungbean, and, on the other hand, helping to better retain many minerals compared to other processes such as dehulling, boiling, autoclaving and microwave cooking (Mubarak, 2005).

Sprouts and microgreens are fresh, functional and nutraceutical foods that are increasingly becoming popular for healthy eating (Ebert, 2015; Kyriacou et al., 2016). As more people worldwide are moving to urban areas, city administrators need solutions to provide healthy diets for urban dwellers at affordable prices (Cohen & Garrett, 2010). Sprouts and microgreens have the potential to contribute to food and nutrition security in cities as they can be easily grown in urban and peri-urban settings where land is often a limiting factor, either by specialized producers or the consumers themselves, independent of seasonal growth cycles, inside, or around, residential areas (Ebert, 2015).

Legumes are second only to cereals in their importance as human food crops (Nair et al., 2013), and grain legumes contribute 33% of the dietary protein nitrogen (N) needs of humans (Vance, Graham & Allan, 2000). Under subsistence agriculture in the tropics and subtropics, the proportion of legume protein N in the human diet can reach twice this figure. About 90% of global mungbean production occurs in South, East and Southeast Asia (Nair et al., 2013). In South Asia, mungbean is consumed mainly as *dhal* (porridge), while in the rest of Asia it is consumed as sprouts, or as noodles. Mungbean and soybean sprouts have long been an essential, year-round component of Asian and vegetarian diets (Ebert, 2015; Ghani et al., 2016) and the former are now finding their way into supermarket chains in the Americas, Europe and East Africa. In the U.S., producers of Chinese foods perform canning of sprouts alone, in water or mix them with other vegetables, such as water chestnuts. Mungbean sprouts are also formulated and offered as dietary supplement in healthcare (Kovacs, 1996).

However, there is scarce information pertaining to the nutritional properties of this produce, which is now becoming more mainstream. The objective of this study was to determine the level of phytonutrients in mungbean and soybean sprouts compared to mature mungbean grain and vegetable soybean. The comparison included landraces from the WorldVeg genebank and mungbean and soybean varieties improved by WorldVeg breeders to assess the effect of breeding on the phytonutrient content of both crops.

2. **Materials and Methods**

2.1 Plant material

Accessions of each crop with contrasting geographical origin and breeding status (landrace versus improved cultivar) were chosen from the WorldVeg genebank to verify potential genotypic differences.

Mungbean. The experimental setup consisted of two relatively old landraces and two improved mungbean lines of the WorldVeg genebank as follows:

- VI000197 A-G (landrace): 100-seed weight: 2.89 g; shiny seeds with green seed coat color; year of acquisition: 1972; origin: Afghanistan
- VI000323 B-G (landrace): 100-seed weight: 4.93 g; dull seeds with green seed coat color; year of acquisition: 1972; origin: Taiwan
- VI060081 B-G (improved mungbean line): 100-seed weight: 6.62g; dull seeds with green seed coat color; year of acquisition: 2010; developed by WorldVeg breeders in Thailand
- VI060110 A-G (improved mungbean line): 100-seed weight: 6.69 g; shiny seeds with green seed coat color; year of acquisition: 2010; developed by WorldVeg breeders in Thailand.

Soybean. For soybean sprouts and vegetable soybean, the following WorldVeg genebank landraces and improved soybean lines were used:

- VI015437 (landrace): medium seed size; 100-seed weight: 19.2 g; yellow seed coat color; year of acquisition: 1973; origin: China; used for sprouts only
- VI015726 (landrace): medium seed size; 100-seed weight: 20 g; yellow seed coat color; year of acquisition: 1973; origin: North Korea; used for sprouts and vegetable soybean
- VI016706 (landrace): small seed size; 100-seed weight: 7 g; light green/yellow seed coat color; year of acquisition: 1973; origin: Indonesia; used for sprouts only

- VI023379 (landrace): small seed size; 100-seed weight: 7.6 g; black seed coat color; year of acquisition: 1975; origin: India; used for sprouts only
- VI022144 (landrace): large seed size; 100-seed weight: 31.1 g; light green seed coat color; year of acquisition: 1979; origin: Japan; used for vegetable soybean only
- AVSB8001 (improved soybean line): medium seed size; 100-seed weight: 13-17 g; yellow seed coat color; year of release: 1985 in Taiwan, 1991 in Vietnam; used for sprouts and vegetable soybean
- AVSB9301 (improved soybean line): medium seed size; 100-seed weight: 20-23 g; yellow seed coat color; year of release: 2004 in Vietnam; used for sprouts and vegetable soybean.

Small-seeded soybean varieties are commonly used for sprouting, resulting in the highest sprout yield per 100 seeds. Medium-seeded soybean varieties are used for processing to produce tofu, soybean milk, soybean oil, etc. Both small- and medium-seeded soybean varieties are harvested at yellow or R8 stage; while large-seeded soybean varieties with >30 g per 100 seeds are used for vegetable soybean, which are harvested and consumed at green or R6 stage.

2.2 Production of mungbean and soybean sprouts, vegetable soybean and mungbean grain

For the production of mungbean and soybean sprouts, seeds were soaked for eight and four hours respectively, in distilled water, followed by rinsing. Seeds (60 g per replicate) were then placed in a single layer on a sheet of paper towel inside perforated plastic trays, which were enclosed in solid plastic boxes for drainage of excess water and to maintain high moisture content for the sprouting process. The experiment was conducted in two batches, with three replicates each, for nutritional analysis. Boxes were arranged in a randomized complete block design (RCBD) and kept in a laboratory room at 26±2 °C. The seedlings were carefully watered three times daily. Mungbean and soybean sprouts were harvested at the end of the third day of germination. The sprouts were washed, seed coats removed and samples were used for nutritional analysis.

For the production of vegetable soybean and mungbean grain, seeds were sown towards the end of summer (soybean in mid-September; mungbean at the beginning of October) in WorldVeg experimental fields in southern Taiwan with three replicates arranged in RCBD. The mungbean field was previously grown to pepper and the soybean field to tomato. Soybean samples were harvested at 69-73 days after sowing (depending on maturity stage of each accession) and mungbean samples at 97 days after sowing, for nutritional analysis.

2.3 Chemicals used

The chemicals 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS), Trolox, β-carotene, lutein, quercetin and kaempferol were purchased from Sigma-Aldrich Chemical Co. (St. Louis, MO, USA), while α-carotene and caffeic acid were obtained from Fluka Co. (Neu-Ulm, Germany). Genistein, daidzein, glycitein, genistin, daidzin and glycitin were purchased from Nacalai tesque INC. (Kyoto, Japan). Violaxanthin and neoxanthin were purchased from ChromaDex Co. (Irvine, CA, USA.), while luteolin was obtained from Extrasynthese Co. (Genay, France). Chlorogenic acid was purchased from MP Biomedicals, LLC. (Santa Ana, CA, USA), 6”-O-malonyl genistin, 6”-O-malonyldaidzin and 6”-O-malonyl glycitin from LC laboratories INC. (Woburn, MA, USA), and 2,4-dinitrophenylhydrazine (DNPH) was obtained from Panreac Co. (Barcelona, Spain). Ascorbic acid and 2,6-

dichlorophenolindophenol (DCPIP) was obtained from Merck Chemical Co. (Darmstadt, Germany).

2.4 Nutritional analysis

About 250 g to 300 g of sprouts and vegetable soybean seeds per replicate were collected. Seventy (70) g were weighed and stored at -70 °C for vitamin C analysis within a week; the remaining portion was weighed, freeze-dried, ground into fine powder and stored at -20 °C for subsequent analysis. Vitamin C is more sensitive than other phytonutrients to heat, light and drying processes, including freeze drying, thus the sampling and preparation method for vitamin C analysis differed from the other phytonutrients. For mungbean grain, no drying process was required and the grain was directly ground to fine powder and stored at -20 °C for nutritional analysis.

Micro-Kjeldahl digestion followed by distillation (AOAC, 1990a) was used to determine protein content of samples. The determination of Ca, Fe, and Zn content was performed by ashing procedure, strong acid washing, followed by detection with Atomic Absorption Spectroscopy (AOAC method 975.03, p. 42; AOAC, 1990b).

Total ascorbic acid content (vitamin C) was determined on the basis of coupling 2,4-dinitrophenylhydrazine (DNPH) with the ketonic groups of dehydroascorbic acid through the oxidation of ascorbic acid by 2,6-dichlorophenolindophenol (DCPIP) to form a yellow-orange color in acidic conditions as described by Hanson et al. (2004). Antioxidant activity was measured using 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) radical (Re et al., 1999) and expressed as trolox equivalents (TE). Details are given by Yang et al. (2006).

Carotenoid determination. Two hundred (200) mg of freeze dried fine powder was briefly rinsed in 0.8 ml of distilled water, followed by 9.2 ml of acetone. The extract was evaporated under a nitrogen air flow and re-dissolved in 2 ml of 1 % tetrahydrofuran (THF) in methanol. Separation and identification of carotenoids was performed using a high performance liquid chromatography (HPLC) system (Waters 2695, Milford, MA, USA) equipped with an auto-sampler, a photodiode array detector (Waters 996) monitoring 210 − 700 nm, Millennium software, and a C_{30} Column (YMC^{TM}, 3.0 µm, 4.6 mm x 150 mm). The running conditions were set at 30 °C using a gradient at 1.3 ml/min from 0 to 1% THF in methanol at 0 −15 min, 1 to 25% THF in methanol at 15 − 25 min, 25 to 70% THF in methanol at 25 − 50 min, and the final 100% THF at 50 − 60 min. Identification of carotenoids (α-carotene, β-carotene, violaxanthin, neoxanthin, and lutein) in samples was performed by comparing retention time and light absorption spectra (350 nm – 700 nm) of known standards and co-elution of spiked known standards to samples. The peak areas were calibrated against known amounts of standards. The content of carotenoid standards was measured according to their optical density reading and specific extinction coefficient ($E^{1\%}{}_{1\,\mathrm{cm}}$) in the respective solvent.

Flavonoid determination. Nine flavonoid aglycones were determined in the frozen samples after hydrochloric hydrolysis of the flavonoid derivatives. A 100 mg frozen sample placed in a 20 mL tube containing 10 mg ascorbic acid dissolved in 5 mL of acidified methanol (1.2 M HCl) was flushed with nitrogen air for 30 sec and then refluxed at 80 °C for 2 h. After cooling down to room temperature, the sample was sonicated for 10 min and centrifuged at 4000 g for 10 min. The supernatant, approximately 2 mL, was taken and filtered through a 0.2 µm syringe filter (Millipore, Bedford, MA). The filtrate was kept at 10 °C for HPLC analyses within 12 h. Flavonoid aglycons were separated using the HPLC system equipped with a Waters 2695 separation module and an Agilent Zorbax ODS column (3.5µm, 4.6 x 150 mm) at 35 °C using a gradient from 0 − 15 min, 1 to 25% acetonitrile (ACN) in 1%

aqueous formic acid (FA); and 15 − 50 min, 25% − 40% ACN in 1% aqueous FA at a flow rate of 0.7 mL/min. The column elute was monitored using a Waters 996 photo diode array detector (250 −700 nm). Identification and quantification of individual flavonoids was carried out using commercial standards.

Isoflavones were separated using the HPLC system equipped with a Waters 996 separation module and an Lichrospher R 100 RP-18 column (5µm, 4 x 250 mm) at 30 °C using a gradient from 0 − 30 min, 90 to 50% of solvent A (0.1% acetic acid in water) and 10 to 50% of solvent B (acetonitrile); 31 – 34 min, 50% of solvent A and 50% of solvent B; 35 – 39 min, 50 to 0 % of solvent A and 50 – 100 % of solvent B at a flow rate of 1.0 mL/min. The column elute was monitored using a Waters 2996 photo diode array detector (210 −400 nm). Identification and quantification of individual isoflavones (genistein, daidzein, glycitein, genistin, daidzin, glycitin, 6”-O-malonyl genistin, 6”-O-malonyldaidzin, 6”-O-malonyl glycitin) was carried out using commercial standards.

2.5 Statistical analysis

Data was statistically analyzed by two-way analysis of variance (ANOVA) using Statistical Analysis Software (SAS) 9.4. Duncan's multiple range test (DMRT) was used to determine significant differences at the $p < 0.05$ level.

3. Results and discussion

3.1 Nutritional analysis of mungbean sprouts and mungbean grain

At the sprouting stage, the improved mungbean lines (VI060081 and VI060110) showed the highest dry matter and protein content, while Ca, Fe and Zn content did not differ among the four genotypes tested (Table 1). At the fully grown stage, mungbean grain of the two relatively old genebank accessions, acquired at the start of the operation of the WorldVeg genebank (VI000197 and VI000323), were superior in protein, Ca, Fe and Zn content compared to the improved mungbean lines. Protein content of all four genotypes was higher than the values reviewed and reported by Nair et al. (2013). The observed lower content of protein and some essential micronutrients of improved mungbean lines compared to relatively old landraces confirms earlier observations with garden crops in the United States (Davis et al., 2004), that breeding for size and yield may have a detrimental effect on the nutrient value of the produce.

The lower values of protein and minerals observed in mungbean sprouts compared to mature grains (Table 1) are primarily a result of water uptake and ensuing biochemical processes during sprouting (Tang, Dong, Ren, Li, & He, 2014) and are in line with observations made by Fordham, Wells, & Chen (1975).

Mungbean sprouts showed very low levels of carotenoids; the content of violaxanthin and neoaxanthin was below the detection threshold (Table 1). However, mean vitamin C content was 2.7-fold higher at the sprouting stage compared with mature mungbean grain. Sprouts of improved mungbean line VI060081 had the highest vitamin C content at this early growth stage. At the fully mature stage, mungbean grain of the relatively old genebank accession VI000323 from Taiwan presented the highest carotenoid and vitamin C content among all four genotypes (Table 1). While the content of carotenoids was enhanced at the grain stage compared to mungbean sprouts, vitamin C content was considerably lower at the fully mature stage.

The vitamin C content of mungbean sprouts was 1.7-fold higher than that of soybean sprouts (Tables 1 & 2) and 2.5-fold higher than that of amaranth sprouts (Ebert, Wu, & Yang, 2015). Our results are in agreement with Fordham et al. (1975) who observed a 7.9-fold increase of total ascorbic acid content in mungbean sprouts compared to mungbean grain. With regard to vitamin C content, our findings are also in line with reports by Chavan & Kadam (1989) who concluded that sprouting of cereal grain generally improves their vitamin value.

Little variation in antioxidant activity (AOA) was measured among mungbean genotypes at the sprouting stage, with the exception of VI000197 having inferior content (Table 1). Antioxidant activity of mungbean sprouts reached only 48% of the value observed in soybean sprouts (Table 2). However, AOA levels of mungbean grain were 6.7- to 11.3-fold higher than at the sprouting stage (Table 1), clearly exceeding AOA levels measured in soybean sprouts, vegetable soybean (Table 2), amaranth sprouts and microgreens (Ebert et al., 2015).

In mungbean sprouts, only caffeic acid and kaempferol were found in detectable quantities, while chlorogenic acid and luteolin were below the detection level (Table 1). In mungbean grain, caffeic acid and kaempferol reached a 13.8-fold and 7.8-fold higher level, respectively. The genebank accession VI000323 from Taiwan showed the highest level of these phytochemicals at both development stages. Phenolic compounds such as phenolic acids and flavonoids are an important source of antioxidants and are relevant for stability, color, flavor and nutritional value of food (Chen & Ho, 1997).

Our results have shown that mungbean sprouts and mungbean grain are of high nutritional value. They can be considered as functional foods that may lower the risk of various diet-related diseases through their antioxidant, antimicrobial, anti-inflammatory, antidiabetic, antihypertensive, and antitumor effects as reviewed by (Tang et al., 2014).

3.2 Nutritional analysis of soybean sprouts and vegetable soybean

At the sprouting stage, dry matter and protein content was highest in VI015437, a relatively old genebank accession from China, while the highest contents of Ca, Fe and Zn were determined in the improved soybean line AVSB9301, released in 2004 in Vietnam (Table 2). While Ca levels in our experiments were similar to those reported in Korean and Chinese soybean sprouts (Lee, 2015), mean protein, Fe and Zn levels were about 2-fold higher in the current studies.

At the vegetable soybean stage, there were only minor differences among genotypes regarding protein, Ca and Zn contents, while Fe content did not differ significantly (Table 2). Compared to the sprouting stage, there was a slight increase in the mean value of protein (14%) content and a more pronounced increase in Zn (45%), Ca (72%), and Fe (151%) content at the vegetable soybean stage.

When comparing the mean protein and mineral content of mungbean and soybean sprouts (Tables 1 & 2), it is noted that the values of soybean are much higher for protein (2.71-fold), Ca (7.95-fold), Fe (2.96-fold), and Zn (2.18-fold). This is in agreement with earlier reports made by Abdullah and Baldwin (1984) who observed comparable or higher contents of several minerals in soybean seeds and sprouts compared to mungbean, on a dry weight basis.

The content of carotenoids in soybean sprouts was rather low (Table 2). The highest content of α-carotene, β-carotene and vitamin C was obtained with VI016706, a relatively old genebank accession from Indonesia, while the improved cultivar AVSB9301, released 2004 in Vietnam had the highest violaxanthin, neoxanthin, and lutein contents. The AOA content of soybean sprouts was more than 2-fold higher than that of mungbean sprouts (Tables 1 & 2), with AVSB8001, released in 1985 in Taiwan, reaching 3049 µm TE.

Vegetable soybean showed an enhanced carotenoid content compared with soybean sprouts; this was especially the case with neoxanthin—a 8.9-fold increase—and α-carotene—a 4.4-fold increase (Table 2). The highest levels were observed with the improved soybean line AVSB9301. Vitamin C content more than doubled at the vegetable soybean stage, while AOA was only slightly enhanced compared with soybean sprouts.

With a mean content of 23.82 mg vitamin C, the consumption of 100 g vegetable soybean would have made a 40% contribution to the previously established recommended dietary allowance (RDA) of 60 mg/d, out of which 46 mg/d are necessary to prevent the vitamin C deficiency disease, scurvy (Carr & Frei, 1999). These authors successfully argued for a reevaluation of the established RDA value for vitamin C to reduce the risk of other chronic diseases such as cancer, cardiovascular disease, and cataract, which are—possibly through antioxidant mechanisms—associated with vitamin C intake. The RDA values for vitamin C recently were adjusted to 90 mg/d for male and 75 mg/d for female non-smoking adults (National Institutes of Health, 2016). Smokers require an additional intake of 35 mg vitamin C per day.

In soybean sprouts, the highest levels of isoflavones, a main class of phytoestrogens, were obtained with the improved breeding line AVSB8001, followed by the relatively old genebank accession VI015437 from China (Table 3). The highest individual isoflavone share was registered with the malonylglucosides 6”-O malonyl genistin, followed by 6”-O malonyl daidzin and 6”-O malonyl glycitin. The isoflavonoids genistein, daidzein and glycitein were only present in low concentrations and were completely absent in vegetable soybean.

The mean isoflavone contents of vegetable soybean reached only 43.2% of the contents found in soybean sprouts, on average (Table 3). The landrace VI022144 presented the highest isoflavone content among vegetable soybean genotypes.

The observed isoflavone contents of vegetable soybeans are very similar to those reported in the USDA database (Bhagwat, Haytowitz & Holden, 2008), while the isoflavone contents of soybean sprouts are 3.2-fold higher in our experiments compared to the values found in the USDA database. The isoflavone concentrations of vegetable soybean and soybean sprouts measured in our experiments are within the range reported by Wang & Murphy (1994) for commercial soybean foods. Our results confirm the observations made by Kim et al. (2006) that the isoflavone content in soybean sprouts is higher than in the seed. Large variation in isoflavone content has been observed among soybean sprout genotypes (Ghani et al., 2016) making genetic selection for high isoflavonole content an interesting breeding goal.

Isoflavones, found in particularly high concentrations in soybeans and flax seeds, are reported to have beneficial effects on human health, particularly on hormone-dependent conditions, such as cancer, menopausal symptoms, cardiovascular disease and osteoporosis (Setchell & Cassidy, 1999). Vegetable soybean and especially soybean sprouts could easily provide the anticarcinogenic dose range from 1.5 to 2.0 mg/kg of body weight per day recommended by (Hendrich, Lee, Xu, Wang, & Murphy, 1994). The present study has shown that both soybean sprouts and vegetable soybean are of high nutritional value containing a wide range of health-promoting phytochemicals, thus justyfing the promotion of these food items for healthy diets.

4. **Conclusions**

Mungbean. At full maturity, mungbean landraces were superior in protein, Ca, Fe, Zn, carotenoid and vitamin C contents compared to improved varieties. Mean vitamin C content was 2.7-fold higher at the sprouting stage compared to mature mungbean grain. In contrast, the content of the phenolic compounds caffeic acid and kaempferol and antioxidant activity was much higher in mungbean grain than in sprouts. A landrace from Taiwan (VI000323) showed the highest levels of caffeic acid and kaempferol at both developmental stages.

Soybean. There was no clear pattern of higher nutritional value of either unimproved or improved soybean lines. Vegetable soybean was superior to soybean sprouts in terms of content of protein (14% increase), Zn (45%), Ca (72%), and Fe (151%). Vitamin C content more than doubled at the vegetable soybean stage, neoxanthin and α-carotene contents showed a 9-fold and 4-fold increase, respectively. Isoflavones were found in high concentrations in soybean sprouts and could easily provide the recommended anticarcinogenic dose range from 1.5 to 2.0 mg/kg of body weight per day.

Soybean sprouts were superior to mungbean sprouts in the content of protein (2.71-fold), Ca (7.95-fold), Fe (2.96-fold), and Zn (2.18-fold). The antioxidant activity of soybean sprouts was more than 2-fold higher than that of mungbean sprouts.

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Author Contributions

A. Ebert designed the study, interpreted the results and drafted the manuscript. J. Chang and M.-R. Yan supervised the implementation of the mungbean and soybean trials and collected and analyzed the data, respectively. R.-Y. Yang supervised the nutritional analyses and contributed to the manuscript.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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Tables

Table 1

Content[1] of dry matter, protein, minerals, carotenoids, vitamin C, antioxidant activity (AOA), phenolic acids (chlorogenic acid, caffeic acid), and flavonoids (luteolin, kaempferol) of mungbean sprouts and mungbean grain per 100 g edible portion of fresh weight.

Accession /cultivar	Dry matter (g)	Protein (g)	Minerals			Carotenoids			
			Ca (mg)	Fe (mg)	Zn (mg)	Violaxanthin (mg)	Neoxanthin (mg)	Lutein (mg)	α-Carotene (mg)
Mungbean sprouts									
VI000197 A-G	9.72 ± 0.42^{b}	3.38 ± 0.16^{b}	7.13 ± 0.15^{a}	0.36 ± 0.07^{a}	0.49 ± 0.02^{a}	n.d.[2]	n.d.	0.18 ± 0.02^{a}	0.01 ± 0.00
VI000323 B-G	11.42 ± 0.95^{b}	3.80 ± 0.25^{b}	7.88 ± 1.09^{a}	0.81 ± 0.14^{a}	0.59 ± 0.11^{a}	n.d.	n.d.	0.18 ± 0.03^{a}	0.01 ± 0.00
VI060081 B-G	14.37 ± 1.03^{a}	4.72 ± 0.26^{a}	8.53 ± 1.23^{a}	0.77 ± 0.51^{a}	0.67 ± 0.32^{a}	n.d.	n.d.	0.15 ± 0.04^{a}	0.01 ± 0.00
VI060110 A-G	14.01 ± 0.87^{a}	5.19 ± 0.18^{a}	7.74 ± 0.37^{a}	0.57 ± 0.11^{a}	0.63 ± 0.05^{a}	n.d.	n.d.	0.19 ± 0.02^{a}	0.01 ± 0.00
Mean ± SD[3]	12.38 ± 2.12	4.27 ± 0.77	7.82 ± 0.89	0.63 ± 0.30	0.60 ± 0.16	n.d.	n.d.	0.18 ± 0.03	0.01 ± 0.00
Mungbean grain									
VI000197 A-G	90.78 ± 0.09^{a}	27.54 ± 0.73^{ab}	109.17 ± 6.11^{a}	7.17 ± 0.68^{ab}	4.56 ± 0.11^{a}	0.08 ± 0.00^{a}	0.10 ± 0.01^{ab}	0.87 ± 0.05^{bc}	n.d.
VI000323 B-G	90.35 ± 0.14^{a}	28.65 ± 1.99^{a}	101.85 ± 4.65^{a}	7.83 ± 0.88^{a}	4.48 ± 0.31^{a}	0.07 ± 0.01^{a}	0.11 ± 0.02^{a}	0.98 ± 0.03^{a}	n.d.
VI060081 B-G	90.37 ± 0.49^{a}	25.33 ± 0.38^{b}	92.12 ± 3.28^{b}	6.26 ± 1.27^{b}	2.45 ± 0.54^{b}	0.07 ± 0.03^{a}	0.10 ± 0.02^{ab}	0.92 ± 0.04^{ab}	n.d.
VI060110 A-G	90.13 ± 0.73^{a}	26.00 ± 0.22^{b}	83.09 ± 1.13^{c}	6.28 ± 0.68^{b}	2.97 ± 0.07^{b}	0.09 ± 0.02^{a}	0.07 ± 0.02^{b}	0.83 ± 0.04^{c}	n.d.
Mean ± SD	90.41 ± 0.45	26.88 ± 1.64	96.56 ± 10.90	6.88 ± 1.04	3.61 ± 1.00	0.08 ± 0.02	0.10 ± 0.02	0.90 ± 0.07	n.d.

Table 1 continued…

Accession /cultivar	β-Carotene (mg)	Vitamin C (mg)	AOA (µmol TE)	Chlorogenic acid (µmol)	Caffeic acid (µmol)	Luteolin (µmol)	Kaempferol (µmol)
Mungbean sprouts							
VI000197 A-G	0.053 ± 0.01^{b}	17.61 ± 0.86^{b}	962 ± 55^{b}	n.d.	9.8 ± 0.8^{b}	n.d.	0.32 ± 0.10^{a}
VI000323 B-G	0.067 ± 0.01^{ab}	18.44 ± 0.41^{b}	1255 ± 52^{a}	n.d.	11.3 ± 0.7^{a}	n.d.	0.37 ± 0.10^{a}
VI060081 B-G	0.067 ± 0.02^{ab}	20.33 ± 1.05^{a}	1214 ± 119^{a}	n.d.	8.8 ± 0.5^{bc}	n.d.	0.35 ± 0.21^{a}
VI060110 A-G	0.073 ± 0.01^{a}	19.05 ± 1.16^{ab}	1348 ± 61^{a}	n.d.	8.1 ± 0.5^{c}	n.d.	0.40 ± 0.10^{a}
Mean ± SD	0.065 ± 0.01	18.86 ± 1.30	1195 ± 163	n.d.	9.5 ± 1.4	n.d.	0.36 ± 0.12
Mungbean grain							
VI000197 A-G	0.16 ± 0.01^{b}	4.72 ± 0.28^{b}	10888 ± 305^{b}	0.08 ± 0.00^{a}	127.6 ± 4.6^{bc}	1.21 ± 0.06^{bc}	3.10 ± 0.90^{a}
VI000323 B-G	0.21 ± 0.03^{a}	9.82 ± 1.24^{a}	8399 ± 426^{c}	0.07 ± 0.01^{a}	142.7 ± 2.0^{a}	1.37 ± 0.03^{a}	3.08 ± 0.93^{a}
VI060081 B-G	0.16 ± 0.02^{b}	7.58 ± 2.04^{ab}	9616 ± 1171^{bc}	0.07 ± 0.03^{a}	133.2 ± 3.6^{ab}	1.25 ± 0.09^{ab}	2.39 ± 1.46^{a}

VI060110 A-G	0.13 ± 0.02^{b}	6.03 ± 2.08^{ab}	12597 ± 106^{a}	0.09 ± 0.02^{a}	120.6 ± 9.7^{c}	1.12 ± 0.08^{c}	2.73 ± 0.88^{a}
Mean ± SD	0.17 ±0.04	7.04 ± 2.40	10375 ±1715	0.08 ± 0.02	131.0 ± 9.8	1.24 ± 0.11	2.82 ± 0.96

[1] Values are means ± standard deviation. Means within a column with different upper case letters are significantly different at $P < 0.05$. An absence of letters indicates no significant difference was observed. [2] not detected; [3] standard deviation.

Table 2

Content[1] of dry matter, protein, minerals, carotenoids, vitamin C, and antioxidant activity (AOA) of soybean sprouts and vegetable soybean per 100 g edible portion of fresh weight.

Accession/ cultivar	Dry matter (g)	Protein (g)	Minerals		
			Ca (mg)	Fe (mg)	Zn (mg)
Soybean sprouts					
VI015437	28.15 ± 1.03^{a}	13.65 ± 0.91^{a}	65.3 ± 2.55^{bc}	1.99 ± 0.20^{abc}	1.32 ± 0.04^{bc}
VI015726	24.70 ± 1.24^{b}	12.73 ± 0.83^{b}	54.7 ± 5.35^{cd}	2.04 ± 0.53^{ab}	1.34 ± 0.25^{abc}
VI016706	17.93 ± 0.79^{c}	9.03 ± 0.18^{c}	46.0 ± 4.76^{d}	1.43 ± 0.29^{c}	1.04 ± 0.06^{d}
VI023379	16.37 ± 0.95^{d}	9.17 ± 0.42^{c}	62.0 ± 2.08^{bc}	1.56 ± 0.21^{bc}	1.14 ± 0.04^{cd}
AVSB8001	25.53 ± 0.80^{b}	12.03 ± 0.46^{b}	68.7 ± 7.74^{ab}	1.98 ± 0.42^{abc}	1.41 ± 0.10^{ab}
AVSB9301	25.87 ± 0.85^{b}	12.89 ± 0.38^{ab}	76.7 ± 7.64^{a}	2.22 ± 0.23^{a}	1.58 ± 0.09^{a}
Mean ± SD[2]	23.09 ± 4.56	11.58 ± 1.94	62.2 ± 11.18	1.87 ± 0.40	1.31 ± 0.21
Vegetable soybean					
VI015726	34.03 ± 0.15^{ab}	13.51 ± 0.08^{a}	117.3 ± 14.8^{a}	4.52 ± 0.37^{a}	1.89 ± 0.01^{ab}
VI022144	32.71 ± 0.18^{b}	12.23 ± 0.25^{b}	94.4 ± 4.8^{b}	4.64 ± 0.04^{a}	1.70 ± 0.01^{b}
AVSB8001	35.29 ± 0.92^{a}	13.32 ± 0.23^{a}	106.0 ± 17.0^{ab}	4.86 ± 0.18^{a}	1.97 ± 0.06^{a}
AVSB9301	34.46 ± 1.01^{a}	13.70± 0.16^{a}	109.0 ± 16.1^{a}	4.77 ± 0.70^{a}	2.04 ± 0.20^{a}
Mean ± SD	34.12 ± 1.14	13.19 ± 0.62	106.7 ± 14.7	4.70 ± 0.37	1.90 ± 0.16

Table 2 continued…

Accession/ cultivar	Carotenoids					Vitamin C (mg)	AOA (μmol TE)
	Violaxanthin (mg)	Neoxanthin (mg)	Lutein (mg)	α-Carotene (mg)	β-Carotene (mg)		
Soybean sprouts							
VI015437	0.050 ± 0.002^{b}	0.0051 ± 0.0004^{b}	0.15 ± 0.02^{c}	0.0012 ± 0.0005^{b}	0.030 ± 0.005^{b}	13.00 ± 0.86^{b}	2534 ± 136^{bc}
VI015726	0.057 ± 0.009^{b}	0.0060 ± 0.0015^{b}	0.18 ± 0.04^{c}	0.0030 ± 0.0018^{ab}	0.033 ± 0.004^{b}	8.67 ± 0.93^{e}	2704 ± 371^{ab}
VI016706	0.053 ± 0.012^{b}	0.0066 ± 0.0006^{b}	0.25 ± 0.02^{b}	0.0132 ± 0.0122^{a}	0.093 ± 0.040^{a}	14.67 ± 0.56^{a}	2156 ± 131^{cd}
VI023379	0.040 ± 0.009^{b}	0.0047 ± 0.0004^{b}	0.18 ± 0.02^{c}	0.0015 ± 0.0008^{b}	0.043 ± 0.004^{b}	10.67 ± 0.28^{cd}	1795 ± 282^{d}
AVSB8001	0.050 ± 0.015^{b}	0.0068 ± 0.0024^{b}	0.26 ± 0.05^{ab}	0.0038 ± 0.0052^{ab}	0.050 ± 0.000^{b}	9.67 ± 1.47^{de}	3049 ± 291^{a}
AVSB9301	0.087 ± 0.013^{a}	0.0093 ± 0.0005^{a}	0.31 ± 0.00^{a}	0.0043 ± 0.0017^{ab}	0.053 ± 0.016^{b}	11.30 ± 0.63^{c}	2761 ± 515^{ab}
Mean ± SD	0.056 ± 0.017	0.0064 ± 0.0019	0.22 ± 0.06	0.0045 ± 0.0062	0.050 ± 0.026	11.33 ± 2.23	2500 ± 502
Vegetable soybean							

VI015726	0.053 ± 0.003^{a}	0.050 ± 0.001^{bc}	0.25 ± 0.01^{ab}	0.023 ± 0.007^{ab}	0.043 ± 0.015^{a}	25.79 ± 5.09^{a}	2853 ± 255^{a}
VI022144	0.070 ± 0.011^{a}	0.043 ± 0.005^{c}	0.19 ± 0.02^{b}	0.013 ± 0.005^{b}	0.043 ± 0.015^{a}	21.38 ± 5.66^{a}	2651 ± 284^{a}
AVSB8001	0.063 ± 0.022^{a}	0.057 ± 0.010^{b}	0.28 ± 0.06^{ab}	0.013 ± 0.005^{b}	0.047 ± 0.021^{a}	25.22 ± 1.66^{a}	3061 ± 509^{a}
AVSB9301	0.083 ± 0.021^{a}	0.077 ± 0.009^{a}	0.32 ± 0.06^{a}	0.030 ± 0.009^{a}	0.050 ± 0.011^{a}	22.89 ± 1.90^{a}	3042 ± 333^{a}
Mean ± SD	0.067 ± 0.018	0.057 ± 0.014	0.26 ± 0.06	0.020 ± 0.009	0.046 ± 0.014	23.82 ± 3.89	2902 ± 352

[1] Values are means ± standard deviation. Means within a column with different upper case letters are significantly different at $P < 0.05$. [2] standard deviation.

Table 3

Content[1] of isoflavones in soybean sprouts and vegetable soybean (mg per 100 g edible portion of fresh weight).

Accession / cultivar	Genistein	Daidzein	Glycitein	Genistin	Daidzin
Soybean sprouts					
VI015437	0.71 ± 0.03^{b}	0.24 ± 0.02^{b}	0.007 ± 0.002^{b}	3.27 ± 0.14^{c}	6.43 ± 0.45^{a}
VI015726	0.52 ± 0.10^{b}	0.15 ± 0.03^{c}	n.d.[2]	2.15 ± 0.44^{d}	3.41 ± 0.62^{c}
VI016706	0.58 ± 0.16^{b}	0.32 ± 0.02^{a}	0.017 ± 0.001^{b}	3.74 ± 0.11^{b}	4.55 ± 0.08^{b}
VI023379	0.24 ± 0.02^{c}	0.12 ± 0.01^{c}	0.027 ± 0.001^{a}	1.55 ± 0.03^{e}	1.74 ± 0.11^{d}
AVSB8001	1.04 ± 0.22^{a}	0.33 ± 0.01^{a}	0.013 ± 0.005^{b}	5.04 ± 0.32^{a}	6.86 ± 0.29^{a}
AVSB9301	0.64 ± 0.03^{b}	0.22 ± 0.01^{b}	n.d.	3.93 ± 0.14^{b}	4.58 ± 0.11^{b}
Mean ± SD[3]	0.62 ± 0.27	0.23 ± 0.08	0.011 ± 0.008	3.28 ± 1.21	4.59 ± 1.81
Vegetable soybean					
VI015726	n.d.	n.d.	n.d.	0.63 ± 0.06^{b}	0.74 ± 0.25^{b}
VI022144	n.d.	n.d.	n.d.	2.25 ± 0.23^{a}	1.66 ± 0.06^{a}
AVSB8001	n.d.	n.d.	n.d.	0.79 ± 0.22^{b}	0.63 ± 0.21^{b}
AVSB9301	n.d.	n.d.	n.d.	0.59 ± 0.16^{b}	0.51 ± 0.07^{b}
Mean ± SD	n.d.	n.d.	n.d.	1.07 ± 0.73	0.89 ± 0.50

Table 3 continued….

Accession / cultivar	Glycitin	6”-O-Malonyl genistin	6”-O-Malonyl daidzin	6”-O-Malonyl glycitin	Total isoflavones
Soybean sprouts					
VI015437	1.91 ± 0.03^{a}	61.06 ± 1.98^{b}	59.20 ± 1.52^{a}	9.81 ± 0.18^{a}	142.61 ± 2.30^{b}
VI015726	0.48 ± 0.06^{e}	51.62 ± 10.19^{c}	33.64 ± 5.95^{c}	3.73 ± 0.28^{e}	95.70 ± 17.19^{d}
VI016706	0.80 ± 0.04^{c}	49.94 ± 2.40^{c}	33.99 ± 1.29^{c}	6.38 ± 0.16^{c}	100.48 ± 3.67^{d}
VI023379	1.17 ± 0.04^{b}	25.14 ± 1.00^{d}	15.16 ± 0.90^{d}	9.72 ± 0.14^{a}	54.87 ± 2.12^{e}
AVSB8001	1.26 ± 0.09^{b}	81.98 ± 2.96^{a}	53.12 ± 2.64^{b}	8.33 ± 0.44^{b}	157.97 ± 6.51^{a}
AVSB9301	0.70 ± 0.03^{d}	67.62 ± 4.53^{b}	34.15 ± 2.69^{c}	4.36 ± 0.07^{d}	116.21 ± 7.44^{c}
Mean ± SD	1.05 ± 0.48	56.23 ± 18.50	38.21 ± 15.06	7.05 ± 2.50	111.28 ± 35.17
Vegetable soybean					
VI015726	0.83 ± 0.17^{b}	15.80 ± 0.93^{b}	13.12 ± 0.81^{b}	5.89 ± 0.34^{a}	37.02 ± 2.53^{b}
VI022144	1.27 ± 0.09^{ab}	35.91 ± 2.56^{a}	21.09 ± 1.45^{a}	6.52 ± 0.80^{a}	68.71 ± 4.56^{a}
AVSB8001	1.97 ± 0.56^{a}	23.56 ± 7.01^{b}	11.66 ± 2.78^{b}	10.91 ± 3.27^{a}	49.52 ± 14.00^{ab}
AVSB9301	1.45 ± 0.58^{ab}	17.85 ± 6.04^{b}	8.77 ± 2.56^{b}	7.91 ± 3.97^{a}	37.08 ± 13.38^{b}
Mean ± SD	1.38 ± 0.55	23.28 ± 9.15	13.66 ± 5.09	7.81 ± 3.00	48.08 ± 16.00

[1] Values are means ± standard deviation. Means within a column with different upper case letters are significantly different at *P*< 0.05. An absence of letters indicates no significant difference was observed. [2] not detected; [3] standard deviation.