Amaranth sprouts and microgreens – a homestead vegetable production option to enhance food and nutrition security in the rural-urban continuum

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ABSTRACT

Traditional vegetables and vegetable legumes can be a source of readily available daily sustenance when grown in home or kitchen gardens. Lower income groups that lack access to or cannot afford global vegetables and animal protein sources would benefit greatly from the increased availability and consumption of traditional vegetables. Phytonutrient levels of edible parts differ according to the growth stages of the plant and often decrease from the seedling (sprout or microgreen) to the fully developed stage. Sprouts and microgreens can easily be grown in urban or peri-urban settings where land is often a limiting factor, either by specialized vegetable farmers or the consumers themselves. Given their short growth cycle, sprouts and microgreens can be grown without soil and without external inputs like fertilizers and pesticides, around or inside residential areas.

Seedlings from semi-domesticated or even wild species typically have high levels of phytonutrients, good flavor, and tender texture. Several crops or different varieties of the same crop can be mixed to create attractive combinations of textures, flavors, and colors. As sprouts and microgreens are usually consumed raw, there is no loss or degradation of heat-sensitive micronutrients through food processing. AVRDC is currently studying potential differences in the levels of essential micronutrients, bioactive compounds, and consumer preferences of selected traditional vegetables and vegetable legumes at different growth and consumption stages.

The results obtained with amaranth are reported in this paper. Amaranth is increasingly becoming popular as a nutrient-dense leafy green beyond Asia and the Caribbean (Saelinger 2013). The phytonutrient content was assessed at three stages: (a) sprouts, (b) microgreens, and (c) fully grown plants. The comparison included landraces from the AVRDC Genebank and commercially available cultivars. This work may expand the use of genebank materials for specialty produce such as sprouts and microgreens with great potential to improve food and nutrition security for people living in urban and peri-urban settings.

Keywords

Traditional vegetables, sprouts, microgreens, food and nutrition security, rural-urban continuum

INTRODUCTION

Diet-related diseases such as obesity, diabetes, cardiovascular disease, hypertension, stroke, and cancer are escalating both in developed and developing countries, in part due to imbalanced food consumption patterns. Health experts are convinced of the multiple benefits of consuming vegetables and fruit on a regular basis and the World Health Organization recommends that people eat at least 400 grams of fruit and vegetables a day (WHO/FAO 2005), while the World Cancer Research Fund would like to see the consumption of fruit and non-starchy vegetables to beat least 600 grams per day (WCRF/AICR 2007). Based on a published meta-analysis of nutritional epidemiology studies it was estimated that approximately 20,000 cancer cases per year could be prevented in the U.S. by increasing fruit and vegetable consumption by 160 g/person/day (Reiss et al. 2012). Another large study conducted by Boffetta et al. (2010) included nearly half a million persons in Europe and covered all cancer types. The authors concluded that with an average increase of fruit and vegetable consumption of approximately 150 g/d, 2.6% cancers in men and 2.3% cancers in women could be avoided. Looking at specific cancers for which there is good evidence for a benefit from fruit and vegetable consumption, the cancer avoidance effect could be much higher.

One of the most valuable benefits of traditional leafy vegetables is their high content of vitamins, minerals, fiber and other micronutrients essential for human health. Many traditional vegetables contain high levels of β-carotene and vitamin C, and in general have higher vitamin E, folate, calcium, iron, and zinc content and higher antioxidant activity compared with global vegetables (Yang and Keding 2009). Including traditional vegetables in the diet has great potential to combat malnutrition and improve overall health. Lower income groups for whom traditional vegetables are more affordable than common global vegetables or animal meat products will benefit greatly from increased availability and consumption of traditional vegetables.

The high nutritional value of many traditional fruits and vegetables has inspired Unilever to assemble a scientific consortium to identify ‘pre-domesticated’ varieties of crops (mainly fruits and vegetables) that have been changed very little by breeding and might contain significantly higher levels of nutrients than the varieties currently used for food production (Unilever 2012). This conclusion is supported by a review study conducted on 43 garden crops based on United States Department of Agriculture (USDA) food composition data, which revealed a statistically reliable decline of six nutrients (protein, Ca, P, Fe, riboflavin and ascorbic acid) between 1950 and 1999 (Davis et al. 2004). These changes might be due to the replacement of older, more nutritious cultivars with modern ones. Similar trends have been observed in wheat grain (Garvin et al. 2006; Fan et al. 2008) and potato tubers (White et al. 2009). Breeding and selection for high yield may have led to a decline in some essential nutrients.

Phytonutrient levels differ according to the growth stages of the plant and often decrease from the seedling (sprout, microgreen) to the fully developed stage (van Hofsten 1979; Barillari et al. 2005; Nakamura et al. 2001; Ebert 2013a,b). In addition to their high nutritional value, microgreens are considered functional foods with particular health-promoting or disease-preventing properties (Samuoliene et al. 2012). Sprouts and microgreens can be easily produced in urban or peri-urban settings where land is often a limiting factor, either by specialized vegetable farmers or the consumers themselves. Given their short growth cycle, sprouts and microgreens can be grown without soil and without external inputs like fertilizers and pesticides, around or inside residential areas. Moreover, sprouts and microgreens are usually consumed raw, hence there is no loss or degradation of micronutrients through food processing.

Through a new project funded by the Council of Agriculture of Taiwan, AVRDC is studying the levels of essential micronutrients and consumer preferences of selected legume crops (mungbean, soybean) and traditional vegetables (amaranth, mustard, radish) at different growth and consumption stages: (a) sprouts; (b) microgreens - seedlings harvested when the first true leaves appear, and (c) fully grown plants at the usual consumption stage. All five crops are well represented in AVRDC's genebank. The comparison included landraces from the AVRDC genebank and modern cultivars available commercially. Due to the large amount of data, the results reported in this paper are limited to amaranth.

MATERIALS AND METHODS

Plant materials and growing conditions

The following amaranth genebank accessions and commercial lines were used for the experiments:

1. VI044470: Genebank accession; species: *Amaranthus tricolor;* cultivar /pedigree: Ames 5134; origin: USA; acquisition date: March 1995.

2. VI047764: Genebank accession; species: *A. tricolor*; cultivar /pedigree: Lal Shak; origin: Bangladesh; acquisition date: June 2000.

3. 'Juan-Chih-Shing': Commercial line; purchased in June 2013 from local market in Tainan City, Taiwan.

4. 'Hung-Shing-Tsai': Commercial line; purchased in June 2013 from local market in Tainan City, Taiwan.

For the production of amaranth sprouts, seeds were soaked for 9 hours in distilled water, followed by rinsing. Seeds were then placed in a single layer on paper cloth inside perforated plastic trays, which were enclosed in solid plastic boxes for drainage of excess water and to maintain high moisture content for sprout growth. The boxes were kept at room temperature at 26±2^{o}C. The seedlings were carefully watered twice daily. Plant samples were harvested in three replicates at 7 days after sowing for nutritional analysis (Table 1). Another sample was taken at 8 days after sowing for consumer assessment of the produce.

For microgreen production, a mixture of peat moss and vermiculite at a 3:1 ratio was used as substrate. Seed was mixed with sand and broadcast in plastic trays. The substrate was kept moist and the plastic trays were placed on benches inside a greenhouse with a water wall and fan to keep temperatures in the range of 26±2^{o}C. Plant samples were harvested in three replicates at 9 days after sowing for nutritional analysis and consumer assessment (Table 1).

For open field production, seeds were broadcast in field plots at the beginning of October and harvested at the full vegetative growth stage (28 days after sowing) for nutritional analysis and consumer evaluation (Table 1).

Consumer evaluation

Plant samples were assessed at three growth/consumption stages (sprouts, microgreens, fully grown leafy vegetable) for consumer evaluation of sensory aspects, such as appearance, color, texture, aroma, sweetness, bitterness, taste, and general acceptability. Each parameter was rated on a scale from 1-5 with the following attributes: 1 = dislike extremely; 2 = dislike slightly; 3 = neither like nor dislike; 4 = like slightly; 5 = like extremely. Volunteers composed of AVRDC employees and their relatives, trainees and students rated the produce. Sprouts were rated by 53 consumers (36 female; 17 male), microgreens by 34 consumers (23 female; 11 male) and fully grown leafy amaranth by 53 consumers (37 female; 16 male).

For statistical analysis of the consumer acceptance data, Friedman's two-way nonparametric ANOVA was used. The least squares means were adjusted for multiple comparisons of the acceptance rank means of the test varieties using Tukey's Honestly Significant Difference (HSD) test.

Nutritional analysis

About 100-200 g of sprouts, 100-200 g of microgreens and at least 600 g of fully grown plants of each vegetable variety were sent to the AVRDC nutrition laboratory for sample preparation and nutritional analysis. Plant samples were cleaned with distilled water and surface water was removed; plant parts were cut and mixed thoroughly for sampling. Samples were weighed, freeze dried, ground into fine powder and stored at -20 ^{o}C for subsequent analyses.

The protein content was measured with micro-Kjeldahl digestion followed by distillation method (AOAC 1990a). The determination of calcium, iron and zinc contents was performed by ashing procedure, strong acid washing, followed by Atomic Absorption Spectroscopy (AOAC1990b). The determination of total ascorbic acid was carried out as described by Hanson et al. (2004) 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. Carotenoids including a-carotene, β-carotene, neoxanthin, and lutein were analyzed using high performance liquid chromatography (HPLC) (Hanson et al. 2004). Simple phenolic acids including caffeic acid, chlorogenic acids and flavonoids were analyzed using HPLC as described by Yang et al. (2008). Carotenoids, phenolic acids and flavonoids were identified and quantified with commercial standards. Antioxidant activity was measured using 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) radical (Re et al. 1999) and expressed as Trolox equivalent (TE). Details were described by Yang et al. (2006).

RESULTS AND DISCUSSION

Consumer evaluation of amaranth sprouts, microgreens and fully grown leafy amaranth

Sprouts of genebank accession VI044470 from USA (variety 1) and commercial cultivar 'Juan-Chih-Shing' from Taiwan (variety 3) were consistently preferred by consumers in terms of appearance, texture and taste as well as general acceptability (Fig. 1). High scores for taste and general acceptance were also given for the second commercial cultivar 'Hung-Shing-Tsai' from Taiwan.

Microgreens of genebank accession VI047764 from Bangladesh were highly appreciated in terms of appearance, but disappointing in terms of texture, taste and general acceptability (Fig. 2). Genebank accession VI044470 and commercial cultivar 'Hung-Shing-Tsai' received the highest rating for texture, taste and general acceptability.

Genebank accession VI044470 and 'Juan-Chih-Shing' consistently received highest ratings for appearance, texture, taste and general acceptability at the fully grown stage (Fig. 3). These same two varieties were clearly preferred at the sprouting stage as well. Only at the microgreen stage did the second commercial cultivar 'Hung-Shing-Tsai' receive slightly better ratings.

Significant differences among the four varieties were detected at all three growth stages with regard to different parameters such as appearance, taste, texture and general acceptability, indicating that consumers were able to perceive differences in sensory attributes.

Nutritional analysis of amaranth sprouts, microgreens and fully grown leafy amaranth

Mean dry matter and protein content was highest in fully grown leafy amaranth, followed by amaranth sprouts, while—surprisingly—amaranth microgreens had the lowest dry matter and protein content (Tables 2,4,6), although they were grown for nine days compared with sprouts grown for seven days only. Among 25 types of microgreens assessed by Xiao and co-workers (2012), garnet amaranth microgreens showed a relatively high dry weight percentage of 9.3, much closer to the dry matter content determined for fully grown leafy amaranth and amaranth sprouts in our trials.

Mean protein, Fe and Zn content was also considerably higher in amaranth sprouts compared with amaranth microgreens (Tables 2,4). Only the mean calcium content of amaranth microgreens was 1.6-fold higher than that in amaranth sprouts. Microgreens of the genebank accession VI044470 and commercial cultivar 'Hung-Shing-Tsai' had the highest calcium levels (Table 4). The zinc content of amaranth sprouts of three varieties was almost identical, only accession VI044470 presented a lower content (Table 2). Sprouts of 'Juan-Chih-Shing' and 'Hung-Shing-Tsai' presented the highest iron and calcium content, respectively. Zinc content of amaranth leaves at fully grown stage was similar to that in amaranth sprouts, while iron and calcium content was 1.9-fold and 7.8-fold higher, respectively (Tables 2,6). Compared with microgreens, calcium content was still 5-fold higher in fully grown amaranth leaves (Tables 4,6).

Vitamin C or ascorbic acid is an essential nutrient for the human body—it is required for the biosynthesis of collagen, carnitine and neurotransmitters (Naidu 2003). While most plants and animals have the ability to synthesize ascorbic acid, apes and humans depend on the intake of this essential nutrient through fruit and vegetables or supplementation in the form of tablets. Health benefits attributed to vitamin C include antioxidant, anti-aetherogenic, anti-carcinogenic, and immunomodulator effects. Rose and Bode (1993) mention three principal reasons that enable ascorbate to assume a prominent role as scavenger of free radicals in the human body: (a) it is chemically suited to react with oxidizing free radicals; (b) it is present in the body at sufficiently high concentrations to be effective; (c) it fits into the physiology of cellular transport and metabolism, and thus contributes to the potential for longevity. The recommended daily allowances (RDA) for adults are 90 mg of ascorbic acid per day for men and 75 mg for women (Frei and Traber 2001). Based on clinical and epidemiological studies reduced incidence of mortality from heart diseases, stroke and cancer can be expected with a dietary intake of 100 mg ascorbic acid per day (Carr and Frei 1999).

There was a substantial increase in vitamin C content from amaranth sprouts to microgreens (2.7-fold) and from amaranth microgreens to fully grown leafy amaranth (2.9-fold) (Tables 3,5,7). Consuming 100 g of leafy amaranth at the fully grown stage would provide 79% of RDA for women. There were statistical differences among varieties at the sprout stage and both genebank accessions had the highest vitamin C content (Table 3). At the microgreen and fully grown stage no statistical difference among varieties was noted. Much higher (6.5-fold) total ascorbic acid concentrations were detected by Xiao et al. (2012) in commercially grown garnet amaranth microgreens compared with the concentrations found in our experiments. Among 25 commercially grown microgreen crops, amaranth had the second highest total ascorbic acid content (131.6 mg/100 g FW) after red cabbage in the trials conducted by the aforementioned authors. These vitamin C concentrations are much higher than those commonly reported for mature amaranth leaves ranging from 11.6-45.3 mg/100 g FW (Punia et al. 2004; Mensah et al. 2008). The USDA National Nutrient Database for Standard Reference, Release 23 indicated a vitamin C content of 43.3 mg and 41.1 mg per 100 g FW of edible portion of raw and cooked amaranth leaves, respectively (Ebert et al. 2011), thus falling within the range reported by Punia et al. (2004) and Mensah et al. (2008). Mean vitamin C content of fully grown amaranth leaves reached 59 mg in our trials, thus slightly above the aforementioned levels.

Higher plants exhibit a relatively uniform carotenoid composition and a small number of carotenoids, i.e., the β-carotene, the xanthophylls lutein and neoxanthin as well as those involved in the xanthyphyll cycle (violaxanthin, antheraxanthin, and zeaxanthin), which are ubiquitously present in the photosynthetic membranes of higher plants (Young 1993). The α-carotene is less frequent, but can also be found in a number of plant species. Both, α-carotene and β-carotene are called provitamin A as they can be easily converted by the human body into vitamin A, which is important for maintenance of visual acuity. Carotenoids are the first line of defense against photo-oxidative stress in plants, given their capacity to quench singlet oxygen as well as triplet chlorophylls through a physical mechanism involving transfer of excitation energy followed by thermal deactivation (Ramel et al. 2012). Another mechanism is known as chemical quenching and involves a chemical reaction between the quencher and singlet oxygen.

Both provitamins A (α-carotene and β-carotene) were detected in all three developmental stages and considerably increased from sprouts to microgreens (Tables 3,5). Microgreens of the genebank accession VI044470 had the highest α-carotene and β-carotene content. The level of α-carotene of microgreens of this accession was higher than those found in mature amaranth leaves, while the β-carotene content was similar in microgreens and mature leaves. The β-carotene content of amaranth microgreens reported earlier was 4.6-fold higher (8.6 mg/100 g FW) than found in our experiments and red sorrel microgreens showed even higher β-carotene content of up to 12.1 mg/100 g FW (Xiao et al. 2012).

Violaxanthin, a natural orange-colored carotenoid found in photosynthetic organs of plants, was analyzed in amaranth sprouts but found to be below detectable levels. It reached 0.91 and 1.75 mg/100 g FW in amaranth microgreens and fully grown amaranth leaves, respectively (Tables 5,7)—again much lower than the violaxanthin levels (4.4. mg/100 g FW) reported by Xiao et al. (2012). Neoxanthin was found at all three growth stages, with substantially higher levels at the microgreen and fully grown stage compared to amaranth sprouts (Tables 3,5,7).

Lutein and zeoxanthin are macular pigments that act as optical filters and play a critical role in the prevention of age-related macular degeneration (Beatty et al. 1999).

Macular pigment is entirely of alimentary origin and its density can be augmented through dietary modification. Apart from restricting photochemical retinal injury by screening blue light, macular pigment might also play a role in limiting oxidative damage by quenching reactive oxygen species. The lutein content increased substantially from amaranth sprouts to microgreens (2.18 mg/100 g FW), but was still slightly lower in the latter compared to fully grown amaranth leaves (Tables 3,5,7). These concentrations are again in contrast to the findings of Xiao et al. (2012), who reported 8.4 mg/100 g FW of lutein/zeoxanthin in amaranth microgreens. Microgreens of genebank accession VI044470 and cultivar 'Hung-Shing-Tsai' showed the highest lutein and neoxanthin content (Table 5).

Highly reactive free radicals and oxygen species are inevitably produced in biological systems and are also encountered exogenously. They may oxidize nucleic acids, proteins, lipids or DNA and are known to cause various degenerative disorders, such as Alzheimer's disease, Parkinson's disease, cardiovascular disturbances, cancer, and aging (Prakash et al. 2001; Uttara et al. 2009). Antioxidants are considered a persuasive therapeutic option to combat neurodegenerative diseases given their capability to neutralize free radicals. Fruits, vegetables and herbs contain a wide range of antioxidants comprising phenolic compounds, such as phenolic acids, flavonoids, quinons, coumarins, lignans, tannins, etc.; nitrogen compounds, such as alkaloids, amines, betalains, etc.; vitamins; terpenoids including carotenoids and other endogenous compounds that have a high antioxidant activity (Uttara et al. 2009; Samuoliene et al. 2012). The antioxidant activity is commonly expressed in micromoles of Trolox equivalents (TE) per 100 g (Prakash et al. 2001).

Surprisingly, the antioxidant activity (AOA) of amaranth sprouts was much higher than that of amaranth microgreens and was highest in fully grown leaves reaching 1924 µmol TE with variety 'Hung-Shing-Tsai' (Tables 3,5,7). While sprouts of genebank accession VI044470 had a relatively low AOA, the other three varieties had a high AOA ranging from 1355 TE to 1491 TE—about double the antioxidant activity measured in amaranth microgreens, on average. Microgreens of VI044470 showed only a slight decrease in AOA compared with sprouts, in contrast to the other three varieties.

Hydroxycinnamic acid compounds are an important source of antioxidants and are usually found as esters of organic acid or glycosides in plants or are bound to protein and cell wall polymers (Chen and Ho 1997). These compounds, which include caffeic acid and chlorogenic acid, have a significant effect on stability, color, flavor and nutritional value of food. Caffeic acid concentration notably increased from amaranth sprouts to microgreens to fully grown amaranth leaves (Tables 3,5,7). Chlorogenic acid was detected only in microgreens of genebank accession VI047764 and was below detectable levels in the other three varieties. Chlorogenic acid was not detected in amaranth sprouts and fully grown leaves.

SUMMARY AND CONCLUSION

Genebank accession VI044470 and commercial cultivar 'Juan-Chih-Shing' consistently received the highest ratings for appearance, texture, taste and general acceptability at the sprout and at the fully grown stage. At the microgreen stage, VI044470 and 'Hung-Shing-Tsai' received the highest ratings.

The phytonutrient content showed significant differences among varieties within the same growth stage and also differed between growth stages. Mean protein, Fe and Zn content was considerably higher in amaranth sprouts compared with amaranth microgreens. There was a substantial increase in vitamin C content from amaranth sprouts, to microgreens (2.7-fold) and from amaranth microgreens to fully grown leafy amaranth (2.9-fold). Both provitamins A, α-carotene and β-carotene were detected in all three developmental stages and considerably increased from sprouts to microgreens. The content of α-carotene was the same at the microgreen and fully developed stage, while β-carotene content was slightly higher at the latter stage.

Sprouts and microgreens offer a niche market for vegetable producers and can easily be grown by consumers themselves, especially in urban or peri-urban settings, providing a constant, year-round source of easily accessible, fresh and nutrient-dense produce and serving as educational and therapeutic tool for children in the homestead. Given their extremely short growth cycle, sprouts and microgreens can easily be grown organically, without external inputs like fertilizers and pesticides.

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Table 1. Timetable for production and harvesting of amaranth sprouts, microgreens and fully grown leafy amaranth in 2013

Dates	**Sprouts**	**Microgreens**	**Fully grown stage**
Sowing for nutritional analysis	3 July 2013	2 July 2013	1 October 2013
Harvesting of samples for nutritionalanalysis	10 July 2013	11 July 2013	29 October 2013
Sowing for consumer evaluation	18 July 2013	2 July 2013	1 October 2013
Harvesting of samples for consumer evaluation	26 July 2013	11 July 2013	29 October 2013
Consumer evaluation	26 July 2013	12 July 2013	29 October 2013

Table 2. Dry matter, protein and minerals of amaranth sprouts per 100 g edible portion of fresh weight

Accession/cultivar	**Dry matter (g)**	**Protein (g)**	**Minerals**		
			Ca (mg)	**Fe (mg)**	**Zn (mg)**
VI044470	6.13[b]	1.91[b]	48.60[c]	0.92[c]	0.43[b]
VI047764	8.80[a]	2.19[ab]	27.82[d]	1.17[bc]	0.52[a]
Juan-Chih-Shing	8.64[a]	2.31[a]	60.85[b]	1.68[a]	0.53[a]
Hung-Shing-Tsai	8.98[a]	2.42[a]	71.33[a]	1.47[ab]	0.52[a]
Mean	8.14	2.21	52.15	1.31	0.50

Values within a column with different letters are significantly different at $P < 0.05$.

Table 3. Carotenoid, vitamin C, antioxidant activity (AOA) and caffeic acid content of amaranth sprouts per 100 g edible portion of fresh weight

Accession / cultivar	Carotenoids					Vitamin C (mg)	AOA (µmol TE)	Caffeic acid (µmol)
	Violaxanthin (mg)	Neoxan-thin (mg)	Lutein (mg)	α-carotene (mg)	β-carotene (mg)			
VI044470	0.00	0.04[a]	0.46[a]	0.01[a]	0.10[a]	8.00[a]	823.00[b]	4.95[a]
VI047764	0.00	0.03[a]	0.43[a]	0.01[a]	0.11[a]	9.98[a]	1442.00[a]	4.79[a]
Juan-Chih-Shing	0.00	0.02[b]	0.38[a]	0.01[a]	0.11[a]	5.00[b]	1355.33[a]	5.26[a]
Hung-Shing-Tsai	0.00	0.02[b]	0.45[a]	0.01[a]	0.10[a]	7.00[ab]	1490.67[a]	5.92[a]
Mean	0.00	0.03	0.43	0.01	0.10	7.59	1277.67	5.23

Values within a column with different letters are significantly different at $P < 0.05$.

Table 4. Dry matter, protein and minerals per 100 g edible portion of fresh weight in amaranth microgreens

Accession/cultivar	Dry matter (g)	Protein (g)	Minerals		
			Ca (mg)	Fe (mg)	Zn (mg)
VI044470	5.33[a]	1.38[ab]	91.00[a]	1.04[a]	0.34[ab]
VI047764	4.43[c]	1.26[b]	69.33[b]	0.71[a]	0.32[b]
Juan-Chih-Shing	4.70[bc]	1.35[ab]	74.33[b]	0.82[a]	0.39[a]
Hung-Shing-Tsai	5.13[ab]	1.55[a]	91.33[a]	1.27[a]	0.37[a]
Mean	4.89	1.39	81.50	0.96	0.36

Values within a column with different letters are significantly different at $P < 0.05$.

Table 5. Carotenoids, vitamin C, antioxidant activity (AOA), chlorogenic acid and caffeic acid content of amaranth microgreens per 100 g edible portion of fresh weight

Accession / cultivar	Violaxanthin (mg)	Neoxan-thin (mg)	Lutein (mg)	α-carotene (mg)	β-carotene (mg)	Vitamin C (mg)	AOA (µmol TE)	Chlorogenic acid (µmol)	Caffeic acid (µmol)
VI044470	0.77[c]	1.00[a]	2.66[a]	0.35[a]	2.34[a]	23.33[a]	639.33[bc]	0.00[b]	14.52[c]
VI047764	0.67[c]	0.75[b]	1.95[b]	0.13[c]	1.87[b]	19.00[a]	567.67[c]	0.35[a]	12.89[d]
Juan-Chih-Shing	0.99[b]	0.62[b]	1.64[b]	0.10[c]	1.37[c]	19.49[a]	680.33[b]	0.00[b]	21.09[a]
Hung-Shing-Tsai	1.20[a]	0.98[a]	2.66[a]	0.27[b]	1.91[b]	18.67[a]	782.67[a]	0.00[b]	16.79[b]
Mean	0.91	0.84	2.18	0.21	1.87	20.13	667.50	0.09	16.32

Values within a column with different letters are significantly different at $P < 0.05$.

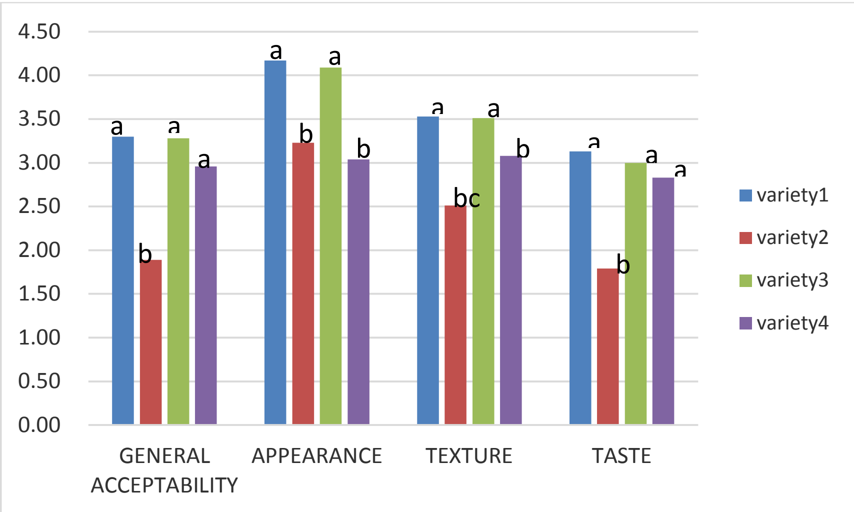
Table 6. Dry matter, protein, oxalate and minerals per 100 g edible portion of fresh weight of amaranth at fully grown stage

Accession/cultivar	Dry matter (g)	Protein (g)	Oxalate (mg)	Minerals		
				Ca (mg)	Fe (mg)	Zn (mg)
VI044470	10.65[a]	2.98[a]	171.38[a]	443.54[a]	2.76[a]	0.42[b]
VI047764	8.96[b]	2.82[b]	287.27[a]	337.31[c]	2.02[c]	0.56[a]
Juan-Chih-Shing	9.39[b]	2.65[c]	249.07[a]	401.27[b]	2.44[b]	0.60[a]
Hung-Shing-Tsai	10.88[a]	3.07[a]	254.17[a]	445.18[a]	2.67[ab]	0.42[b]
Mean	9.97	2.88	240.47	406.83	2.47	0.50

Table 7. Content of carotenoids, vitamin C, antioxidant activity (AOA), chlorogenic acid, and caffeic acid per 100 g edible portion of fresh weight of amaranth at fully grown stage

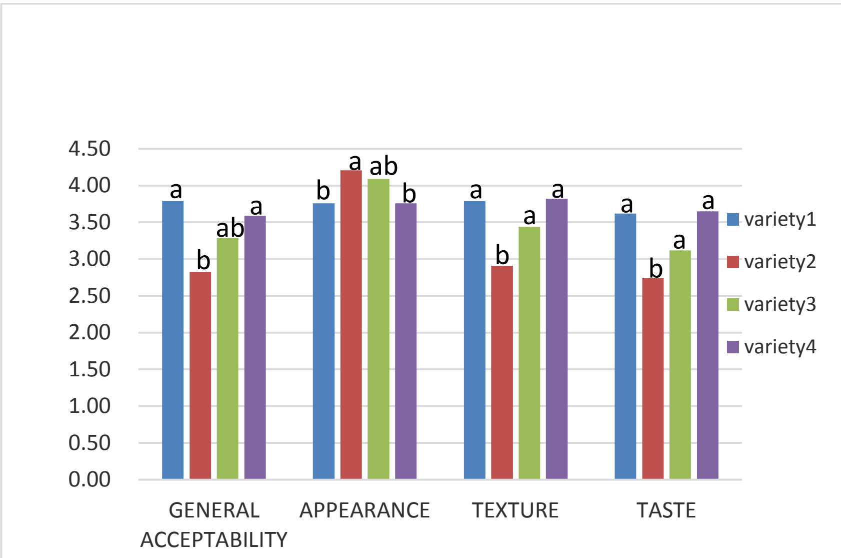
Accession /cultivar	Violaxanthin (mg)	Neoxanthin (mg)	Lutein (mg)	α-carotene (mg)	β-carotene (mg)	Vitamin C (mg)	AOA (μmol TE)	Chlorogenic acid (μmol)	Caffeic acid (μmol)
VI044470	1.43[a]	0.99[ab]	2.61[a]	0.21[a]	1.16[b]	56.33[a]	1815.72[ab]	0.00	40.51[b]
VI047764	2.03[a]	1.51[a]	4.14[a]	0.29[a]	4.45[a]	56.95[a]	1604.09[b]	0.00	39.72[b]
Juan-Chih-Shing	1.79[a]	0.72[b]	2.21[a]	0.12[a]	2.21[ab]	59.37[a]	1643.77[b]	0.00	66.81[a]
Hung-Shing-Tsai	1.75[a]	1.12[ab]	3.03[a]	0.22[a]	2.23[ab]	63.85[a]	1923.55[a]	0.00	49.39[ab]
Mean	1.75	1.09	3.00	0.21	2.51	59.12	1746.78	0.00	49.11

Values within a column with different letters are significantly different at *P*< 0.05.a



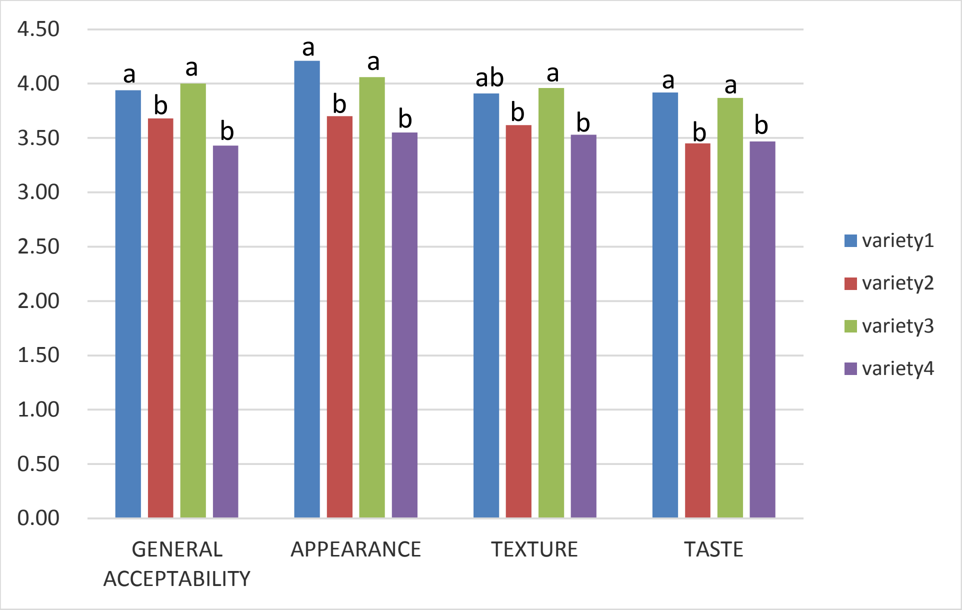
Columns headed by different letters within each of the four parameters indicate statistical difference by the LSMEANS/PDIFF at P>0.05

Figure 1. Results of consumer evaluation of amaranth sprouts



Columns headed by different letters within each of the four parameters indicate statistical difference by the LSMEANS/PDIFF at P>0.05

Figure 2. Results of consumer evaluation of amaranth microgreens



Columns headed by different letters within each of the four parameters indicate statistical difference by the LSMEANS/PDIFF at P>0.05.

Figure 3. Results of consumer evaluation of fully grown leafy amaranth