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Effect of Drying Techniques on Phytochemical and Vitamin Compositions of Three Species of Amaranth

Oguji O.A. [a*], Obiegbuna J.E. [a], Ubaka I.T. [a] and Chukwunenye, V.C. [a]

[a] *Nnamdi Azikiwe University, Awka P.M.B. 5025, Awka, Anambra State, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Amaranth species are highly valued for their rich phytochemical and vitamin content, making them important for both nutrition and health. However, preserving these nutrients during post-harvest processing, particularly drying, is critical to maintaining their benefits. This study investigates the impact of different drying techniques on the phytochemical and vitamin compositions of three Amaranth species: *Amaranthus tricolor*, *Amaranthus hybridus*, and *Amaranthus cruentus*. The experimental design involved subjecting fresh samples of each species to three different drying treatments: shade drying, oven drying at 40°C, and oven drying at 60°C. Standard analytical procedures were followed to quantify phytochemicals (flavonoids, tannins, saponins, alkaloids, phenols, and phytates) and vitamins (A and C). Data were statistically analyzed using the Statistical

**Corresponding author: E-mail: ogujiann@gmail.com;*

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Product and Service Solutions (SPSS), with two-way analysis of variance (ANOVA) employed to compare the means across the different drying methods. The results revealed significant variations in the phytochemical compositions across the drying treatments. For *Amaranthus tricolor*, the phytochemical contents ranged from 13.81 to 15.92 mgCE/g for flavonoids, 1.65 to 2.84 mgTAE/g for tannins, 1.23% to 1.63% for saponins, 2.04% to 4.93% for alkaloids, 5.54 to 10.12 mgGAE/g for phenols, and 0.1% to 0.19% for phytates. Similarly, *Amaranthus hybridus* showed ranges of 12.01 to 12.71 mgCE/g for flavonoids, 1.01 to 3.65 mgTAE/g for tannins, 1.37% to 1.52% for saponins, 2.95% to 6.76% for alkaloids, 3.62 to 7.83 mgGAE/g for phenols, and 0.16% to 0.91% for phytates. *Amaranthus cruentus* demonstrated phytochemical ranges of 15.76 to 18.83 mgCE/g for flavonoids, 0.53 to 2.90 mgTAE/g for tannins, 1.75% to 1.87% for saponins, 1.98% to 4.0% for alkaloids, 5.54 to 8.35 mgGAE/g for phenols, and 0.12% to 0.18% for phytates. Vitamin A content ranged from 7.0 to 10.52 mg/100g in *Amaranthus tricolor*, 8.67 to 10.61 mg/100g in *Amaranthus hybridus*, and 9.09 to 10.73 mg/100g in *Amaranthus cruentus*. Vitamin C content ranged from 41.60 to 45.15 mg/100g in *Amaranthus tricolor*, 33.80 to 37.85 mg/100g in *Amaranthus hybridus*, and 44.08 to 50.61 mg/100g in *Amaranthus cruentus*. The findings emphasize that all drying techniques employed—shade drying, oven drying at 40°C, and oven drying at 60°C—are effective in retaining high levels of vitamins and phytochemicals in the three Amaranth species. However, the choice of drying method may be tailored depending on specific nutrient retention goals. This study provides valuable insights for optimizing drying processes to preserve the nutritional quality of Amaranth species.

Keywords: Plant; Amaranthus tricolor; Amaranthus hybridus; Amaranthus cruentus; room-dried; oven-dried.

1. INTRODUCTION

Plants generate a multitude of chemical compounds that serve diverse purposes, such as defending against insects, fungi, diseases, and herbivorous mammals [1]. The fresh, edible parts of herbaceous plants are commonly known as vegetables, which are vital to a nutritious diet. They are emphasized in dietary guidelines due to their high levels of dietary fiber, vitamins, minerals (particularly electrolytes), and phytochemicals, especially antioxidants [2].

The plant Amaranthus spp. is significant in both food and medicine, with its nutritional and ethnomedicinal applications widely utilized globally for preventing and managing certain diseases. Fresh Amaranth plants are plentiful in the summer and rainy seasons but have a short shelf life due to their high moisture content, resulting in nutrient loss and market scarcity (Nighitha and Santhi, 2019). This necessitates prompt processing to prevent substantial nutritional and economic losses and to ensure availability during the off-season at profitable prices [3].

Amaranth (*Amaranthus spp*.) is an edible green leafy vegetable native to Central America, including Mexico and nearby countries. It thrives in both temperate and tropical climates and is cultivated for its grains and leaves [4]. The primary species of grain amaranth are *Amaranthus caudatus, Amaranthus cruentus,* and *Amaranthus hypochondriacus,* with *Amaranthus hybridus* and *Amaranthus tricolor* being grown to a lesser extent for their leaves [5]. Fresh leaves from species like *Amaranthus tricolor, Amaranthus cruentus, Amaranthus hypochondriacus, Amaranthus dubius, Amaranthus blitum,* and *Amaranthus edulis* are commonly used in soups and salads.

Amaranthus tricolor, also known as Joseph's coat or Red Amaranth, is an edible species cultivated for both ornamental and culinary uses. It is grown annually for its vibrant, colorful foliage rather than its flowers, earning it the name Joseph's coat [6].

Amaranthus hybridus, commonly called Smooth Pigweed or Green, Smooth, or Red Amaranth, is an annual herbaceous plant that reproduces solely through seeds. Its stems are thick, often ribbed, and may have a red tinge. At maturity, the entire plant can turn reddish, and its seeds are round or dark brown [7].

Amaranthus cruentus, known as Red Amaranth, is a tall annual herbaceous plant with clusters of dark pink flowers. It reproduces only by seeds and has a short growing period of 4-6 weeks. At maturity, the plant can turn completely reddish [8,9].

Drying is a key traditional method for preserving vegetables. It transforms leafy vegetables into a

lightweight product that is easy to transport and store.

2. MATERIALS AND METHODS

2.1 Sources of Raw Materials

The fresh species of Amaranth were obtained from Aguluezechukwu farmland, Aguata Local Government Area of Anambra State, Nigeria. These species are *Amaranthus tricolor, Amaranthus hybridus*, and *Amaranthus cruentus*; and they were selected based on their high yield and agronomic desirability. The plant sample(s) collected were taken to the Department of Botany, Nnamdi Azikiwe University Awka, where it were identified and authenticated by Mr. Iroka Chisom, a taxonomist in the Department. A sample(s) specimen were deposited and a voucher number NAUH-062^{A}, NAUH-232^{A} and NAUH-233^{A} were issued to *Amaranthus hybridus*, *Amaranthus tricolor* and *Amaranthus cruentus* respectively.

2.2 Sample Preparation and Drying of Three Species of Amaranth

This was done in the Food Processing Laboratory of the Department of Food Science and Technology, Nnamdi Azikiwe University, Awka, Anambra state. The samples stalks were removed and the samples rinsed with clean running tap water to remove unwanted external material such as dust, soil and other contaminants. The samples were sliced thinly using sharp stainless knife to enable proper drying. Then moisture evaporated using different drying techniques which includes room temperature and oven drying at different temperatures (40°C and 60°C). for 2 days with constant turning over to minimize the extent of fungal growth. The dried samples were ground into fine powder using blender and sieved through a 0.5 mm mesh sieve to obtain a dried powdered samples that were used for analyses. They were packaged in sealed polythene bags to prevent moisture absorption. It was thereafter taken to Alpha Laboratory Awka, Anambra state for further analysis. Anambra state is located in the south-eastern part of Nigeria and situated between latitudes 5° 32' and 6° 45' N and longitude 6° 43' and 7° 22' E, respectively.

2.3 Experimental Design

This experiment was laid out in a 3 *by* 4 Factorial Design comprising of 12 treatments and 3 replications shown in the Table 1. The three species A. *hybridus* (AH), A. *tricolor* (AT) and A. *Cruentus* (AC) were studied under fresh, room dried, oven dried at 40^{o}C and oven dried at 60^{o}C conditions, labelled 1, 2, 3 and 4 respectively in Table 1. Each of the species was analyzed for phytochemical and vitamin compositions.

3. METHODS OF ANALYSIS

3.1 Phytochemical Analyses

3.1.1 Determination of flavonoids, saponins and tannins

The flavonoids, saponins and tannins content were determined according to the method of Onwuka [10].

3.1.2 Determination of alkaloids

The alkaloid content was determined according to the method of Harborne [11].

3.1.3 Determination of phytates

The phytate content was determined according to the method of Young and Greaves [12].

3.1.4 Determination of total phenols

The phenolic content of the sample(s) was determined according to the AOAC method [13].

3.2 Vitamins Analyses

3.2.1 Determination of vitamin A (retinol) and vitamin C (ascorbic acid)

Vitamin A content was determined according to the method of AOAC [13].

Table 1. Design matrix

Amaranth	Fresh	Withering (Room drying)	Oven Drying	
			40^{o}C	60^{o}C
A. Hybridus	AH_1	AH_2	AH_3	AH_4
A. tricolor	AT_1	AT_2	AT_3	AT_4
A. Cruentus	AC_1	AC_2	AC_3	AC_4

4. RESULTS AND DISCUSSION

4.1 Phytochemical Composition of *Amaranth tricolor*, *Amaranth hybridus*, *Amaranth cruentus*

The phytochemicals contents of fresh and dried Amaranthus leaves are shown in Table 2. Fresh *Amaranthus cruentus* had significantly ($p < 0.05$) the highest flavonoid (19.82 mg/100g), Saponins (1.86 mg/100 g) and phenols (9.62 mg/100 g); while *Amaranthus hybridus* specie had the highest tannins (3.53 mg/100 g) and alkaloid (6.76 mg/ 100 g) and *Amaranthus tricolor* had the highest phytate (1.91 mg/ 100g) content. The fresh leaves of *Amaranthus tricolor* had significantly ($p < 0.05$) higher amount of flavonoid than *Amaranthus hybridus* that had 11.45 mg /100 g. Highest amount of the flavonoid was maintained by dried *Amaranthus cruentus* (18.83 – 15.76 mg/ 100 g). Shade drying that took place at about 30 ± 20°C and oven drying at 40°C increased ($p < 0.05$) the content of the flavonoid. This was evident in the values recorded in *Amaranthus hybridus* and *Amaranthus tricolor* leaves. The effect of shade drying and drying at 40°C did not differ significantly ($p > 0.05$) as observed in the *Amaranthus tricolor* with values of 15.85 and 15.92 mg/100 g, respectively; and in *Amaranthus cruentus* with flavored content of 18.65 and 18.83 mg /100 g, respectively. Drying at 60°C significantly ($p< 0.05$) reduced the flavonoid content indicating its heat sensitivity. An average of total flavonoid content of 94.26 RE mg/g DW and 103.16 RE mg/g DW were reported for green and red amaranth, respectively, by Hague et al. [14]. Umakanta et al. [15] reported a range of 62.54 to 157.40 RE mg/g DW with a mean of 94.81 RE mg/g DW of flavonoid for 12 genotypes of Amaranthus while Akubugwo et al. [7] observed a value of 0.83 mg/100 g flavonoid for *Amaranth* hybridus. Khair et al. [16] also reported a range of 62.6 to 77.7 GAE mg/g and 53.6 – 70.4 GAE mg/g total flavonoid for two Amaranth species.

Table 2. Phytochemical compositions of three amaranthus species leaves as affected by drying techniques

Amaranth Species	Drying Technique			
	Fresh (non-dried)	Shade dried	Oven dried (40°C)	Oven dried (60°C)
		Flavonoid (mgCE/ 100 g		
A. tricolor	15.47^{b}_{x}±0.19	15.85^{b}_{w}±0.03	15.92^{b}_{w}±0.03	13.81^{b}_{y}±0.01
A. hybridus	11.45^{c}_{y} ±0.04	12.01^{c}_{x}±0.01	12.71^{c}_{w}±0.02	12.11^{c}_{x}±0.00
A. cruentus	19.82^{a}_{w}±0.01	18.65^{a}_{x}±0.03	18.83^{a}_{x}±0.01	15.76^{a}_{y}±0.05
		Tannins (mg/ 100 g		
A. tricolor	2.14^{b}_{x}±0.03	2.84^{c}_{w}±0.02	2.03^{b}_{y}±0.02	1.65^{a}_{z}±0.00
A. hybridus	3.53^{a}_{x}±0.03	3.65^{a}_{w}±0.02	2.23^{a}_{y}±0.03	1.01^{b}_{z}±0.02
A. cruentus	1.92^{c}_{x}±0.02	2.90^{b}_{w}±0.00	0.65^{c}_{y}±0.01	0.53^{c}_{z}±0.01
		Saponins (mg/100 g)		
A. tricolor	1.51^{c}_{x}±0.00	1.23^{c}_{y}±0.04	1.63^{b}_{w}±0.01	1.26^{c}_{y}±0.00
A. hybridus	1.76^{b}_{w}±0.01	1.52^{b}_{x}±0.00	1.37^{c}_{z}±0.00	1.46^{b}_{y}±0.02
A. cruentus	1.86^{a}_{w}±0.00	1.87^{a}_{w}±0.02	1.75^{a}_{x}±0.01	1.86^{a}_{w}±0.01
		Alkaloids (mg/ 100 g)		
A. tricolor	4.52^{b}_{x}±0.02	4.93^{b}_{w}±0.02	2.13^{b}_{y}±0.03	2.04^{b}_{z}±0.04
A. hybridus	6.76^{a}_{w}±0.01	6.76^{a}_{w}±0.01	3.66^{a}_{x}±0.02	2.95^{a}_{y}±0.03
A. cruentus	3.82^{c}_{x}±0.02	4.00^{c}_{w}±0.00	2.03^{c}_{y}±0.03	1.98^{c}_{z}±0.02
		Phenols (mg/ 100 g)		
A. tricolor	9.20^{b}_{x}±0.05	10.12^{a}_{w}±0.03	7.62^{a}_{y}±0.02	5.54^{a}_{z}±0.00
A. hybridus	7.78^{c}_{x}±0.04	7.83^{c}_{w}±0.01	5.74^{c}_{y}±0.00	3.62^{b}_{z}±0.03
A. cruentus	9.62^{a}_{w}±0.00	8.35^{b}_{x}±0.00	6.81^{b}_{y}±0.01	5.54^{a}_{z}±0.02
		Phytate		
A. tricolor	1.91^{a}_{w}±0.04	0.10^{b}_{z}±0.01	0.15^{b}_{y}±0.03	0.19^{a}_{x}±0.01
A. hybridus	1.13^{c}_{w}±0.01	0.17^{a}_{y}±0.01	0.91^{a}_{x}±0.01	0.16^{b}_{y}±0.00
A. cruentus	1.72^{b}_{w}±0.00	0.18^{a}_{x}±0.01	0.12^{c}_{z}±0.00	0.18^{ab}_{x}±0.01

I. Values are mean ± standard deviation of triplicate determinations

II. Values/means with different superscripts within column; and different subscripts along a row are significant ($p < 0.05$)

Table 3. Vitamins A and C compositions of three amaranthus species leaves as affected by drying techniques

Amaranth Species	Drying Technique			
	Fresh (non-dried)	Shade dried	Oven dried (40ºC)	Oven dried (60ºC)
	Vitamin A (mg/ 100 g)			
A. tricolor	10.09^{c}_{x}±0.09	10.52^{c}_{w}±0.02	8.95^{b}_{y}±0.02	7.00^{c}_{z}±0.00
A. hybridus	10.64^{b}_{w}±0.01	10.61^{b}_{w}±0.01	9.05^{a}_{x}±0.05	8.67^{b}_{y}±0.02
A. cruentus	10.73^{a}_{w}±0.02	10.73^{a}_{w}±0.02	9.13^{a}_{x}±0.03	9.09^{a}_{x}±0.08
	Vitamin C (mg/ 100 g)			
A. tricolor	40.18^{b}_{z}±0.00	43.77^{b}_{x}±0.00	45.15^{b}_{w}±0.02	41.60^{b}_{y}±0.05
A. hybridus	36.25^{c}_{y}±0.17	36.84^{c}_{x}±0.04	37.85^{c}_{w}±0.04	33.80^{c}_{z}±0.00
A. cruentus	52.03^{a}_{w}±0.04	50.61^{a}_{x}±0.02	50.32^{a}_{y}±0.01	44.08^{a}_{z}±0.02

I. Values are mean ± standard deviation of triplicate determinations

II. Values/means with different superscripts within column; and different subscripts along a row are significant (p < 0.05)

Amaranth hybridus leaves had the highest tannin content with 3.53 mg/ 100 g, and lowest in *Amaranth cruentus* with 1.92 mg/100 g. *Amaranthus hybridus* maintained the highest also in the shade dried and 40°C oven dried leaves (3.65 and 2.23 mg/100 g, respectively). The Tannin content increased in the shade dried leaves than in the 40°C oven dried leaves. Drying at 60°C significantly ($p < 0.05$) reduced the tannins content.

Like in flavonoids, *Amaranth cruentus* fresh leaves had the highest saponins (1.86 mg/100 g) and maintained significantly the highest (1.87 – 1.75 mg/100 g) in the dried leaves among other species. Fresh and dried leaves of *Amaranth tricolor* had the lowest saponins content (1.51-1.23 mg/ 100g); and *Amaranth hybridus* the range of 1.76 – 1.37 mg/ 100g. Unlike in tannin and flavonoid, shade drying rather than increasing the saponin content decreased it signifying more heat sensitivity of saponins. Drying at 40°C and 60°C had more severe effect on the saponins as the content decreased with increasing temperature.

As seen in Table 2, fresh and dried *Amaranthus hybridus* leaves had the highest alkaloid content of 6.76 to 2.95 mg/100g. This was followed by *Amaranthus tricolor* with the content of 4.52 to 2.04 mg/ 100g and then *Amaranthus cruentus* with the lowest content of 4.00 - 1.98 mg/100g indicating that among the three species, *Amaranthus cruentus* had the lowest source. Also just like in flavonoid and tannins, alkaloid content was increased by shade drying that took place at about 30 ± 20°C but was decreased by drying at 40°C and 60°C with the loss in the latter being more severe.

Table 2 revealed that fresh leaves of *Amaranthus cruentus* had significantly ($p < 0.05$) the highest content of phenols (9.62 mg/100g) than *Amaranthus tricolor* that had 9.20 mg/100g and *Amaranthus hybridus* that had 7.78 mg/100g. However, among the dried leaves, *Amaranthus tricolor* had the highest content with the range of 10.20 to 5.54 mg/100g and was followed by *Amaranthus cruentus* with the range of 8.35-5.54 mg/100g and then *Amaranthus hybridus* with 7.83 – 3.62 mg/100g. In all, shade drying conserved the highest phenol content of 10.12, 8.35 and 7.83 mg/100g in *Amaranthus tricolor*, *Amaranthus cruentus* and *Amaranthus hybridus* respectively; and oven drying at 60°C the least values of 5.54 and 3.62 mg/100g.

The fresh leaves of *Amaranthus tricolor* had the highest amount of phytate (1.91mg/100g) compared to other species, *Amaranthus cruentus* had (1.72mg/100g) and then *Amaranthus hybridus* (1,13mg/100g). Amaranthus hybridus showed a notable increase in phytate content after drying the species and ranged from 0.16 -0.91mg/100g surpassing the phytate levels of *Amaranthus tricolor* having 0.10 – 0.15mg/100g and *Amaranthus cruentus* 0.12 – 0.18 mg/100g. This suggests that the drying process observed might enhance phytate concentration in *Amaranthus hybridus*.

4.2 Vitamin Composition of *Amaranth tricolor*, *Amaranth hybridus*, *Amaranth cruentus*

The Vitamins A and C compositions of Amaranthus leaves are shown in Table 3. There is a significant ($p < 0.05$) difference among the fresh Amaranthus species and the dried samples occasioned by different drying

techniques/temperatures. The Vitamin A content for fresh *Amaranthus cruentus* was highest (10.73 mg/100g) while that of *Amaranthus tricolor* was the lowest (10.73 mg/100g). This trend was maintained in the dried samples where *Amaranthus cruentus* had the highest range of 10.73 mg/100 g to 9.09 mg/100 g; and *Amaranthus tricolor* the lowest range of 10.52 mg/100g to 7.00 mg/100g. *Amaranthus hybridus* maintained a middle range of 10.61 mg/100 g to 8.67 mg/100g. Shade drying did not significantly ($p < 0.05$) affect the vitamin A content of the Amaranthus leaves but drying at 40°C and 60°C did with drying at 60°C being the most severe. Akubugwo et al. [7] reported the vitamin A content of 3.29 mg/100g for sundried leaves of *Amaranthus hybridus*. The quantity of vitamin A in the species of amaranth could play its role in a multitude of physiological processes, which include vision, bone health, immune function and coagulation [17].

Table 3 revealed that Amaranthus leaves had higher amount of vitamin C than vitamin A with *Amaranthus cruentus* maintaining the highest amount of 52.03 to 44.08 mg/100g. However, *Amaranthus hybridus*, had the least amount (36.25 to 33.80 mg/100g). *Amaranthus tricolor* took the middle range of 45.15 to 40.18 mg/100g. Drying at 40°C seemed to have conserved more vitamin C in Amaranthus leaves than Shade drying and drying at 60°C. The variation in vitamin C retention in the shade-dried sample at 40°C might be due to the lower heat drying period [18]. The benefit of vitamin C could help boost the body immunity. They contain bioactive compounds which protect the body from nutritional deficiency diseases and free radicals that cause oxidative damage to cells [19].

5. CONCLUSION

This study demonstrates that the dried leaves of *Amaranthus tricolor*, *Amaranthus hybridus* and *Amaranthus cruentus* have good food values and phytochemical potential in maintenance of healthy living. From the analysis, these species of Amaranth especially *Amaranthus cruentus* (fresh and all treatments) contain good source of health-promoting bioactive chemical constitutes needed in prevention and management of some non-communicable diseases.

Based on the different drying treatments employed, the dried species of Amaranth contained different proportion of nutrients. Drying at 40^{o}C retained a higher proportion of heat sensitive nutrients such as vitamin C.

Drying at 60^{o}C, resulted in greater degradation of heat sensitive nutrients due to the higher temperature. The result of this study indicates that the best drying technique for high retention of vitamins and phytochemicals, food values, and vitamins in these samples is shade drying.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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