

Article

Phytonutrients, Colorant Pigments, Phytochemicals, and Antioxidant Potential of Orphan Leafy *Amaranthus* Species

Umakanta Sarker ^{1,*}, Md. Golam Rabbani ², Shinya Oba ³, Wagdy M. Eldehna ^{4,5}, Sara T. Al-Rashood ⁶, Nada M. Mostafa ^{7,†} and Omayma A. Eldahshan ^{7,†}

¹ Department of Genetics and Plant Breeding, Faculty of Agriculture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh

² Department of Horticulture, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh; drmgrabbani@yahoo.com

³ Laboratory of Field Science, Faculty of Applied Biological Sciences, Gifu University, Yanagido 1-1, Gifu 501-1193, Japan; soba@gifu-u.ac.jp

⁴ School of Biotechnology, Badr University in Cairo, Badr City 11829, Egypt; wagdy2000@gmail.com

⁵ Department of Pharmaceutical Chemistry, Faculty of Pharmacy, Kafrelsheikh University, Kafrelsheikh 33516, Egypt

⁶ Department of Pharmaceutical Chemistry, College of Pharmacy, King Saud University, P.O. Box 2457, Riyadh 11451, Saudi Arabia; salrashood@ksu.edu.sa

⁷ Department of Pharmacognosy, Faculty of Pharmacy, Ain Shams University, Cairo 11566, Egypt; nadamostafa@pharma.asu.edu.eg (N.M.M.); oeldahshan@pharma.asu.edu.eg (O.A.E.)

* Correspondence: umakanta@bsmrau.edu.bd

† These authors contributed equally to the work.

Citation: Sarker, U.; Rabbani, M.G.; Oba, S.; Eldehna, W.M.; Al-Rashood, S.T.; Mostafa, N.M.; Eldahshan, O.A. Phytonutrients, Colorant Pigments, Phytochemicals, and Antioxidant Potential of Orphan Leafy *Amaranthus* Species. *Molecules* **2022**, *27*, 2899. <https://doi.org/10.3390/molecules27092899>

Academic Editors: Alice Martins and Joaquina Pinheiro

Received: 9 April 2022

Accepted: 28 April 2022

Published: 2 May 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Abstract: The underutilized *Amaranthus* leafy vegetables are a unique basis of pigments such as β -cyanins, β -xanthins, and betalains with radical scavenging capacity (RSC). They have abundant phytonutrients and antioxidant components, such as pigments, vitamins, phenolics, and flavonoids. Eight selected genotypes (four genotypes from each species) of underutilized *Amaranthus* leafy vegetables were evaluated for phytonutrients, pigments, vitamins, phenolics, flavonoids, and antioxidants in a randomized complete block design under ambient field conditions with three replicates. The studied traits showed a wide range of variations across eight genotypes of two species of *Amaranthus* leafy vegetables. The highest fat, β -xanthins, K, dietary fiber, Mg, β -cyanins, Mn, chlorophyll *ab*, Zn, TP, TF, betalains, chlorophyll *a* content, and (RSC) (DPPH) and RSC (ABTS⁺) were obtained from *A. tricolor* accessions. Conversely, the highest protein, Cu, carbohydrates, Ca, and chlorophyll *b* content were obtained from *A. lividus* accessions. The highest dry matter, carotenoids, Fe, energy, and ash were obtained from *A. tricolor* and *A. lividus*. The accession AT2 confirmed the highest vit. C and RSC (DPPH) and RSC (ABTS⁺); AT5 had the highest TP content; and AT12 had the highest TF content. *A. tricolor* accessions had high phytochemicals across the two species, such as phytopigments, vitamins, phenolics, antioxidants, and flavonoids, with considerable nutrients and protein. Hence, *A. tricolor* accessions can be used as high-yielding cultivars comprising ample antioxidants. The correlation study revealed that vitamin C, pigments, flavonoids, β -carotene, and phenolics demonstrated a strong RSC, and showed a substantial contribution to the antioxidant potential (AP) of *A. tricolor*. The investigation exposed that the accessions displayed a plentiful origin of nutritional values, phytochemicals, and AP with good quenching ability of reactive oxygen species (ROS) that provide enormous prospects for nourishing the mineral-, antioxidant-, and vitamin-threatened community.

Keywords: underutilized leafy vegetables; proximate composition; minerals; antioxidant pigments; polyphenols; flavonoids; vitamin C; DPPH; antioxidant activity; ABTS⁺

1. Introduction

Amaranth is a promising crop with widespread divergence [1–7]. Across seventy species of the family of Amaranthaceae, 17 are consumed as vegetables, and 3 are consumed as grains [8]. Amaranth is a fast-growing C_4 plant with versatile uses, including vegetables, ornamentals, and grains. It is a widely acclimated vegetable with a wide-spread distribution in America, Australia, Africa, Europe, and Asia. It is a low-cost vegetable whose edible stems and leaves have abundant protein, including methionine and lysine (important amino acids for humans) [9–12]; digestible fiber; ascorbic acid; carotenoids; and minerals containing Ca, Cu, Mg, Zn, K, Fe, and Mn [13–37]. *Amaranthus* leafy vegetables are used as many traditional medicines, especially antimicrobial [38–48], anthelmintic [49–52], antiviral [53], neuroprotective [54], anti-inflammatory [55,56], antiulcer [57], anticancer [58–60], hepatoprotective [61–64], anti-hyperlipidemic [65–70], antidiabetic, antidepressant, antimalarial activities, and snake antidotes [71–76]. It also has abundant phytopigments, including β -cyanins, anthocyanin, β -xanthins, betalains, carotenoids, and chlorophylls [77–84] with high RSC [85–95]. It also has sufficient phytochemicals, including ascorbic acids, phenolic acids, and flavonoids [96–102] and AP [103–120]. These compounds of natural origin quench ROS [121–139], and predominantly influence the industry of foods [140,141]. Phytopigments, including β -cyanins, carotenoids, β -xanthins, betanin, and amaranthine, have the important RSC [141]. They are broadly acclimated to different abiotic stresses such as water deficits [142–150] and salinization [151–154].

There is significant variability and phenotypic plasticity of *Amaranthus* germplasms in Asia, Africa, Bangladesh, and South America [155], with versatile usages. In Africa and South-East Asia, including India and Bangladesh, amaranth is a cheap and popular leafy vegetable. The flavor, taste, and beautiful color make it a typical leafy vegetable in Asia and many global regions. It grows year-round in Bangladesh, including the leafy vegetables gap in summer [19,20].

Nowadays, both consumers and researchers give attention to consuming vegetables for achieving antioxidants of natural origin [156–159]. *Amaranthus* has significant groups of natural antioxidants, such as β -cyanin, β -xanthin, amaranthine, betalain, phenolics, carotenoids, vitamin C, and flavonoids [140,141]. These natural antioxidant phytochemicals defend against many diseases, such as atherosclerosis, emphysema, cardiovascular diseases, cancer, cataracts, arthritis, retinopathy, and degenerative diseases of neurons, and contribute significantly to human health promotion [160–162]. Natural products with AP have an extensive interest. Numerous medicinal plants having interesting AP have been proposed as protective capacities because of constituents' presence, including vitamins C, flavonoids, carotenoids, phenolics, and other non-nutrient components [163].

In the current years, our research group is investigating the opportunity of applying leafy vegetable amaranth as a foundation of natural pigments because of their ample β -cyanins, β -xanthins, betalains color pigments, and phytochemicals of interest in the food industry [77,78]. Our research group carefully chose a few high-yielding AP *A. tricolor* and *A. lividus* cultivars from the gene pool in our earlier studies [19,20,77,78]. This study evaluates the comparative performance of the selected eight best genotypes of two species of *A. tricolor* and *A. lividus*, in terms of minerals, nutrients, antioxidants phytochemicals, and pigments having high AP.

2. Materials and Methods

2.1. Materials

The seeds of eight accessions of *A. lividus* and *A. tricolor* were selected from our earlier collected germplasms.

2.2. Layout and Design

The study was implemented at Bangabandhu Sheikh Mujibur Rahman Agricultural University using a completely randomized block design (RCBD) in three replicates. Each experimental plot comprises a 1 m² area with 20 cm rows and a 5 cm plant distance.

2.3. Management Practices

We applied 150 kg MP, 200 kg urea, 100 kg TSP, 60 kg gypsum, and 10 compost (cowdung: straw = 1:2 *w/w*) per ha of land. We maintained suitable cultural management. Thinning was performed to keep the particular space of plants in a row. The experimental plots were kept free from weeds by applying appropriate and regular weeding and hoeing. We applied regular irrigation in the plot for appropriate growth of the crop. Leaf samples were collected from 30-day-old plants.

2.4. Solvent and Reagents

Solvent: Methanol and acetone. Reagents: cesium chloride, dithiothreitol (DTT), HClO₄, ascorbic acid, HNO₃, H₂SO₄, and Trolox, ABTS⁺, Folin–Ciocalteu reagent, DPPH, gallic acid, 2, 2-dipyridyl, rutin, hexahydrate aluminum chloride, K acetate, sodium carbonate, and K persulfate.

2.5. Determination of Proximate Composition

Crude fat, ash, moisture, crude protein, fiber, and energy (gross) were estimated according to the Association of Official Agricultural Chemists (AOAC) method [164]. We followed the Micro-Kjeldahl method to calculate the nitrogen, and finally, crude protein was measured by multiplying nitrogen by 6.25 (AOAC method 976.05). The crude protein, total moisture, ash, and crude fat (%) were subtracted from 100 for calculating carbohydrate (g 100 g^{−1} FW).

2.6. Determination of Minerals

In an oven, the leaves were dried out for 24 h at 70 °C. Dried samples were ground in a mill. We determined Ca, K, Mg, Fe, Mn, Cu, and Zn using the nitric and perchloric acid method [165]. A dried leaf sample (0.5 g) was digested with 10 mL H₂SO₄ (96%), 400 mL HNO₃ (65%), and 40 mL HClO₄ (70%) in the presence of carborundum beads. A blue-colored phosphomolybdenum complex was formed by adding antimony and ascorbic acid to the complex solution (yellow). Atomic absorption spectrophotometry (AAS) (Hitachi, Tokyo, Japan) was used to read the absorbance at 213.9 nm (Zn), 285.2 nm (Mg), 279.5 nm (Mn), 766.5 nm (K), 422.7 nm (Ca), 248.3 nm (Fe), and 324.8 nm (Cu).

2.7. Estimation of Carotenoids and Chlorophylls

The leaf samples were added in acetone (80%) to determine carotenoids, and chlorophyll *a*, *ab*, and *b* [165]. Carotenoids, chlorophyll *b*, and chlorophyll *a* were calculated by measuring the absorbance at 470, 663, and 646 nm, respectively, using a spectrophotometer (Hitachi, Japan).

2.8. β-Cyanins and β-Xanthins Content Measurement

β-Cyanins and β-xanthins were measured by extracting the leaf samples in 80% MeOH containing 50 mM ascorbic acid [166,167]. β-cyanins and β-xanthins were determined by measuring the absorbance at 540 and 475 nm, respectively, using a spectrophotometer (Hitachi, U-1800, Tokyo, Japan). The results of β-cyanins and β-xanthins were expressed by calculating, as nanograms, betanin and indicaxanthin equivalent per g of fresh weight for β-cyanins and β-xanthins, respectively.

2.9. Estimation of β -Carotene

We used our described method for the estimation of β -carotene [168,169]. In a mortar and pestle, 500 mg of fresh leaves was added with 10 mL acetone (80%), and ground precisely. The extract was centrifuged for 3–4 min at 10,000 \times g. After removing the supernatant in a volumetric flask, the final volume was marked up to 20 mL. A spectrophotometer (Hitachi, Tokyo, Japan) was used to take the absorbance at 510 nm and 480 nm. Data were expressed as milligrams of β -carotene per 100 g of fresh weight.

β -Carotene = $7.6 \{(\text{Abs. at } 480 \text{ nm}) - 1.49 (\text{Abs. at } 510 \text{ nm}) \times \text{Final volume}\} / (1000 \times \text{fresh weight of leaf})$

2.10. Determination of Ascorbic Acid

The fresh leaf samples were pre-incubated, and dehydroascorbic acid (DHA) was reduced to ascorbic acid (AsA) using Dithiothreitol (DTT). AsA reduced Fe^{3+} to Fe^{2+} . 2, 2-dipyridyl forms complexes with reduced Fe^{2+} [170]. The optical density was taken using a spectrophotometer (Hitachi, Japan) at 525 nm to estimate ascorbic acid (AsA). We calculated ascorbic acid in milligrams per 100 g of fresh weight.

2.11. Samples Extraction and Determination of TP, TF, and RSC

The extraction was performed from the fresh and dried ground leaves (30 d) with a mortar and pestle for total polyphenols (TP) content, total flavonoids (TF) content, and RSC determination. In a tightly capped bottle, 0.25 g of leaves were added in 10 mL MeOH (90%), and placed in a shaking water bath (Tokyo, Japan). The extract was filtered after 1 h and stored for TP, TF, and RSC. Phenolic content was determined by the Folin–Ciocalteu reagent [170]. The optical density was taken at 760 nm using a spectrophotometer (HITACHI, Japan). TP was calculated as gallic acid equivalent $\mu\text{g GAE g}^{-1}$ of FW using an equation ($Y = 0.009X + 0.019$) obtained from a standard gallic acid graph. The aluminum chloride colorimetric method was followed to estimate the total flavonoid content [170]. The optical density was measured at 415 nm using a spectrophotometer (HITACHI, Japan). A rutin standard graph ($Y = 0.013X$) was made to estimate TF as $\mu\text{g RE g}^{-1}$ DW. The RSC was estimated by the diphenyl-picrylhydrazyl (DPPH) radical degradation method [171], and ABTS $^{+}$ assay was carried out using the method of Sarker and Oba [172]. Percentage of inhibition of ABTS $^{+}$ and DPPH equivalent to the control was applied to measure the RSC using following the equation:

$$\text{RSC (\%)} = (\text{AC} - \text{AS}/\text{AC}) \times 100 \quad (1)$$

where AC is the absorbance of the control (150 μL and 10 μL MeOH for RSC (ABTS), RSC (DPPH) instead of leaf extract), and AS is the absorbance of the samples. The results were calculated as $\mu\text{g Trolox equivalent g}^{-1}$ DW.

2.12. Statistical Analysis

The replication mean was obtained by averaging the replication-wise row data. Analysis of variance (ANOVA) of the mean data was analyzed using Statistix 8 software [173–176]. Duncan Multiple Range Test at a 1% level of probability was followed to compare means data. The results were expressed as the mean \pm SD. The correlation was analyzed using Statistix 8 software.

3. Results and Discussion

The variance analysis revealed that all the parameters significantly differed regarding the accessions, indicating a wide range of variations across the genotypes of two species of *Amaranthus* leafy vegetables. An extensive range of variability was also stated in red and green color amaranth [167].

3.1. Proximate Contents

The composition of the proximate (g 100 g⁻¹ FW) of eight selected accessions of two underutilized species of *Amaranthus* leafy vegetables is shown in Table 1. The content of moisture of eight selected accessions of two underutilized *Amaranthus* leafy vegetable species varied from 82.85 to 88.52. AT2 displayed the highest moisture content (88.52) after *A. tricolor* genotype AT12 (86.43) and AT9 (86.38). Alternately, SA10 had the least moisture content (82.85), which was statistically similar to SA14, SA3, SA21, and AT5. Across eight accessions of two underutilized species, AT5, SA3, SA10, SA14, and SA21 showed low moisture content (18% dry matter). As lower moisture ensures a higher dry weight of leaves, these accessions could be used as superior dry biomass. The moisture content is directly related to the maturity of the leaves. The results obtained from underutilized species were corroborated by the reports of sweet potato leaves [177]. In comparison to leafy vegetables, the leaves of eight selected accessions of two underutilized species of *Amaranthus* leafy vegetables had good protein content that significantly varied regarding accessions (3.66 to 6.52). The highest protein content was recorded in SA14 (6.52). On the contrary, SA21 displayed the least protein content (3.66). Compared to leafy vegetables, higher protein content was obtained from AT2, AT5, AT9, AT12, SA3, and SA10. Vegetable amaranth is the primary source of protein for vegetarians and poor people in developing countries. The protein content of the accessions of two underutilized species was much more prominent as compared to *A. tricolor* (1.26%) [20].

Table 1. Proximate compositions (g 100 g⁻¹ fresh weight) of two underutilized species of *Amaranthus* leafy vegetables.

Accessions	Water (%)	Crude Protein	Crude Fat	Carbohydrate	Ash	Energy (kcal)	Fiber
<i>A. tricolor</i>							
AT2	88.52 ± 1.86 a	5.35 ± 0.04 b	0.27 ± 0.04 b	0.38 ± 0.05 h	5.48 ± 0.02 ab	25.11 ± 0.32 d	7.19 ± 0.15 d
AT5	81.92 ± 1.44 c	5.33 ± 0.05 b	0.33 ± 0.03 a	6.50 ± 0.06 d	5.62 ± 0.02 a	53.80 ± 0.31 a	9.22 ± 0.17 b
AT9	86.38 ± 1.35 b	5.37 ± 0.06 b	0.29 ± 0.03 ab	5.05 ± 0.07 f	2.91 ± 0.02 d	43.81 ± 0.38 c	10.24 ± 0.13 a
AT12	86.43 ± 1.35 b	5.32 ± 0.04 b	0.35 ± 0.04 a	4.07 ± 0.06 g	3.83 ± 0.03 c	40.71 ± 0.26 c	8.34 ± 0.12 c
<i>A. lividus</i>							
SA3	81.86 ± 1.56 c	5.35 ± 0.05 b	0.27 ± 0.04 b	7.00 ± 0.05 c	5.52 ± 0.04 ab	53.81 ± 0.36 a	8.56 ± 0.17 c
SA10	81.85 ± 1.38 c	5.34 ± 0.03 b	0.23 ± 0.03 bc	7.46 ± 0.06 b	5.12 ± 0.03 b	52.55 ± 0.42 ab	7.76 ± 0.15 cd
SA14	81.87 ± 1.51 c	6.52 ± 0.04 a	0.18 ± 0.03 c	5.87 ± 0.06 e	5.56 ± 0.04 a	53.82 ± 0.35 a	6.66 ± 0.15 e
SA21	81.91 ± 1.62 c	3.66 ± 0.04 c	0.16 ± 0.03 c	9.56 ± 0.05 a	4.71 ± 0.02 d	51.60 ± 0.36 b	9.18 ± 0.12 b
Significance	**	**	**	**	**	**	**
CV%	2.36	1.35	0.24	0.66	0.55	0.75	0.38

CV, coefficient of variation; in a column, different letters in mean values are significantly differed by Duncan Multiple Range Test (**, $p < 0.01$); $n = 3$.

In this investigation, the selected accessions of two underutilized species displayed lesser fat, owing to leafy vegetables, and they might be utilized as foods free from cholesterol. AT12 confirmed the highest fat (0.35), although SA21 had the least fat (0.16) that had a statistical similarity with SA14. The results of sweet potato [177] were corroborated with our current results. They stated that fat covering the body's organs influences cell function and perpetuation body temperature. Vegetable fats are the primary sources of essential fatty acids, such as omega-6 and omega-3. Fats play a significant role in the absorption, digestion, and transport of vitamins E, D, A, and K, which are soluble in fats. The selected accessions of two underutilized species confirmed good carbohydrate content with ample variations regarding accessions (0.38 to 9.56). SA21 confirmed the highest carbohydrates (9.56), though AT2 had the least carbohydrates (0.38). The accessions of two underutilized species were principally diverse for energy (28.95 to 58.47). The accession AT5, SA3, and

SA14 demonstrated the highest energy (53.80, 53.81, and 53.82, respectively). On the other hand, AT2 displayed the least energy (25.11). AT5 and SA14 exhibited the highest ash (5.62 and 5.56, respectively), whereas AT9 showed the least ash (2.91). Fiber was largely diverse among accessions (6.66 to 10.24). AT9 confirmed the highest fiber (10.24) after AT5 and SA21. Inversely, SA14 had the least fiber (6.66). Fiber had a noteworthy involvement in the cure of constipation, the augmentation of digestibility, and palatability [19]. Our results displayed that those leaves of selected accessions of two underutilized species have copious protein, moisture, carbohydrates, and digestible fiber. The highest fat and fiber were obtained from *A. tricolor* accessions. Similarly, the highest protein and carbohydrates were obtained from *A. lividus* accessions. The highest dry matter, energy, and ash were obtained from both *A. tricolor* and *A. lividus* accessions. The moisture and protein contents received from accessions were superior to the moisture and protein contents of the green, red, stem, and weedy amaranth and *A. blitum* [178–182]. The carbohydrates of advanced line AT7 were greater than red, green amaranth, *A. spinosus*, and *A. blitum* [178–180,182], although the carbohydrates of AT7 were corroborative with stem amaranth [181]. The fiber of AT3 and AT7 were superior to red, stem, and green amaranth and *A. blitum* [178,180–182], although corroborated by weedy amaranth [179].

3.2. Mineral Content

Macroelements (mg g⁻¹ FW) and microelements (µg g⁻¹ FW) of eight selected accessions of two underutilized species of *Amaranthus* leafy vegetables are shown in Table 2. The selected accessions of two underutilized species demonstrated good K content. AT12 had the highest K content (6.72) after AT2, AT5, and AT9. On the contrary, the highest K content was recorded in SA14 and SA21 (3.77 and 3.72, respectively). SA3 showed the highest Ca content (3.45) after AT2, AT9, and AT12. Inversely, SA21 displayed the least Ca (1.56). The accessions of two underutilized species demonstrated good Mg content with prominent variations regarding accessions (2.65 to 3.74). AT12 confirmed the highest Mg (3.62). Inversely, AT7 confirmed the lowest Mg (3.74) after AT2, AT5, and AT9. It exposed that sufficient K (6.72), Mg (3.74), and Ca (3.45) were noted in the selected accessions of two underutilized species (based on fresh weight). Several species of amaranth literature [183] stated sufficient, Mg, Ca, and K. Furthermore, they detected that Ca, Mg, and K of amaranth were much more protuberant than nightshade, black spider flower, kale, and spinach. Mg, Ca, and K obtained from the accessions of two underutilized species were superior to Mg, Ca, and K of literature [183]. *A. tricolor* had the highest K and Mg. In contrast, the *A. lividus* demonstrated the highest Ca. K content of advanced lines was more than K of green amaranth [180], though K obtained from these advanced lines was inferior to K of weedy amaranth [179]. Ca content observed in the study was corroborative to the results of green and weedy amaranth [179,180]. Mg noticed in these accessions was greater than our previous green and weedy amaranth [179,180]. The protuberant differences were observed in Fe content regarding accessions (10.72 to 18.34). AT12 and SA10 displayed the highest Fe (18.34 and 18.24, respectively), though the least Fe was displayed in SA21 and AT5 (10.72 and 10.76, respectively). Our study revealed that preponderant variations were noticed.

Table 2. Macroelements (mg g⁻¹ FW) and microelements (µg g⁻¹ FW) of two underutilized species of *Amaranthus* leafy vegetables.

Genotypes	Macroelements			Microelements			
	K	Ca	Mg	Fe	Mn	Cu	Zn
<i>A. tricolor</i>							
AT2	4.96 ± 0.11 b	2.32 ± 0.15 b	3.38 ± 0.17 b	11.86 ± 0.26 c	6.86 ± 0.13 c	1.32 ± 0.03 d	6.85 ± 0.13 e
AT5	4.97 ± 0.10 b	1.93 ± 0.16 c	3.39 ± 0.13 b	10.76 ± 0.23 e	7.92 ± 0.17 b	1.05 ± 0.02 e	7.08 ± 0.15 d
AT9	4.95 ± 0.14 b	2.36 ± 0.15 b	3.42 ± 0.18 b	15.05 ± 0.28 b	6.79 ± 0.14 c	1.04 ± 0.03 e	7.06 ± 0.16 d
AT12	6.72 ± 0.11 a	2.35 ± 0.11 b	3.74 ± 0.12 a	18.34 ± 0.25 a	15.12 ± 0.18 a	2.12 ± 0.03 c	17.12 ± 0.14 a

SA3	432.35 ± 2.17 d	242.16 ± 1.62 d	674.51 ± 1.25 e	524.56 ± 1.72 c	558.35 ± 1.52 b	1082.91 ± 1.65 b	45.44 ± 0.41 f
SA10	134.15 ± 2.32 g	82.71 ± 1.61 h	216.86 ± 1.12 h	192.44 ± 1.58 h	196.55 ± 1.42 h	388.99 ± 1.42 h	82.57 ± 0.42 c
SA14	478.45 ± 2.17 c	285.32 ± 1.73 a	763.77 ± 1.23 c	292.62 ± 1.72 f	292.25 ± 1.37 f	554.87 ± 1.57 f	58.74 ± 0.42 e
SA21	256.26 ± 2.22 f	93.33 ± 1.69 g	349.53 ± 1.31 g	243.24 ± 1.6 g	265.86 ± 1.68 g	509.10 ± 1.72 g	122.94 ± 0.45 a
Significance	**	**	**	**	**	**	**
CV%	3.55	1.28	1.46	2.16	2.35	1.23	2.33

CV, coefficient of variation; In a column, different letters in mean values are significantly differed by Duncan Multiple Range Test (**, $p < 0.01$); $n = 3$.

Selected accessions of two underutilized species demonstrated wide variations in chlorophyll *b* content (82.71 to 285.32). SA14 confirmed the highest chlorophyll *b* (285.32) after AT5. In contrast, SA10 confirmed the least chlorophyll *b* (82.71). Noteworthy and outstanding variations in chlorophyll *ab* were confirmed in the accessions of two underutilized species (216.86 to 913.20). Across the two underutilized species, AT5 exhibited the highest chlorophyll *ab* (913.20) after AT2, although SA10 confirmed the least chlorophyll *ab* (216.86). Notably, chlorophyll *a*, *ab*, and *b* (636.56, 913.20, and 285.32) in the accessions of two underutilized species, were superior to red and green amaranth [186]. *A. tricolor* accessions confirmed the highest chlorophyll *a* and *ab*. Similarly, *A. lividus* accessions confirmed the highest chlorophyll *b*. Chlorophylls *a*, *ab*, and *b* of the study were superior to red, green, stem, and weedy amaranth and *A. blitum* [178–182].

The accessions of two underutilized species established good β -cyanins content with significant variability among accessions (192.44 to 542.75). AT9 confirmed the highest β -cyanins (542.75) after AT2. Inversely, SA10 showed the least β -cyanins (192.44 ng g⁻¹). The selected accessions of two underutilized species established good β -xanthins with significant variability regarding accessions (196.55 to 596.73). AT9 confirmed the highest β -xanthins (596.73) after SA3. Inversely, SA10 showed the least β -xanthins (196.55). The accessions of two underutilized species established good content of betalains with protruding variability among accessions (388.99 to 1139.48). The betalains were the highest in AT9 (1139.48) after SA3. Inversely, the least betalains were stated in SA10 (388.99). Moreover, carotenoids and betalains showed major variability in the accessions of two underutilized species (45.44 to 123.28). AT12 and SA21 confirmed the highest carotenoids (123.28 and 122.94). Inversely, SA3 confirmed the least carotenoids (45.44). Notably, chlorophyll *a*, *ab*, and *b* (636.56, 913.20, 285.32); β -cyanins (542.75); β -xanthins (596.73); betalains (1139.48); and carotenoids (123.28), in the accessions of two underutilized species, were corroborated to green and red amaranth [186]. β -cyanins, β -xanthins, and betalains pigments were the highest in *A. tricolor* accessions. Inversely, the highest carotenoids were obtained from both *A. tricolor* and *A. lividus*. Betalains, β -cyanins, and β -xanthins in the study were superior to red, green, stem amaranth, and *A. blitum* [178,180–182]. Carotenoids in the study were superior to green amaranth [180], and verified to weedy amaranth [179], although the carotenoids of this study were inferior to red and stem amaranth and *A. blitum* [178,181,182].

3.4. Phytochemical Contents and Scavenging Activity

TP, β -carotene, TF, ascorbic acid, and RSC of the selected accessions of two underutilized species are shown in Table 4. Pronounced variability was recorded in the β -carotene content of the selected accessions of two underutilized species (27.67 in AT5 to 68.82 in AT12).

Table 4. The performance of TP ($\mu\text{g GAE g}^{-1}\text{ FW}$), vitamin C ($\text{mg } 100\text{ g}^{-1}\text{ FW}$), β -Carotene ($\text{mg } 100\text{ g}^{-1}\text{ FW}$), RSC (DPPH) ($\mu\text{g g}^{-1}\text{ TEAC DW}$), TF ($\mu\text{g RE g}^{-1}\text{ DW}$), and RSC (ABTS⁺) ($\mu\text{g TEAC g}^{-1}\text{ DW}$) of two underutilized species of *Amaranthus* leafy vegetables.

Genotypes	β -Carotene	Vitamin C	TP	TF	RSC (DPPH)	RSC (ABTS ⁺)
<i>A. tricolor</i>						
AT2	62.58 \pm 0.65 b	192.75 \pm 1.48 a	29.48 \pm 0.42 b	158.84 \pm 1.26 c	36.27 \pm 0.11 a	68.87 \pm 0.34 a
AT5	27.67 \pm 0.56 g	98.56 \pm 1.52 c	32.88 \pm 0.38 a	172.55 \pm 1.29 b	35.08 \pm 0.12 b	64.55 \pm 0.31 b
AT9	48.55 \pm 0.62 d	18.54 \pm 1.49 h	29.45 \pm 0.37 b	151.88 \pm 1.36 d	33.84 \pm 0.09 c	64.56 \pm 0.39 b
AT12	68.82 \pm 0.69 a	72.98 \pm 1.46 e	22.43 \pm 0.45 e	176.88 \pm 1.28 a	33.85 \pm 0.11 c	60.88 \pm 0.38 c
<i>A. lividus</i>						
SA3	32.74 \pm 1.68 f	58.74 \pm 1.48 g	18.62 \pm 0.42 f	151.75 \pm 1.24 d	22.75 \pm 0.11 g	40.86 \pm 0.37 g
SA10	61.83 \pm 1.66 b	65.84 \pm 1.52 f	15.66 \pm 0.42 g	148.56 \pm 1.25 cd	24.45 \pm 0.15 f	42.44 \pm 0.41 f
SA14	39.35 \pm 1.58 e	175.87 \pm 1.45 b	26.24 \pm 0.36 c	140.71 \pm 1.23 e	26.23 \pm 0.14 e	48.95 \pm 0.46 e
SA21	54.74 \pm 1.56 c	87.76 \pm 1.58 d	25.45 \pm 0.42 d	157.93 \pm 1.28 c	28.86 \pm 0.18 d	55.76 \pm 0.48 d
Significance	**	**	**	**	**	**
CV%	1.53	2.26	3.72	1.32	1.63	0.87

CV, coefficient of variation; TF = total flavonoid content, RSC = radical scavenging capacity, TP = total polyphenol content, $n = 3$; in a column, mean values with different letters are differed significantly by Duncan Multiple Range Test (**, $p < 0.01$).

AT2 and SA10 confirmed the high β -carotene. The accessions of two underutilized species demonstrated prominent variations in ascorbic acid (18.54 to 192.75). AT2 confirmed the highest ascorbic acid (192.75), and the least in AT9 (18.54). Noteworthy variations were noted in TP of the accessions of two underutilized species (15.66 to 32.88). AT5 established the highest TP of 32.88 after AT2 and AT9. Conversely, SA10 showed the least TP (15.66). The accessions of two underutilized species demonstrated high TF with substantial variability among accessions (140.71 to 176.88). AT12 showed the highest TF (176.88) after AT5, whereas SA14 had the least TF (140.71). The accessions of two underutilized species confirmed high RSC (DPPH) and RSC (ABTS⁺). AT2 showed the highest RSC (DPPH and ABTS⁺) (36.27, 68.87) after AT5 (35.08, 64.55) and AT9 (33.84, 64.56). On the other hand, the least RSC (DPPH) and RSC (ABTS⁺) were recorded in SA3 (22.75, 40.86) after SA10 (24.45, 42.44). A parallel tendency of RSC (DPPH) and RSC (ABTS⁺) methods authenticated the measurement of two different methods of AP. The accessions of two underutilized species exhibited outstanding ascorbic acid and β -carotene (192.75 and 68.82). TP (32.88), TF (176.88), RSC (DPPH) (36.27), and RSC (ABTS⁺) (68.87) found in this study were superior to red and green amaranth [187]. The β -carotene of these lines was confirmative to weedy amaranth [179]. The ascorbic acid of AT11 was superior to green, weedy, stem, amaranth, and *A. blitum* [179,181,182], and corroborative to red morph amaranth [178]. TP content was greater than green and weedy amaranth [179,180]. TF, RSC (DPPH), and RSC (ABTS⁺) documented in the accessions of two underutilized species were greater than the red, green, stem, and weedy amaranth and *A. blitum* morph [178–182]. The accession AT2 had the highest vitamin C and RSC (DPPH) and RSC (ABTS⁺); AT5 had the highest TP content; and AT12 had the highest TF content. *A. tricolor* accessions had high phytochemicals across the two species, such as phytopigments, vitamins, phenolics, flavonoids, and antioxidants, including considerable nutrients and protein. *A. tricolor* accessions can be used as high-yielding cultivars comprising ample antioxidants. The accessions confirmed an immense foundation of phytochemicals, and nutritional values and AP presented enormous prospects for feeding the mineral-, vitamin-, and antioxidant-deficient community.

3.5. The Correlation Studies

The correlation of β -carotene, pigments, TP, ascorbic acid, TF, and RSC (ABTS⁺) and RSC (DPPH) of accessions of two underutilized species are shown in Table 5, representing

exciting results. All pigments confirmed positive and significant correlations with TP, TF, and RSC (ABTS⁺) and RSC (DPPH), indicating that the increase in TP, TF, and RSC (DPPH) and RSC (ABTS⁺) were straightly linked to the augmentation of chlorophylls, β -cyanins, carotenoids, betalains, and β -xanthins or vice versa. Its destined pigments had good RSC. Similarly, β -carotene had a significant positive relationship with TP, ascorbic acid, TF, and RSC (ABTS⁺) and RSC (DPPH), although it exhibited significant negative associations among all pigments. Ascorbic acid had a significant positive relationship with TP, TF, and RSC (ABTS⁺) and RSC (DPPH), although it displayed insignificant negative associations among pigments. In amaranth, Sarker, and Oba [142] also observed a similar trend. A significant positive association was displayed among TP, TF, and RSC (ABTS⁺) and RSC (DPPH), which is corroborative to the results of amaranth and salt stressed-purslane [187–190]. The validation of the antioxidant capacity of the selected advanced lines of vegetable amaranth by two different methods of antioxidant capacity measurements was confirmed with the significant positive associations between RSC (ABTS⁺) and RSC (DPPH).

Table 5. The coefficient of correlation of antioxidant pigments, TPC ($\mu\text{g GAE g}^{-1}\text{ FW}$), β -Carotene ($\text{mg } 100\text{ g}^{-1}\text{ FW}$), vitamin C ($\text{mg } 100\text{ g}^{-1}\text{ FW}$), RSC (DPPH) ($\mu\text{g g}^{-1}\text{ TEAC DW}$), TFC ($\mu\text{g RE g}^{-1}\text{ DW}$), and RSC (ABTS⁺) ($\mu\text{g TEAC g}^{-1}\text{ DW}$), chlorophylls ($\mu\text{g g}^{-1}\text{ FW}$); β -Cyanins, β -xanthins, and betalains ($\text{ng g}^{-1}\text{ FW}$); carotenoids ($\text{mg } 100\text{ g}^{-1}\text{ FW}$) of two underutilized species of *Amaranthus* leafy vegetables.

Traits	Chl <i>b</i>	Chl <i>ab</i>	β -Cyanins	β -Xanthins	Betalains	β -Carotene	Vitamin C	TP	TF	RSC (DPPH)	RSC (ABTS ⁺)
Chlorophyll <i>l a</i>	0.86 **	0.92 **	0.89 **	0.85 **	0.82 **	−0.73 *	−0.015	0.77 *	0.75 *	0.86 **	0.86 **
Chlorophyll <i>l b</i>		0.85 **	0.77 **	0.85 **	0.86 **	−0.67	−0.018	0.72 *	0.74 *	0.84 **	0.84 **
Chlorophyll <i>l ab</i>			0.72 *	0.76 *	0.83 **	−0.76*	−0.014	0.75 *	0.82 **	0.73 *	0.85 **
β -cyanins				0.87 **	0.96 **	−0.75 *	−0.116	0.76 *	0.81 **	0.88 **	0.87 **
β -xanthins					0.95 **	−0.86 **	−0.123	0.74 *	0.72*	0.76 *	0.83 **
Betalains						−0.88 **	−0.129	0.86 **	0.77*	0.84 **	0.88 **
β -Carotene							0.73*	0.82 **	0.88 **	0.86 **	0.85 **
Vitamin C								0.74 *	0.86 **	0.85 **	0.86 **
TP									0.84 **	0.82 **	0.92 **
TF										0.86 **	0.86 **
RSC (DPPH)											0.95 **

Chl *b*, chlorophyll *b*; TP, total polyphenol content; TF, total flavonoid content; RSC, radical scavenging capacity; total antioxidant capacity; Chl *ab*, chlorophyll *b*; *, **, significant at 5% and 1% level.

Phytochemicals and pigments including β -carotene, TP, ascorbic acid, and TF had intense AP, as these showed significant associations with RSC (DPPH) and RSC (ABTS⁺).

4. Conclusions

The selected accessions of two underutilized species demonstrated leafy vegetables as abundant sources of K, Fe, Mn, Ca, dry matter, Cu, Zn, protein, Mg, dietary fiber, and carbohydrates. It is an excellent origin of antioxidant pigments and phytochemicals, including TP, β -carotene, TF, ascorbic acid, and antioxidants. The accessions of *A. tricolor* had abundant phytochemicals and RSC, including considerable proximate, pigments, and nutraceuticals compared to the accessions of *A. lividus*. The interrelationship exposed that phytochemicals and pigments of leafy vegetable amaranth accessions confirmed good RSC of 2,2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) and 2,2-Diphenyl-1-picrylhydrazyl equivalent to Trolox. Although *A. tricolor* and *A. lividus* are underutilized, these are

promising leafy vegetables. Enormous bioactive phytochemicals and antioxidants of *A. tricolor* and *A. lividus* enable growing them as preferable cultivars, and they can be used in the daily diet as fresh salad, boiled, leafy vegetables, and other culinary dishes. Based on their nutritional status, they are comparable to spinach, and can be grown throughout the year, including a gap period of leafy vegetables in summer. They are a potential source of nutritional value, antioxidant phytopigments, β -carotene, ascorbic acid, phenolics, flavonoids, and antioxidants in our daily diet to accomplish nutritional and antioxidant sufficiency.

Author Contributions: Conceptualization, U.S., M.G.R., S.O.; methodology, U.S.; software, U.S.; validation, U.S., M.G.R., S.O., N.M.M., O.A.E., W.M.E., S.T.A.-R.; formal analysis, U.S., N.M.M., O.A.E.; investigation, U.S., N.M.M., O.A.E.; resources, U.S.; data curation, U.S.; writing—original draft preparation, U.S.; writing—review and editing, U.S., M.G.R., S.O., N.M.M., O.A.E., W.M.E., S.T.A.-R.; visualization, U.S., N.M.M., O.A.E.; supervision, U.S.; funding acquisition, N.M.M., O.A.E., W.M.E., S.T.A.-R. All authors have read and agreed to the published version of the manuscript.

Funding: The research work was funded by the Department of Genetics and Plant Breeding, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh. The authors acknowledge also financial support from the Researchers Supporting Project number (RSP-2021/103), King Saud University, Riyadh, Saudi Arabia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data recorded in the current study are available in all Tables and Figures of the manuscript.

Acknowledgments: For supporting the research work, the authors acknowledge the Department of Genetics and Plant Breeding, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh. The authors acknowledge financial support from the Researchers Supporting Project number (RSP-2021/103), King Saud University, Riyadh, Saudi Arabia.

Conflicts of Interest: All the authors have no conflict of interest.

References

1. Rastogi, A.; Shukla, S. Amaranth: A New Millennium Crop of Nutraceutical Values. *Crit. Rev. Food Sci. Nutr.* **2013**, *53*, 109–125.
2. Das, S. Amaranths: The Crop of Great Prospect. In *Amaranthus: A Promising Crop of Future*; Springer: Singapore, 2016; pp. 13–48.
3. Sreelathakumary, I.; Peter, K.V. Amaranth: *Amaranthus* spp. In *Genetic Improvement of Vegetable Crops*; Elsevier: Amsterdam, The Netherlands, 1993; pp. 315–323.
4. Sauer, J.D. The Grain Amaranths and Their Relatives: A Revised Taxonomic and Geographic Survey. *Ann. Mo. Bot. Gard.* **1967**, *54*, 103.
5. Anu, R.; Mishra, B.K.; Mrinalini, S.; Ameena, S.; Rawli, P.; Nidhi, V.; Sudhir, S. Identification of Heterotic Crosses Based on Combining Ability in Vegetable Amaranthus (*Amaranthus tricolor* L.). *Asian J. Agric. Res.* **2015**, *9*, 84–94.
6. Nguyen, D.C.; Tran, D.S.; Tran, T.T.H.; Ohsawa, R.; Yoshioka, Y. Genetic Diversity of Leafy Amaranth (*Amaranthus tricolor* L.) Resources in Vietnam. *Breed. Sci.* **2019**, *69*, 640–650.
7. Shukla, S.; Bhargava, A.; Chatterjee, A.; Srivastava, A.; Singh, S.P. Genotypic Variability in Vegetable Amaranth (*Amaranthus tricolor* L. for Foliage Yield and Its Contributing Traits over Successive Cuttings and Years. *Euphytica* **2006**, *151*, 103–110.
8. Jensen, A. Chlorophylls and Carotenoids. In *Handbook of Physiological Methods and Biochemical Methods*; Hellebust, J.A., Craigie J.S., Eds.; Cambridge University Press: Cambridge, UK, 1978; pp. 5–70.
9. Andini, R.; Yoshida, S.; Ohsawa, R. Variation in Protein Content and Amino Acids in the Leaves of Grain, Vegetable and Weedy Types of Amaranths. *Agronomy* **2013**, *3*, 391–403.
10. Manólio Soares, R.A.; Mendonça, S.; Andrade de Castro, L.I.; Cardoso Corrêa Carlos Menezes, A.C.; Gomes Arêas, J.A. Major Peptides from Amaranth (*Amaranthus cruentus*) Protein Inhibit HMG-CoA Reductase Activity. *Int. J. Mol. Sci.* **2015**, *16*, 4150.
11. Písariková, B.; Krácmár, S.; Herzig, I. Amino acid Contents and Biological Value of Protein Amaranth. *Czech J. Anim. Sci.* **2005**, *50*, 169–174.
12. López, D.N.; Galante, M.; Raimundo, G.; Spelzini, D.; Boeris, V. Functional Properties of Amaranth, Quinoa and Chia Proteins and the Biological Activities of Their Hydrolyzates. *Food Res. Int.* **2019**, *116*, 419–429.

13. Alvarez-Jubete, L.; Arendt, E.K.; Gallagher, E. Nutritive Value of Pseudocereals and Their Increasing Use as Functional Gluten-Free Ingredients. *Trends Food Sci. Technol.* **2010**, *21*, 106–113.
14. Achigan-Dako, E.G.; Sogbohossou, O.E.D.; Maundu, P. Current Knowledge on *Amaranthus* spp.: Research Avenues for Improved Nutritional Value and Yield in Leafy Amaranths in Sub-Saharan Africa. *Euphytica* **2014**, *197*, 303–317.
15. Akin-Idowu, P.E.; Odunola, O.A.; Gbadegesin, M.A.; Ademoyegun, O.T.; Aduloju, A.O.; Olagunju, Y.O. Nutritional Evaluation of Five Species of Grain Amaranth—An Underutilized Crop. *Int. J. Sci.* **2017**, *3*, 18–27.
16. Alegbejo, J. Nutritional Value and Utilization of Amaranthus (*Amaranthus* spp.)—A Review. *Bayero J. Pure Appl. Sci.* **2014**, *6*, 136.
17. Shukla, S.; Bhargava, A.; Chatterjee, A.; Pandey, A.C.; Mishra, B.K. Diversity in Phenotypic and Nutritional Traits in Vegetable Amaranth (*Amaranthus tricolor*), A Nutritionally Underutilised Crop. *J. Sci. Food Agric.* **2010**, *90*, 139–144.
18. Soriano-García, M.; Ilnamiqui Arias-Olguín, I.; Pablo Carrillo Montes, J.; Genaro Rosas Ramírez, D.; Silvestre Mendoza Figueroa, J.; Flores-Valverde, E.; Rita Valladares-Rodríguez, M. Nutritional Functional Value and Therapeutic Utilization of Amaranth. *J. Anal. Pharm. Res.* **2018**, *7*, 596–600.
19. Sarker, U.; Islam, M.T.; Rabbani, M.G.; Oba, S. Genotypic Variability for Nutrient, Antioxidant, Yield and Yield Contributing Traits in Vegetable Amaranth. *J. Food Agric. Environ.* **2014**, *12*, 168–174. Available online: <https://www.wfpublisher.com/Abstract/5378> (accessed on).
20. Sarker, U.; Islam, M.T.; Rabbani, M.G.; Oba, S. Variability, heritability and genetic association in vegetable amaranth. *Span. J. Agric. Res.* **2015**, *13*, 0702. <https://doi.org/10.5424/sjar/2015132-6843>.
21. Sarker, U.; Islam, M.T.; Rabbani, M.G.; Oba, S. Variability in Composition of Vitamins and Mineral Antioxidants in Vegetable Amaranth. *Genetika* **2015**, *47*, 85–96. <https://doi.org/10.2298/GENSR1501085S>.
22. Sarker, U.; Islam, M.T.; Rabbani, M.G.; Oba, S. Genetic Variation and Interrelationships among Antioxidant, Quality, and Agronomic Traits in Vegetable Amaranth. *Turk. J. Agric. For.* **2016**, *40*, 526–535.
23. Sarker, U.; Islam, M.T.; Rabbani, M.G.; Oba, S. Genotypic Diversity in Vegetable Amaranth for Antioxidant, Nutrient and Agronomic Traits. *Indian J. Genet. Plant Breed.* **2017**, *77*, 173–176.
24. Shukla, S.; Bhargava, A.; Chatterjee, A.; Srivastava, J.; Singh, N.; Singh, S.P. Mineral Profile and Variability in Vegetable Amaranth (*Amaranthus tricolor*). *Plant Foods Hum. Nutr.* **2006**, *61*, 23–28.
25. Chakrabarty, T.; Sarker, U.; Hasan, M.; Rahman, M.M. Variability in Mineral Compositions, Yield and Yield Contributing Traits of Stem Amaranth (*Amaranthus lividus*). *Genetika* **2018**, *50*, 995–1010.
26. Akubugwo, I.E.; Obasi, N.A.; Chinyere, G.C.; Ugbogu, A.E. Nutritional and Chemical Value of *Amaranthus hybridus* L. Leaves from Afikpo, Nigeria. *Afr. J. Biotechnol.* **2007**, *6*, 2833–2839.
27. Ezenwa, M.I.; Ogbadoyi, E.O. Effect of Heading on Some Micronutrients, Anti-Nutrients and Toxic Substances in *Amaranthus cruentus* Grown in Minna, Niger State, Nigeria. *J. Food Nutr. Res.* **2011**, *1*, 147–154.
28. Lobo, M.; Samman, N.; Castanheira, I. Characterisation of Nutrient Profile of Quinoa (*Chenopodium quinoa*), Amaranth (*Amaranthus caudatus*), and Purple Corn (*Zea mays* L.) Consumed in the North of Argentina: Proximates, Minerals and Trace Elements. *Food Chem.* **2014**, *148*, 420–426.
29. Nyonje, W.A.; Schafleitner, R.; Abukutsa-Onyango, M.; Yang, R.-Y.; Makokha, A.; Owino, W. Precision phenotyping and association between morphological traits and nutritional content in Vegetable Amaranth (*Amaranthus* spp.). *J. Agric. Food Res.* **2021**, *5*, 100165.
30. Schafleitner, R.; Lin, Y.P.; Dinssa, F.; N'Danikou, S.; Finkers, R.; Minja, R.; Abukutsa-Onyango, M.; Nyonje, W.; Lin, C.Y.; Wu, T.H.; et al. The world vegetable center Amaranthus germplasm collection: Core collection development and evaluation of agronomic and nutritional traits. *Crop Sci.* **2022**. <https://doi.org/10.1002/csc2.20715>.
31. Srivastava, R. Nutritional Quality of Some Cultivated and Wild Species of *Amaranthus* L. *Int. J. Pharm. Sci. Res.* **2011**, *2*, 3152.
32. Venskutonis, P.R.; Kraujalis, P. Nutritional Components of Amaranth Seeds and Vegetables: A Review on Composition, Properties, and Uses. *Compr. Rev. Food Sci. Food Saf.* **2013**, *12*, 381–412.
33. Wesche-Ebeling, P.; Maiti, R.; García-Díaz, G.; González, D.I.; Sosa-Alvarado, F. Contributions to the Botany and Nutritional Value of Some Wild *Amaranthus* species (Amaranthaceae) of Nuevo Leon, Mexico. *Econ. Bot.* **1995**, *49*, 423–430.
34. Mekonnen, G.; Woldesenbet, M.; Teshale, T.; Biru, T. Amaranthus Caudatus Production and Nutrition Contents for Food Security and Healthy Living in Menit Shasha, Menit Goldya and Maji Districts of Bench Maji Zone, South Western Ethiopia. *Nutr. Food Sci. Int. J.* **2018**, *7*, 001–007.
35. Mlakar, S.G.; Turinek, M.; Jakop, M.; Bavec, M.; Bavec, F. Nutrition Value and Use of Grain Amaranth: Potential Future Application in Bread Making. *Agriculturae* **2009**, *6*, 43–53.
36. Jimoh, M.O.; Afolayan, A.J.; Lewu, F.B. Suitability of *Amaranthus* species for Alleviating Human Dietary Deficiencies. *S. Afr. J. Bot.* **2018**, *115*, 65–73.
37. Jimoh, M.O.; Afolayan, A.J.; Lewu, F.B. Nutrients and Antinutrient Constituents of *Amaranthus caudatus* L. Cultivated on Different Soils. *Saudi J. Biol. Sci.* **2020**, *27*, 3570–3580.
38. Ahmed, S.A.; Hanif, S.; Iftkhar, T. Phytochemical Profiling with Antioxidant and Antimicrobial Screening of *Amaranthus viridis* L. Leaf and Seed Extracts. *Open J. Med. Microbiol.* **2013**, *3*, 16–171.
39. Al-Mamun, M.A.; Husna, J.; Khatun, M.; Hasan, R.; Kamruzzaman, M.; Hoque, K.M.F.; Reza, M.A.; Ferdousi, Z. Assessment of Antioxidant, Anticancer and Antimicrobial Activity of Two Vegetable Species of *Amaranthus* in Bangladesh. *BMC Complement. Altern. Med.* **2016**, *16*, 157.

40. Vardhana, H. In Vitro Antibacterial Activity of *Amaranthus spinosus* Root Extracts. *Pharmacophore* **2011**, *2*, 266–270.
41. Guo, L.; Wang, Y.; Bi, X.; Duo, K.; Sun, Q.; Yun, X.; Zhang, Y.; Fei, P.; Han, J. Antimicrobial Activity and Mechanism of Action of The *Amaranthus tricolor* Crude Extract Against *Staphylococcus aureus* and Potential Application in Cooked Meat. *Foods* **2020**, *9*, 359.
42. Jimoh, M.O.; Afolayan, A.J.; Lewu, F.B. Toxicity and Antimicrobial Activities of *Amaranthus caudatus* L. (Amaranthaceae) Harvested from Formulated Soils at Different Growth Stages. *J. Evid. Based Complement. Altern. Med.* **2020**, *25*, 1–11.
43. Lipkin, A.; Anisimova, V.; Nikonorova, A.; Babakov, A.; Krause, E.; Bienert, M.; Grishin, E.; Egorov, T. An Antimicrobial Peptide Ar-Amp from *Amaranthus retroflexus* L. Seeds. *Phytochemistry* **2005**, *66*, 2426–2431.
44. Maiyo, Z.C.; Ngunjiri, R.N.; Matasyoh, J.C.; Chepkorir, R. Phytochemical Constituents and Antimicrobial Activity of Leaf Extract of Three *Amaranthus* Plant Species. *Afr. J. Biotechnol.* **2010**, *9*, 3178–3182.
45. Moyer, T.B.; Heil, L.R.; Kirkpatrick, C.L.; Goldfarb, D.; Lefever, W.A.; Parsley, N.C.; Wommack, A.J.; Hicks, L.M. PepSAVI-MS Reveals a Proline-Rich Antimicrobial Peptide in *Amaranthus tricolor*. *J. Nat. Prod.* **2019**, *82*, 2744–2753.
46. Terzieva, S.; Velichkova, K.; Grozeva, N.; Valcheva, N.; Dinev, T. Antimicrobial Activity of *Amaranthus* spp. Extracts Against Some Mycotoxigenic Fungi. *Bulg. J. Agric. Sci.* **2019**, *25*, 120–123.
47. Jimoh, M.O.; Afolayan, A.J.; Lewu, F.B. Micromorphological Assessment of Leaves of *Amaranthus caudatus* L. Cultivated on Formulated Soil Types. *Appl. Ecol. Environ. Res.* **2019**, *17*, 13593–13605.
48. De Vita, D.; Messorio, A.; Toniolo, C.; Frezza, C.; Scipione, L.; Berteau, C.M.; Micera, M.; Di Sarno, V.; Madia, V.N.; Pindinello, I.; et al. Towards A New Application of Amaranth Seed Oil as An Agent Against *Candida albicans*. *Nat. Prod. Res.* **2021**, *35*, 4621–4626.
49. Baral, M.; Chakraborty, S.; Chakraborty, P. Evaluation of Anthelmintic and Anti-Inflammatory Activity of *Amaranthus spinosus* L. *Int. J. Curr. Pharm. Res.* **2010**, *2*, 2–5.
50. Kumar, B.S.A.; Lakshman, K.; Jayaveera, K.N.; Velmurugan, C.; Manoj, B.; Sridhar, S.M. Anthelmintic Activity of Methanol Extract of *Amaranthus caudatus* L. *Internet J. Food Saf.* **2010**, *12*, 127–129.
51. Kumar, A.; Lakshman, K.; Jayaveera, K.N.; Nandeesh, R.; Manoj, B.; Ranganayakulu, D. Comparative In Vitro Antihelminthic Activity of Three Plants from Amaranthaceae Family. *Arch. Biol. Sci.* **2010**, *62*, 185–189.
52. Reyad-ul-Ferdous, M.; Shahjahan, D.S.; Tanvir, S.; Mukti, M. Present Biological Status of Potential Medicinal Plant of *Amaranthus viridis*: A comprehensive review. *Am. J. Clin. Exp. Med.* **2015**, *3*, 12–17.
53. Chang, Y.J.; Pong, L.Y.; Hassan, S.S.; Choo, W.S. Antiviral Activity of Betacyanins from Red Pitahaya (*Hylocereus polyrhizus*) and Red Spinach (*Amaranthus dubius*) Against Dengue Virus Type 2 (GenBank accession no. MH488959). *Access Microbiol.* **2020**, *2*, 1–6.
54. Amornrit, W.; Santiyanont, R. Neuroprotective Effect of *Amaranthus lividus* and *Amaranthus tricolor* and Their Effects on Gene Expression of RAGE During Oxidative Stress in SH-SY5Y Cells. *Genet. Mol. Res.* **2016**, *15*, gmr15027562.
55. Lin, B.F.; Chiang, B.L.; Lin, J.Y. *Amaranthus spinosus* Water Extract Directly Stimulates Proliferation of B Lymphocytes in vitro. *Int. Immunopharmacol.* **2005**, *5*, 711–722.
56. Olajide, O.; Ogunleye, B.; Erinle, T. Anti-inflammatory Properties of *Amaranthus spinosus* Leaf Extract. *Pharm. Biol.* **2004**, *42*, 521–525.
57. Hussain, Z.; Amresh, G.; Singh, S.; Rao, C.V. Antidiarrheal and Antiulcer Activity of *Amaranthus spinosus* in Experimental Animals. *Pharm. Biol.* **2009**, *47*, 932–939.
58. House, N.C.; Puthenparampil, D.; Malayil, D.; Narayanankutty, A. Variation in The Polyphenol Composition, Antioxidant, and Anticancer Activity Among Different *Amaranthus* Species. *S. Afr. J. Bot.* **2020**, *135*, 408–412.
59. Jin, Y.; Xuan, Y.; Chen, M.; Chen, J.; Jin, Y.; Piao, J.; Tao, J. Antioxidant, Anti-inflammatory and Anticancer Activities of *Amaranthus viridis* L. Extracts. *Asian J. Chem.* **2013**, *25*, 8901–8904.
60. Amornrit, W.; Santiyanont, R. Effect of *Amaranthus* on Advanced Glycation End-Products Induced Cytotoxicity and Proinflammatory Cytokine Gene Expression in SH-SY5Y Cells. *Molecules* **2015**, *20*, 17288.
61. Zeashan, H.; Amresh, G.; Singh, S.; Rao, C.V. Hepatoprotective Activity of *Amaranthus spinosus* in Experimental Animals. *Food Chem. Toxicol.* **2008**, *46*, 3417–3421.
62. Aneja, S.; Vats, M.; Aggarwal, S.; Sardana, S. Phytochemistry and Hepatoprotective Activity of Aqueous Extract of *Amaranthus tricolor* L. Roots. *J. Ayurveda Integr. Med.* **2013**, *4*, 211–215.
63. Zeashan, H.; Amresh, G.; Singh, S.; Rao, C.V. Protective Effect of *Amaranthus spinosus* Against D-Galactosamine/Lipopolysaccharide-Induced Hepatic Failure. *Pharm. Biol.* **2010**, *48*, 1157–1163.
64. Zeashan, H.; Amresh, G.; Singh, S.; Rao, C.V. Hepatoprotective and Antioxidant Activity of *Amaranthus spinosus* Against CCl₄ Induced Toxicity. *J. Ethnopharmacol.* **2009**, *125*, 364–366.
65. Balakrishnan, S.; Pandhare, R. Antihyperglycemic and Antihyperlipidaemic Activities of *Amaranthus spinosus* L. Extract on Alloxan Induced Diabetic Rats. *Malays. J. Pharm. Sci.* **2010**, *8*, 13–22.
66. Krishnamurthy, G.; Lakshman, K.; Pruthvi, N.; Chandrika, P.U. Antihyperglycemic and Hypolipidemic Activity of Methanolic Extract of *Amaranthus viridis* Leaves in Experimental Diabetes. *Indian J. Pharmacol.* **2011**, *43*, 450–454.
67. Girija, K.; Lakshman, K.; Udaya, C.; Sabhya Sachi, G.; Divya, T. Antidiabetic and Anti-cholesterolemic Activity of Methanol Extracts of Three Species of *Amaranthus*. *Asian Pac. J. Trop. Biomed.* **2011**, *1*, 133–138.
68. Allegra, M.; Tesoriere, L.; Livrea, M.A. Betanin Inhibits the Myeloperoxidase/Nitrite-Induced Oxidation of Human Low-Density Lipoproteins. *Free Radic. Res.* **2007**, *41*, 335–341.

69. Clemente, A.; Desai, P. Evaluation of the Hematological, Hypoglycemic, Hypolipidemic and Antioxidant Properties of *Amaranthus tricolor* Leaf Extract in Rat. *Trop. J. Pharm. Res.* **2011**, *10*, 595–602.
70. Yang, Y.; Fukui, R.; Jia, H.; Kato, H. Amaranth supplementation improves hepatic lipid dysmetabolism and modulates gut microbiota in mice fed a high-fat diet. *Foods* **2021**, *10*, 1259.
71. Hilou, A.; Nacoulma, O.G.; Guiguemde, T.R. In Vivo Antimalarial Activities of Extracts from *Amaranthus spinosus* L. and *Boerhaavia erecta* L. in Mice. *J. Ethnopharmacol.* **2006**, *103*, 236–240.
72. Hsiao, L.W.; Tsay, G.J.; Mong, M.C.; Liu, W.H.; Yin, M.C. Aqueous Extract Prepared from Steamed Red Amaranth (*Amaranthus gangeticus* L.) Leaves Protected Human Lens Cells Against High Glucose Induced Glycative and Oxidative Stress. *J. Food Sci.* **2021**, *86*, 3686–3697.
73. Prajitha, V.; Thoppil, J.E. Cytotoxic and Apoptotic Activities of Extract of *Amaranthus spinosus* L. in *Allium cepa* and Human Erythrocytes. *Cytotechnology* **2017**, *69*, 123–133.
74. Ashok Kumar, B.S.; Lakshman, K.; Velmurugan, C.; Sridhar, S.M.; Gopisetty, S. Antidepressant Activity of Methanolic Extract of *Amaranthus spinosus*. *Basic Clin. Neurosci.* **2014**, *5*, 11–17.
75. Jimoh, M.O.; Afolayan, A.J.; Lewu, F.B. Therapeutic uses of *Amaranthus caudatus* L. *Trop. Biomed.* **2019**, *36*, 1038–1053.
76. Kusumaningtyas, R.; Kobayashi, S.; Takeda, S. Mixed Species Gardens in Java and the Transmigration Areas of Sumatra, Indonesia: A Comparison. *J. Trop. Agric.* **2006**, *44*, 15–22.
77. Sarker, U.; Islam, M.T.; Rabbani, M.G.; Oba, S. Variability in Total Antioxidant Capacity, Antioxidant Leaf Pigments and Foliage Yield of Vegetable Amaranth. *J. Integr. Agric.* **2018**, *17*, 1145–1153.
78. Sarker, U.; Islam, M.T.; Rabbani, M.G.; Oba, S. Antioxidant Leaf Pigments and Variability in Vegetable Amaranth. *Genetika* **2018**, *50*, 209–220. <https://doi.org/10.2298/GENSR1801209S>.
79. Cai, Y.; Sun, M.; Wu, H.; Huang, R.; Corke, H. Characterization and Quantification of Betacyanin Pigments from Diverse *Amaranthus* Species. *J. Agric. Food Chem.* **1998**, *46*, 2063–2070.
80. Miguel, M.G. Betalains in Some Species of The Amaranthaceae Family: A Review. *Antioxidants* **2018**, *7*, 53.
81. Cai, Y.; Corke, H. *Amaranthus* Betacyanin Pigments Applied in Model Food Systems. *J. Food Sci.* **1999**, *64*, 869–873.
82. Cai, Y.; Sun, M.; Corke, H. Identification and Distribution of Simple and Acylated Betacyanins in the Amaranthaceae. *J. Agric. Food Chem.* **2001**, *49*, 1971–1978.
83. Cai, Y.; Sun, M.; Corke, H. HPLC Characterization of Betalains from Plants in the Amaranthaceae. *J. Chromatogr. Sci.* **2005**, *43*, 454–460.
84. Cai, Y.; Sun, M.; Corke, H. Characterization and Application of Betalain Pigments from Plants of the Amaranthaceae. *Trends Food Sci. Technol.* **2005**, *16*, 370–376.
85. Belhadj Slimen, I.; Najar, T.; Abderrabba, M. Chemical and Antioxidant Properties of Betalains. *J. Agric. Food Chem.* **2017**, *65*, 675–689.
86. Esatbeyoglu, T.; Wagner, A.E.; Motafakkerazad, R.; Nakajima, Y.; Matsugo, S.; Rimbach, G. Free Radical Scavenging and Antioxidant Activity of Betanin: Electron Spin Resonance Spectroscopy Studies and Studies in Cultured Cells. *Food Chem. Toxicol.* **2014**, *73*, 119–126.
87. Gandía-Herrero, F.; Escribano, J.; García-Carmona, F. The Role of Phenolic Hydroxy Groups in the Free Radical Scavenging Activity of Betalains. *J. Nat. Prod.* **2009**, *72*, 1142–1146.
88. Gandía-Herrero, F.; Escribano, J.; García-Carmona, F. Structural Implications on Color, Fluorescence, and Antiradical Activity in Betalains. *Planta* **2010**, *232*, 449–460.
89. Gandía-Herrero, F.; Escribano, J.; García-Carmona, F. Purification and Antiradical Properties of the Structural Unit of Betalains. *J. Nat. Prod.* **2012**, *75*, 1030–1036.
90. Gandía-Herrero, F.; Escribano, J.; García-Carmona, F. Biological Activities of Plant Pigments Betalains. *Crit. Rev. Food Sci. Nutr.* **2016**, *56*, 937–945.
91. Khan, M.I. Plant Betalains: Safety, Antioxidant Activity, Clinical Efficacy, and Bioavailability. *Compr. Rev. Food Sci. Food Saf.* **2016**, *15*, 316–330.
92. Khan, M.I.; Giridhar, P. Plant Betalains: Chemistry and Biochemistry. *Phytochemistry* **2015**, *117*, 267–295.
93. Stintzing, F.C.; Carle, R. Functional Properties of Anthocyanins and Betalains in Plants, Food, and in Human Nutrition. *Trends Food Sci. Technol.* **2004**, *15*, 19–38.
94. Taira, J.; Tsuchida, E.; Katoh, M.C.; Uehara, M.; Ogi, T. Antioxidant Capacity of Betacyanins as Radical Scavengers for Peroxyl Radical and Nitric Oxide. *Food Chem.* **2015**, *166*, 531–536.
95. Sarker, U.; Lin, Y.P.; Oba, S.; Yoshioka, Y.; Ken, H. Prospects and potentials of underutilized leafy Amaranths as vegetable use for health-promotion. *Plant Physiol. Biochem.* **2022**, *182*, 104–123. <https://doi.org/10.1016/j.plaphy.2022.04.011>.
96. Pasko, P.; Bartoń, H.; Zagrodzki, P.; Gorinstein, S.; Fořta, M.; Zachwieja, Z. Anthocyanins, Total Polyphenols and Antioxidant Activity in Amaranth and Quinoa Seeds and Sprouts During Their Growth. *Food Chem.* **2009**, *115*, 994–998.
97. Li, H.; Deng, Z.; Liu, R.; Zhu, H.; Draves, J.; Marcone, M.; Sun, Y.; Tsao, R. Characterization of Phenolics, Betacyanins and Antioxidant Activities of The Seed, Leaf, Sprout, Flower and Stalk Extracts of Three *Amaranthus* species. *J. Food Compos. Anal.* **2015**, *37*, 75–81.
98. Barba de la Rosa, A.P.; Fomsgaard, I.S.; Laursen, B.; Mortensen, A.G.; Olvera-Martínez, L.; Silva-Sánchez, C.; Mendoza-Herrera, A.; González-Castañeda, J.; De León-Rodríguez, A. Amaranth (*Amaranthus hypochondriacus*) as An Alternative Crop for

- Sustainable Food Production: Phenolic Acids and Flavonoids with Potential Impact on Its Nutraceutical Quality. *J. Cereal Sci.* **2009**, *49*, 117–121.
99. Peiretti, P.G.; Meineri, G.; Gai, F.; Longato, E.; Amarowicz, R. Antioxidative Activity and Phenolic Compounds of Pumpkin (*Cucurbita Pepo*) Seeds and Amaranth (*Amaranthus caudatus*) Grain Extracts. *Nat. Prod. Res.* **2017**, *31*, 2178–2182.
 100. Stintzing, F.C.; Kammerer, D.; Schieber, A.; Adama, H.; Nacoulma, O.G.; Carle, R. Betacyanins and Phenolic Compounds from *Amaranthus spinosus* L. and *Boerhavia erecta* L. *Z. Naturforsch. C* **2004**, *59*, 1–8.
 101. Kalinova, J.; Dadakova, E. Rutin and Total Quercetin Content in Amaranth (*Amaranthus* spp.). *Plant Foods Hum. Nutr.* **2009**, *64*, 68–74.
 102. Asao, M.; Watanabe, K. Functional and Bioactive Properties of Quinoa and Amaranth. *Food Sci. Technol. Res.* **2010**, *16*, 163–168.
 103. Sarker, U.; Islam, M.T.; Rabbani, M.G.; Oba, S. Phenotypic Divergence in Vegetable Amaranth for Total Antioxidant Capacity, Antioxidant Profile, Dietary Fiber, Nutritional and Agronomic Traits. *Acta Agric. Scand. Sect. B-Soil Plant Sci.* **2018**, *68*, 67–76. <https://doi.org/10.1080/09064710.2017.1367029>.
 104. Tang, Y.; Xiao, Y.; Tang, Z.; Jin, W.; Wang, Y.; Chen, H.; Yao, H.; Shan, Z.; Bu, T.; Wang, X. Extraction of Polysaccharides from *Amaranthus hybridus* L. by Hot Water and Analysis of Their Antioxidant Activity. *Peer J.* **2019**, *7*, e7149.
 105. Ozsoy, N.; Yilmaz, T.; Kurt, O.; Can, A.; Yanardag, R. In Vitro Antioxidant Activity of *Amaranthus lividus* L. *Food Chem.* **2009**, *116*, 867–872.
 106. Okunlola, G.O.; Jimoh, M.A.; Olatunji, O.A.; Olowolaju, E.D. Comparative Study of The Phytochemical Contents of *Cochorus olitorius* and *Amaranthus hybridus* at Different Stages of Growth Comparative Study of The Phytochemical Contents. *Ann. West Univ. Timis. Ser. Biol.* **2017**, *20*, 43–48.
 107. Sarikurku, C.; Sahinler, S.S.; Tepe, B. *Astragalus gymmolobus*, *A. leporinus* var. *hirsutus*, and *A. onobrychis*: Phytochemical Analysis and Biological Activity. *Ind. Crops Prod.* **2020**, *150*, 112366.
 108. Tatiya, A.U.; Surana, S.J.; Khope, S.D.; Gokhale, S.B.; Sutar, M.P. Phytochemical Investigation and Immunomodulatory Activity of *Amaranthus spinosus* L. *Indian J. Pharm. Educ. Res.* **2007**, *444*, 337–341.
 109. Pamela, E.A.I.; Olufemi, T.A.; Yemisi, O.O.; Aduloju, O.A.; Usifo, G.A. Phytochemical Content and Antioxidant Activity of Five Grain Amaranth Species. *Am. J. Food Sci. Technol.* **2017**, *5*, 249–255.
 110. Pasko, P.; Barton, H.; Foltá, M.; Gwizdz, J. Evaluation of Antioxidant Activity of Amaranth *Amaranthus cruentus* Grain and by-Products Flour, Popping, Cereal. *Rocz. Państwowe Zakładu Hig.* **2007**, *581*, 35–40.
 111. Nsimba, R.Y.; Kikuzaki, H.; Konishi, Y. Antioxidant Activity of Various Extracts and Fractions of *Chenopodium quinoa* and *Amaranthus* spp. Seeds. *Food Chem.* **2008**, *106*, 760–766.
 112. Tang, Y.; Tsao, R. Phytochemicals in Quinoa and Amaranth Grains and Their Antioxidant, Anti-Inflammatory, and Potential Health Beneficial Effects: A Review. *Mol. Nutr. Food Res.* **2017**, *61*, 1600767.
 113. Barku, V.Y.A.; Opoku-Boahen, Y.; Owusu-Ansah, E.; Mensah, E.F.; Barku, V.Y.A.; Opoku-Boahen, Y.; Owusu-Ansah, E.; Mensah, E.F. Antioxidant Activity and The Estimation of Total Phenolic and Flavonoid Contents of The Root Extract of *Amaranthus spinosus*. *Asian J. Plant Sci. Res.* **2013**, *3*, 69–74.
 114. Bulbul, I.J.; Nahar, L.; Ripa, F.A.; Haque, O. Antibacterial, Cytotoxic and Antioxidant Activity of Chloroform, N-Hexane and Ethyl Acetate Extract of Plant *Amaranthus spinosus*. *Int. J. PharmTech Res.* **2011**, *33*, 1675–1680.
 115. Kumar, B.S.A.; Lakshman, K.; Jayaveera, K.N.; Shekar, D.S.; Kumar, A.A.; Manoj, B. Antioxidant and Antipyretic Properties of Methanolic Extract of *Amaranthus spinosus* Leaves. *Asian Pac. J. Trop. Med.* **2010**, *3*, 702–706.
 116. Ishtiaq, S.; Ahmad, M.; Hanif, U.; Akbar, S.; Kamran, S.H. Phytochemical and *in-vitro* Antioxidant Evaluation of Different Fractions of *Amaranthus graecizans* subsp. *Silvestris* Vill. Brenan. *Asian Pac. J. Trop. Biomed.* **2014**, *412*, 965–971.
 117. Jimoh, M.O.; Afolayan, A.J.; Lewu, F.B. Antioxidant and Phytochemical Activities of *Amaranthus caudatus* L. Harvested from Different Soils at Various Growth Stages. *Sci. Rep.* **2019**, *9*, 12965.
 118. Karamac, M.; Gai, F.; Longato, E.; Meineri, G.; Janiak, M.A.; Amarowicz, R.; Peiretti, P.G. Antioxidant Activity and Phenolic Composition of Amaranth (*Amaranthus caudatus*) During Plant Growth. *Antioxidants* **2019**, *8*, 173.
 119. Kraujalis, P.; Venskutonis, P.R.; Kraujalienė, V.; Pukalskas, A. Antioxidant properties and preliminary evaluation of phytochemical composition of different anatomical parts of amaranth. *Plant Foods Hum. Nutr.* **2013**, *68*, 322–328.
 120. Kumari, S.; Elancheran, R.; Devi, R. Phytochemical Screening, Antioxidant, Antityrosinase, And Antigenotoxic Potential of *Amaranthus viridis* Extract. *Indian J. Pharmacol.* **2018**, *50*, 130–138.
 121. Lopez-Mejía, O.A.; Lopez-Malo, A.; Palou, E. Antioxidant Capacity of Extracts from Amaranth *Amaranthus hypochondriacus* L. Seeds or Leaves. *Ind. Crop. Prod.* **2014**, *53*, 55–59.
 122. Lucero-Lopez, V.R.; Razzeto, G.S.; Gimenez, M.S.; Escudero, N.L. Antioxidant Properties of *Amaranthus hypochondriacus* Seeds and Their Effect on The Liver of Alcohol-Treated Rats. *Plant Foods Hum. Nutr.* **2011**, *66*, 157–162.
 123. Salvamani, S.; Gunasekaran, B.; Shukor, M.Y.; Shaharuddin, N.A.; Sabullah, M.K.; Ahmad, S.A. Anti-HMG-CoA Reductase, Antioxidant, and Anti-Inflammatory Activities of *Amaranthus viridis* Leaf Extract as A Potential Treatment for Hypercholesterolemia. *Evid. Based Complement. Altern. Med.* **2016**, *2016*, 8090841.
 124. Sandoval-Sicairos, E.S.; Milán-Noris, A.K.; Luna-Vital, D.A.; Milán-Carrillo, J.; Montoya-Rodríguez, A. Anti-Inflammatory and Antioxidant Effects of Peptides Released from Germinated Amaranth During In Vitro Simulated Gastrointestinal Digestion. *Food Chem.* **2021**, *1*, 128394.
 125. Medoua, G.N.; Oldewage-Theron, W.H. Effect of Drying and Cooking on Nutritional Value and Antioxidant Capacity of Morogo (*Amaranthus hybridus*) A Traditional Leafy Vegetable Grown in South Africa. *J. Food Sci. Technol.* **2014**, *51*, 736–742.

126. Tesoriere, L.; Allegra, M.; Gentile, C.; Livrea, M.A. Betacyanins as Phenol Antioxidants. Chemistry and Mechanistic Aspects of the Lipoperoxyl Radical-Scavenging Activity in Solution and Liposomes. *Free Radic. Res.* **2009**, *43*, 706–717.
127. Repo-Carrasco-Valencia, R.; Peña, J.; Kallio, H.; Salminen, S. Dietary Fiber and Other Functional Components in Two Varieties of Crude and Extruded Kiwicha (*Amaranthus caudatus*). *J. Cereal Sci.* **2009**, *49*, 219–224.
128. Jo, H.J.; Chung, K.H.; Yoon, J.A.; Lee, K.J.; Song, B.C.; An, J.H. Radical Scavenging Activities of Tannin Extracted from Amaranth (*Amaranthus caudatus* L.). *J. Microbiol. Biotechnol.* **2015**, *25*, 795–802.
129. Subhasree, B.; Baskar, R.; Laxmi Keerthana, R.; Lijina Susan, R.; Rajasekaran, P. Evaluation of Antioxidant Potential in Selected Green Leafy Vegetables. *Food Chem.* **2009**, *115*, 1213–1220.
130. Lacatusu, I.; Arsenie, K.L.V.; Badea, G.; Popa, O.; Oprea, O.; Badea, N. New Cosmetic Formulations with Broad Photoprotective and Antioxidative Activities Designed by Amaranth and Pumpkin Seed Oils Nanocarriers. *Ind. Crops Prod.* **2018**, *123*, 424–433.
131. Steffensen, S.K.; Pedersen, H.A.; Labouriau, R.; Mortensen, A.G.; Laursen, B.; de Troiani, R.M.; Noellemeyer, E.J.; Janovska, D.; Stavelikova, H.; Taberner, A.; et al. Variation of Polyphenols and Betaines in Aerial Parts of Young, Field-Grown *Amaranthus* genotypes. *J. Agric. Food Chem.* **2011**, *59*, 12073–12082.
132. Niveyro, S.L.; Mortensen, A.G.; Fomsgaard, I.S.; Salvo, A. Differences Among Five Amaranth Varieties (*Amaranthus* spp.) Regarding Secondary Metabolites and Foliar Herbivory by Chewing Insects in The Field. *Arthropod-Plant Interact.* **2013**, *7*, 235–245.
133. Amin, I.; Norazaidah, Y.; Hainida, K.I.E. Antioxidant Activity and Phenolic Content of Raw and Blanched *Amaranthus* species. *Food Chem.* **2006**, *94*, 47–52.
134. Bao, X.; Han, X.; Du, G.; Wei, C.; Zhu, X.; Ren, W.; Zeng, L.; Zhang, Y. Antioxidant Activities and Immunomodulatory Effects in Mice of Betalain In Vivo. *Food Sci.* **2019**, *40*, 196–201.
135. Conforti, F.; Statti, G.; Loizzo, M.R.; Sacchetti, G.; Poli, F.; Menichini, F.; In Vitro Antioxidant Effect and Inhibition of Alpha-Amylase of Two Varieties of *Amaranthus caudatus* Seeds. *Biol. Pharm. Bull.* **2005**, *28*, 1098–1102.
136. Al-Madhagy, S. A.; Mostafa, N. M.; Youssef, F. S.; Awad, G. E. A.; Eldahshan, O. A.; Singab, A. N. B. Metabolic Profiling of a Polyphenolic-Rich Fraction of *Coccinia grandis* Leaves Using LC-ESI-MS/MS and In Vivo Validation of Its Antimicrobial and Wound Healing Activities. *Food Funct.* **2019**, *10*, 6267–6275.
137. Todirascu-Ciornea, E.; El-Nashar, H. A.; Mostafa, N. M.; Eldahshan, O. A.; Boiangiu, R. S.; Dumitru, G.; Hritcu, L.; Singab, A. N. B. *Schinus terebinthifolius* Essential Oil Attenuates Scopolamine-Induced Memory Deficits Via Cholinergic Modulation and Antioxidant Properties in A Zebrafish Model. *Evid.-Based Complement. Altern. Med.* **2019**, *2019*, 1–11.
138. Mostafa, N. M.; Edmond M. P.; El-Shazly, M.; Fahmy, H. A.; Sherif, N. H.; Singab, A. N. B. Phytoconstituents and Renoprotective Effect of *Polyalthia longifolia* Leaves Extract on Radiation-Induced Nephritis in Rats via TGF- β /Smad Pathway. *Nat. Prod. Res.* **2021**. doi:10.1080/14786419.2021.1961252.
139. Mostafa, N. M.; Abd El-Ghffar, E. A.; Hegazy, H. G.; Eldahshan, O. A. New Methoxyflavone from *Casimiroa sapota* and the Biological Activities of Its Leaves Extract Against Lead Acetate Induced Hepatotoxicity in Rats. *Chem. Biodivers.* **2018**, *15*, e1700528.
140. Repo-Carrasco-Valencia, R.; Hellstrom, J.K.; Philava, J.M.; Mattila, P.H. Flavonoids and Other Phenolic Compounds in Andean Indigenous Grains: Quinoa (*Chenopodium quinoa*), Kaniwa (*Chenopodium pallidicaule*) and Kiwicha (*Amaranthus caudatus*). *Food Chem.* **2010**, *120*, 128–133.
141. Cai, Y.; Sun, M.; Corke, H. Antioxidant Activity of Betalains from Plants of The Amaranthaceae. *J. Agric. Food Chem.* **2003**, *51*, 2288–2294.
142. Sarker, U.; Oba, S. Response of Nutrients, Minerals, Antioxidant Leaf Pigments, Vitamins, Polyphenol, Flavonoid and Antioxidant Activity in Selected Vegetable Amaranth under Four Soil Water Content. *Food Chem.* **2018**, *252*, 72–83.
143. Sarker, U.; Oba, S. Drought Stress Enhances Nutritional and Bioactive Compounds, Phenolic Acids and Antioxidant Capacity of *Amaranthus* Leafy Vegetable. *BMC Plant Biol.* **2018**, *18*, 258. <https://doi.org/10.1186/s12870-018-1484-1>.
144. Sarker, U.; Oba, S. Drought Stress Effects on Growth, ROS Markers, Compatible Solutes, Phenolics, Flavonoids, and Antioxidant Activity in *Amaranthus tricolor*. *Appl. Biochem. Biotechnol.* **2018**, *186*, 999–1016. <https://doi.org/10.1007/s12010-018-2784-5>.
145. Sarker, U.; Oba, S. Catalase, Superoxide Dismutase and Ascorbate-Glutathione Cycle Enzymes Confer Drought Tolerance of *A. tricolor*. *Sci. Rep.* **2018**, *8*, 16496. <https://doi.org/10.1038/s41598-018-34944-0>.
146. Jamalluddin, N.; Massawe, F.J.; Mayes, S.; Ho, W.K.; Singh, A.; Symonds, R.C. Physiological Screening for Drought Tolerance Traits in Vegetable Amaranth (*Amaranthus tricolor*) Germplasm. *Agriculture* **2021**, *11*, 994.
147. Liu, F.; Stützel, H. Biomass Partitioning, Specific Leaf Area, and Water Use Efficiency of Vegetable Amaranth (*Amaranthus* spp.) in Response to Drought Stress. *Sci. Hortic.* **2004**, *102*, 15–27.
148. Bello, Z.A.; Walker, S. Evaluating AquaCrop Model for Simulating Production of *Amaranthus* (*Amaranthus cruentus*) a Leafy Vegetable, Under Irrigation and Rainfed Conditions. *Agric. For. Meteorol.* **2017**, *247*, 300–310.
149. Sedibe, M.M.; Combrink, N.J.J.; Reinten, E.Y. Leaf Yield of *Amaranthus hypochondriatus* L. (Imbuya), Affected by Irrigation Systems and Water Quality. *S. Afr. J. Plant Soil* **2013**, *22*, 171–174.
150. Sosnoskie, L.M.; Kichler, J.M.; Wallace, R.D.; Culpepper, A.S. Multiple Resistance in Palmer Amaranth to Glyphosate and Pyri-thiobac Confirmed in Georgia. *Weed Sci.* **2011**, *59*, 321–325.
151. Sarker, U.; Oba, S. Salinity Stress Enhances Color Parameters, Bioactive Leaf Pigments, Vitamins, Polyphenols, Flavonoids and Antioxidant Activity in Selected *Amaranthus* Leafy Vegetables. *J. Sci. Food Agric.* **2019**, *99*, 2275–2284. <https://doi.org/10.1002/jsfa.9423>.

152. Sarker, U.; Oba, S. Augmentation of Leaf Color Parameters, Pigments, Vitamins, Phenolic Acids, Flavonoids and Antioxidant Activity in Selected *Amaranthus tricolor* under Salinity Stress. *Sci. Rep.* **2018**, *8*, 12349. <https://doi.org/10.1038/s41598-018-30897-6>.
153. Sarker, U.; Islam, M.T.; Oba, S. Salinity Stress Accelerates Nutrients, Dietary Fiber, Minerals, Phytochemicals and Antioxidant Activity in *Amaranthus tricolor* Leaves. *PLoS ONE* **2018**, *13*, 0206388. <https://doi.org/10.1371/journal.pone.0206388>.
154. Omamt, E.N.; Hammes, P.S.; Robbertse, P.J. Differences in Salinity Tolerance for Growth and Water-Use Efficiency in Some *Amaranth* (*Amaranthus* spp.) Genotypes. *N. Z. J. Crop Hortic. Sci.* **2006**, *34*, 11–22.
155. Rajan, S.; Markose, B.L. Horticultural Science Series-6. In *Propagation of Horticultural Crops*; Peter, K.M.V., Ed.; New India Publishing Agency: New Delhi, India, 2007; Volume 6, pp. 110–113.
156. Ashmawy, A. M.; Mostafa, N.M.; Eldahshan, O.A. GC/MS Analysis and Molecular Profiling of Lemon Volatile Oil against Breast Cancer. *J. Essent. Oil Bear. Plants.* **2019**, *22* (4), 903–916.
157. El-Nashar, H. A. S.; Mostafa, N. M.; El-Badry, M. A.; Eldahshan, O. A.; Singab, A. N. B. Chemical Composition, Antimicrobial and Cytotoxic Activities of Essential Oils from *Schinus polygamus* (Cav.) Cabrera Leaf and Bark Grown in Egypt. *Nat. Prod. Res.* **2021**, *35*(23), 5369–5372. doi:10.1080/14786419.2020.1765343.
158. El-Nashar, H. A. S.; Mostafa, N. M.; Eldahshan, O. A.; Singab, A. N. B. A New Antidiabetic and Anti-Inflammatory Biflavonoid from *Schinus polygama* (Cav.) Cabrera Leaves. *Nat. Prod. Res.* **2020**, 1–9. doi: 10.1080/14786419.2020.1864365.
159. Abdelghffar, E. A.; El-Nashar, H. A.S.; AL-Mohammadi, A. G. A.; Eldahshan, O. A., Orange fruit (*Citrus sinensis*) Peel Extract Attenuates Chemotherapy-Induced Toxicity in Male Rats. *Food Funct.* **2021**, *12*, 9443–9455.
160. Dugupta, N.; De, B. Antioxidant Activity of Some Leafy Vegetables of India: A Comparative Study. *Food Chem.* **2007**, *101*, 471–474.
161. Isabelle, M.; Lee, B.L.; Lim, M.T.; Koh, W.P.; Huang, D.; Ong, C.N. Antioxidant Activity and Profiles of Common Fruits in Singapore. *Food Chem.* **2010**, *123*, 77–84.
162. Steffensen, S.K.; Rinnan, A.; Mortensen, A.G.; Laursen, B.; Troiani, R.M.; Noellemeyer, E.J.; Janovska, D.; Dusek, K; Délano-Frier, J.; Taberner, A.; et al. Variations in the Polyphenol Content of Seeds of Field Grown *Amaranthus* Accessions. *Food Chem.* **2011**; *129*, 131–138.
163. Rice-Evans, C.A.; Miller, N.J.; Papanga, G. Antioxidant Properties of Phenolic Compounds. *Trends Plant Sci.* **1997**, *2*, 152–159.
164. Sarker, U.; Oba, S. Nutritional and Bioactive Constituents and Scavenging Capacity of Radicals in *Amaranthus hypochondriacus*. *Sci. Rep.* **2020**, *10*, 19962. <https://doi.org/10.1038/s41598-020-71714-3>.
165. Sarker, U.; Hossain, M.N.; Iqbal, M.A.; Oba, S. Bioactive Components and Radical Scavenging Activity in Selected Advance Lines of Salt-Tolerant Vegetable Amaranth. *Front. Nutr.* **2020**, *7*, 587257. <https://doi.org/10.3389/fnut.2020.587257>.
166. Sarker, U.; Oba, S. Nutraceuticals, Phytochemicals, and Radical Quenching Ability of Selected Drought-Tolerant Advance Lines of Vegetable Amaranth. *BMC Plant Biol.* **2020**, *20*, 564. <https://doi.org/10.1186/s12870-020-02780-y>.
167. Sarker, U.; Oba, S. Antioxidant Constituents of Three Selected Red and Green Color Amaranthus Leafy Vegetable. *Sci. Rep.* **2019**, *9*, 18233. <https://doi.org/10.1038/s41598-019-52033-8>.
168. Sarker, U.; Oba, S. Leaf Pigmentation, Its Profiles and Radical Scavenging Activity in Selected *Amaranthus tricolor* Leafy Vegetables. *Sci. Rep.* **2020**, *10*, 18617. <https://doi.org/10.1038/s41598-020-66376-0>.
169. Sarker, U.; Oba, S. Color Attributes, Betacyanin, and Carotenoid Profiles, Bioactive Components, and Radical Quenching Capacity in Selected *Amaranthus gangeticus* Leafy Vegetables. *Sci. Rep.* **2021**, *11*, 11559. <https://doi.org/10.1038/s41598-021-91157-8>.
170. Sarker, U.; Oba, S. The Response of Salinity Stress-Induced *A. tricolor* to Growth, Anatomy, Physiology, Non-Enzymatic and Enzymatic Antioxidants. *Front. Plant Sci.* **2020**, *11*, 559876. <https://doi.org/10.3389/fpls.2020.559876>.
171. Sarker, U.; Oba, S. Phenolic Profiles and Antioxidant Activities in Selected Drought-Tolerant Leafy Vegetable Amaranth. *Sci. Rep.* **2020**, *10*, 18287. <https://doi.org/10.1038/s41598-020-71727-y>.
172. Sarker, U.; Oba, S. Polyphenol and Flavonoid Profiles and Radical Scavenging Activity in Selected Leafy Vegetable *Amaranthus gangeticus*. *BMC Plant Biol.* **2020**, *20*, 499. <https://doi.org/10.1186/s12870-020-02700-0>.
173. Rashad, M.M.I.; Sarker, U. Genetic Variations in Yield and Yield Contributing Traits of Green Amaranth. *Genetika* **2020**, *52*, 393–407.
174. Hasan-Ud-Daula, M.; Sarker, U. Variability, Heritability, Character Association, and Path Coefficient Analysis in Advanced Breeding Lines of Rice (*Oryza Sativa* L.). *Genetika* **2020**, *52*, 711–726.
175. Hasan, M.J.; Kulsum, M.U.; Majumder, R.R.; Sarker, U. Genotypic Variability for Grain Quality Attributes in Restorer Lines of Hybrid Rice. *Genetika* **2020**, *52*, 973–989. <https://doi.org/10.2298/GENSR2003973H>.
176. Azad, A.K.; Sarker, U.; Ercisli, S.; Assouguem, A.; Ullah, R.; Almeer, R.; Sayed, A.A.; Peluso, I. Evaluation of Combining Ability and Heterosis of Popular Restorer and Male Sterile Lines for the Development of Superior Rice Hybrids. *Agronomy* **2022**, *12*, 965. <https://doi.org/10.3390/agronomy12040965>.
177. Sun, H.; Mu, T.; Xi, L.; Zhang, M.; Chen, J. Sweet Potato (*Ipomoea batatas* L.) Leaves as Nutritional and Functional Foods. *Food Chem.* **2014**, *156*, 380–389.
178. Sarker, U.; Oba, S. Protein, Dietary Fiber, Minerals, Antioxidant Pigments and Phytochemicals, and Antioxidant Activity in Selected Red Morph *Amaranthus* Leafy Vegetable. *PLoS ONE* **2019**, *14*, 0222517. <https://doi.org/10.1371/journal.pone.0222517>.
179. Sarker, U.; Oba, S. Nutraceuticals, Antioxidant Pigments, and Phytochemicals in the Leaves of *Amaranthus spinosus* and *Amaranthus viridis* Weedy Species. *Sci. Rep.* **2019**, *9*, 20413. <https://doi.org/10.1038/s41598-019-50977-5>.

180. Sarker, U.; Hossain, M.M.; Oba, S. Nutritional and Antioxidant Components and Antioxidant Capacity in Green Morph Amaranthus Leafy Vegetable. *Sci. Rep.* **2020**, *10*, 1336. <https://doi.org/10.1038/s41598-020-57687-3>.
181. Sarker, U.; Oba, S.; Daramy, M.A. Nutrients, Minerals, Antioxidant Pigments and Phytochemicals, and Antioxidant Capacity of the Leaves of Stem Amaranth. *Sci. Rep.* **2020**, *10*, 3892. <https://doi.org/10.1038/s41598-020-60252-7>.
182. Sarker, U.; Oba, S. Nutrients, Minerals, Pigments, Phytochemical, and Radical Scavenging Activity in *Amaranthus blitum* Leafy Vegetable. *Sci. Rep.* **2020**, *10*, 3868. <https://doi.org/10.1038/s41598-020-59848-w>.
183. Jimenez-Aguilar, D.M.; Grusak, M.A. Minerals, Vitamin C, Phenolics, Flavonoids and Antioxidant Activity of *Amaranthus* Leafy Vegetables. *J. Food Compos. Anal.* **2017**, *58*, 33–39.
184. Madruga, M.S.; Camara, F.S. The Chemical Composition of “Multimistura” as a Food Supplement. *Food Chem.* **2000**, *68*, 41–44.
185. Shahidi, F.; Chavan, U.D.; Bal, A.K.; McKenzie, D.B. Chemical Composition of Beach Pea (*Lathyrus maritimus* L.) Plant Parts. *Food Chem.* **1999**, *64*, 39–44.
186. Khanam, U.K.S.; Oba, S. Bioactive Substances in Leaves of Two Amaranth Species, *Amaranthus lividus*, and *A. hypochondriacus*. *Can. J. Plant Sci.* **2013**, *93*, 47–58.
187. Khanam, U.K.S.; Oba, S.; Yanase, E.; Murakami, Y. Phenolic Acids, flavonoids and Total Antioxidant Capacity of Selected Leafy Vegetables. *J. Funct. Foods* **2012**, *4*, 979–987.
188. Hossain, M.N.; Sarker, U.; Raihan, M.S.; Al-Huqail, A.A.; Siddiqui, M.H.; Oba, S. Influence of Salinity Stress on Color Parameters, Leaf Pigmentation, Polyphenol and Flavonoid Contents, and Antioxidant Activity of *Amaranthus lividus* Leafy Vegetables. *Molecules* **2022**, *27*, 1821. <https://doi.org/10.3390/molecules27061821>.
189. Sarker, U.; Oba, S.; Ercisli, S.; Assouguem, A.; Alotaibi, A.; Ullah, R. Bioactive Phytochemicals and Quenching Activity of Radicals in Selected Drought-Resistant *Amaranthus tricolor* Vegetable Amaranth. *Antioxidants* **2022**, *11*, 578. <https://doi.org/10.3390/antiox11030578>.
190. Alam, M.A.; Juraimi, A.S.; Rafii, M.Y.; Hamid, A.A.; Aslani, F.; Alam, M.Z. Effects of Salinity and Salinity-Induced Augmented Bioactive Compounds in Purslane (*Portulaca oleracea* L.) for Possible Economical Use. *Food Chem.* **2015**, *169*, 439–447. <https://doi.org/10.1016/j.foodchem.2014.08.019>.