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# Characterization of Nutritional Potential of *Amaranthus sp.* Grain Production

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**Abstract:** The growing demand for nutritious foods has spurred investigations into alternative sources of nutrition beyond traditional options. For this reason, the present study approaches the amaranth, which is a plant with high potential, highlighting the morphological growth, grain biomass production, and quantitative traits of seven varieties of amaranth cultivated in the pedoclimatic conditions of Somes meadow in Transylvania. A bifactorial trial was implemented with factors amaranth species and amaranth varieties. Two amaranth species and seven varieties were studied. Differences are reported between morpho-productive and quantitative traits of the seven amaranth varieties studied in this research. The interrelationships between amaranth morphological traits quantified by using Pearson simple correlations show that morphological traits moderately contribute to grain fresh biomass yield, while morphological traits and fresh biomass strongly contributed to grains dry biomass yield. Our study shows that morpho-productive, and nutritional characteristics of the seven amaranth varieties comprised by our study recommend the plans to be used in various nutritional aims, being a valuable replacer of traditional raw materials in specific food and feed industry sectors.

**Keywords:** morpho-productive traits; correlations; food; seed

## 1. Introduction

The increasing need for healthy foods has promoted the research of alternatives to usual nutritional resources [1]. Such an alternative is the use of amaranth, which is a pseudocereal well known for its good nutritional attributes, and functional food potential [2]. Pseudocereals are grains that even though are produced by other botanical families than cereals (which belong to Poaceae family), they have similar nutritional traits to them. They are characterized by elevated protein content and absence of gluten [3]. The considerable genetic diversity and adaptability to challenging environmental conditions are highly beneficial characteristics for effectively handling these plants [4–6].

Amaranthus sp., which originated from South America [7] is represented by nearly 60 species, with the majority not commonly featured in human and/or animal nutrition. Some amaranth varieties of leaves (e.i. A. *blitum, A. cruentus, A. dubius, A. edulis, A. hypochondriacus, A. tricolor*) may be used, fresh, in slads and soups. Seeds from some varieties (e.i. *A. caudatus, A. cruentus, A. hybridus, A. hypochondriacus, A. mantegazzianus*) are used as raw material in food industry, or for enhancing the

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flavor and nutritional value of various food items such as bread, cookies, cakes, etc. [8]. Other varieties (e.i. *A. retroflexus, A. spinosus, A. viridis*), are not edible for humans or animals [9]. Due to its rich nutritional content, practical utility, environmental resilience, adaptability to difficult cultivation conditions, FAO experts have acknowledged amaranth among the plants of the future [10,11].

Broadly speaking, amaranth has the capacity to lower serum cholesterol levels through the coordinated impact of multiple factors [12]. Amaranth biocompounds, as fats and soluble fibers contains phytosterols that exhibit hypocholesterolemic effects [13].

Amaranth grains are used in monogastric feed (broilers, rabbits, and pigs) [7]. Studies conducted on rabbits and pigs show an increase of rabbit meat dry matter, protein, and fat contents [14], and pig meat dry matter [15]. The grains are also used in human nutrition as flakes, flour, or even as source of functional drinks [7,16]. Amaranth flour can replace wheat flour entirely or partially and may be used for preparing a large diversity of food, such as pasta, cookies, breads, porridge, etc. [17–19].

Amaranth is particularly notable for its high protein content, which is higher than most other grains as wheat, maize, barley, or oat [20,21]. The protein in amaranth is also considered to be of high quality because it contains all the essential amino acids, including lysine, which is often lacking in other grains, [22,23]. Like other grains, amaranth is primarily composed of carbohydrates. It has low glycemic index, meaning it has a minimal impact on blood sugar levels. This makes it a suitable choice for people monitoring their blood sugar levels. Amaranth is a good source of both soluble and insoluble dietary fiber, containing up to 5%, which is important for digestive health [20,24]. Fiber helps regulate bowel movements, promotes satiety, and may help lower cholesterol levels. It contains various vitamins, including vitamin A, vitamin C, vitamin E, and several B vitamins such as folate, riboflavin, and niacin. These vitamins play essential roles in proteins and carbohydrates metabolism, skin health, blood circulation, immune function, and overall health [21,25]. Amaranth grains are considered rich in minerals such as iron, calcium, potassium, magnesium, phosphorus, or zinc, which are minerals of high value for bone health, muscle function, and overall cellular function within the body. Amaranth is naturally gluten-free, making it a suitable grain alternative for individuals with gluten intolerance or celiac disease [7,23]. It is low in saturated fatty acids (C16:0, C18:0), but contains up to 73% primarily unsaturated fatty acids (PUFA) in amaranth oil, which are beneficial for heart health when consumed in moderation [24].

Amaranth is considered functional food because it is a valuable source of antioxidants, including phenolic compounds and flavonoids, which help protect the body against oxidative stress and reduce the risk of chronic diseases such as heart disease and cancer [22,23]. Polyphenols are phytochemicals known for their antioxidant properties and potential health-promoting effects [25,26]. The total polyphenolic content of amaranth may vary depending on factors like variety, growing conditions, and processing methods. The amaranth contains rutin, a flavonoid known for its antioxidant and anti-inflammatory properties. Rutin is associated with improved cardiovascular health and may help reduce the risk of heart disease. Another flavonoid present in amaranth, quercetin, has been studied for its antioxidant, anti-inflammatory, and immune-modulating effects. It may also have potential anticancer properties. Kaempferol is a flavonoid with antioxidant and anti-inflammatory properties found in various plant foods, including amaranth. It may contribute to the health benefits associated with consuming amaranth. Caffeic acid is a phenolic acid present in amaranth and other plant-based foods. It has antioxidant properties and may help protect against oxidative damage [27,28]. Gallic acid is another phenolic acid found in amaranth, and often total polyphenolic content (TPC) is expressed as gallic acid equivalents (GAE/g). It exhibits antioxidant and anti-inflammatory effects and may contribute to the overall health-promoting properties of amaranth [29]. Studies assessing the total polyphenolic content of amaranth have reported varying concentrations from 1.04 up to 14.94 mg GAE/g dry matter, thus, amaranth being considered a good source of polyphenols [30,31]. The exact content can depend on factors such as the part of the plant analyzed (seeds, leaves, or stems), the variety of amaranth, and the methods used for extraction and analysis [22,32].

The aim of the present study is to emphasize the morphological development, grain biomass yield and quantitative characteristics of seven amaranth varieties cultivatred in pedoclimatic

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conditions of Somes meadow in Transylvania, for identifying their suitability to be used in consumption as functional food.

## 2. Materials and Methods

The research was performed in a private farm from Somes meadow, Mireșu Mare commune (47°29′16″N, 23°21′26″E). The regional specific 30 years mean temperature is 8–9 °C, and 700–800 mm mean annual rainfall regimen [33]. Phaeozem soil [34] characterizes the experimental field. It is fertile (with high humus content of 3.20–4.45%) weak acidic (pH = 6.00–6.35) loam clay soil (45.00–56.00% clay).

A bifactorial trial was implemented with factors amaranth species and amaranth varieties. Two amaranth species and seven varieties were studied. Alegria and Amont (*Amaranthus cruentus* L. species), and Golden, Mercado, Hopi Red Dye and Opopeo (*Amaranthus hypochondriacus* L. species). No disease and weed fights were necessary. The sown was made at 0.5 cm depth, with plants density of 70,000 plants/ha, in three repetitions, on experimental field of 6,000 m², with plots of 250 m², by each repetition and variety. In the end of experimental period, the morpho-productive (stem height, number of leaves, grain fresh and dry biomass yields) traits and quantitative (grain dry matter, crude protein, crude ash, crude fat, crude fiber, non-nitrogen extractives and TPC) traits, and their interactions.

The crude chemical composition of amaranth grains was performed according to laboratory methodology proposed by Șara and Odagiu [35]. The TPC were quantified as gallic acid equivalents—mg GAE/g grains [29].

SPSS and XLSTAT were used for statistical data processing. Basic statistics with its components Descriptive statistics and Correlations calculation was implemented with for mean, and standard error of mean calculation, together with simple Pearson correlations between green and dry biomass yields, by each experimental variety. Multivariate analysis was implemented for emphasizing the influence of morphological and quantitative traits on fresh and dry biomatter yields.

## 3. Results

### *3.1. The Morpho-Productive Traits of Six Amaranthus sp. Varieties*

The plants height ranges from 79.33 cm (Opopeo variety) to 101.33 cm (Amont variety), while the number of leaves from 21.67 corresponding to Amont to 32 corresponding to Alegria (Table 1). No significant differences ($p > 0.05$) are found between mean plant height belonging to Amont, Mercado, and Hopy Red Dye varieties on one hand, and between Alegria and Golden, on the other hand. The mean plant height observed in Opopeo differs ($p < 0.05$) from the mean plant heights reported for all other five *Amaranthus* sp. varieties. No differences are observed between the mean number of leaves corresponding to Alegria and Mercado. Between mean number of leaves of Golden and Hopy Red Dye varieties, also no significant differences are observed. Amont variety shows the smallest mean number of leaves, which significantly differs from the means reported for all other five studied varieties. The mean number of leaves observed in Opopeo also differs significantly from the means reported for all other varieties of *Amaranthus* sp.

**Table 1.** The mean plants heights and leaves number of *Amaranthus* sp. varieties.

| Variety | N | Plants height (cm) | Number of leaves |
|---|---|---|---|
| Alegria | 10 | 86.00 ± 0.76b | 32.00 ± 0.93b |
| Amont | 10 | 101.25 ± 2.62a | 21.71 ± 0.69d |
| Golden | 10 | 84.48 ± 1.62b | 23.55 ± 0.71c |
| Mercado | 10 | 98.33 ± 0.95a | 31.67 ± 0.76b |
| Hopy Red Dye | 10 | 99.00 ± 1.23a | 24.46 ± 0.75c |
| Opopeo | 10 | 79.35 ± 1.23c | 27.39 ± 1.17a |

* the differences between any two yield averages are significant, if their values are followed by letters, or groups of different letters.

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Table 2 shows the mean values of green and dry biomass yields of studied of *Amaranthus* sp. varieties. The lowest means of both green and dry biomass yields are observed in Amont (19,432.60 kg green biomass/ha, and 6,603.20 kg dry biomass/ha, respectively), while the highest in Alegria (2,948.60 kg green biomass/ha, and 10,068.06 kg dry biomass/ha, respectively). Similar mean green biomass yields are observed in Alegria and Mercado, but also between Hopy Red Dye and Opopeo. Significant differences are seen between Amont mean green biomass yield and mean yields corresponding to the other studied varieties. No significant differences are between mean dry biomass yields of Hopy Red Dye and Opopeo varieties, but between mean dry biomass yields of above-mentioned varieties and those corresponding to all other *Amaranthus* sp. varieties, significant differences are observed.

**Table 2.** The mean green and dry biomass yield of *Amaranthus* sp. varieties.

| Variety | N | Green biomass yield (kg/ha) | Dry biomass yield (kg/ha) |
|---|---|---|---|
| Alegria | 10 | 25948.60 ± 8.21a | 10068.06 ± 10.69a |
| Amont | 10 | 19432.60 ± 7.52b | 6603.20 ± 8.59b |
| Golden | 10 | 20886.80 ± 7.21c | 7542.22 ± 8.37c |
| Mercado | 10 | 25690.60 ± 8.89a | 9831.79 ± 13.51d |
| Hopy Red Dye | 10 | 22676.60 ± 7.68d | 8279.23 ± 9.62e |
| Opopeo | 10 | 22817.21 ± 5.68d | 8371.56 ± 13.41e |

* the differences between any two yield averages are significant, if their values are followed by letters, or groups of different letters.

The mean green and dry seed yields are presented in Table 3. The highest green seed yield, of 2,768.60 kg/ha corresponds to Alegria, while the lowest of 2,277.80 kg/ha to Amont variety. Alegria and Mercado varieties show similar green seed yields among all *Amaranthus* sp. varieties. Also, between green seed yields corresponding to Hopy Red Dye and Opopeo no significant yields are observed. The mean green seed yield reported in Amont, on one hand, and mean green seed yield reported in Golden, on the other hand, differ significantly from mean yields reported for the other studied varieties. In Alegria variety is reported the highest mean dry seed yield (2,270.86 kg/ha), and in Amont, the lowest (1,843.26 kg/ha). Similar dry seed yields are observed in Golden, Hopy Red Dye and Opopeo varieties. Significant differences are reported between dry seed yields corresponding to Alegria, Amont, and Mercado on one hand, and between above-mentioned varieties and Golden, Hopy Red Dye, and Opopeo, on the other hand.

**Table 3.** The green and dry grain mean yields of amaranth varieties.

| Variety | N | Green seed yield (kg/ha) | Dry seed yield (kg/ha) |
|---|---|---|---|
| Alegria | 10 | 2768.60 ± 10.22a | 2270.86 ± 20.05a |
| Amont | 10 | 2277.80 ± 7.23b | 1843.26 ± 13.41b |
| Golden | 10 | 2407.80 ± 9.85c | 1939.90 ± 17.47c |
| Mercado | 10 | 235790 ± 4.03a | 2187.36 ± 16.08d |
| Hopy Red Dye | 10 | 2650.20 ± 11.19d | 1949.39 ± 5.95c |
| Opopeo | 10 | 2612.00 ± 9.93d | 1982.90 ± 12.77c |

* the differences between any two yield averages are significant, if their values are followed by letters, or groups of different letters.

*3.2. The Relationships between Morpho-Productive Traits of Six Amaranthus sp. Varieties*

We correlated the dry biomass and dry seed yields (Figure 1, Table 4 and Table 5). The correlations are strong, very strong and significant ($p < 0.05$) for Amont, Golden, Hopy Red Dye, and Opopeo varieties (Tables 4 and 5).

**Table 4.** The correlation matrix between dry biomass and dry grain yields.

| Variety | Alegria | Amont | Golden | Mercado | Hopy Red Dye | Opopeo |
|---|---|---|---|---|---|---|
| Alegria | **1** | 0.485 | 0.768 | 0.486 | 0.471 | 0.551 |
| Amont | 0.485 | **1** | 0.420 | **0.845** | **0.994** | **0.922** |
| Golden | 0.768 | 0.420 | **1** | 0.411 | 0.484 | 0.504 |
| Mercado | 0.486 | **0.845** | 0.411 | **1** | **0.844** | **0.911** |
| Hopy Red Dye | 0.471 | **0.994** | 0.484 | **0.844** | **1** | **0.950** |
| Opopeo | 0.551 | **0.922** | 0.504 | **0.911** | **0.950** | **1** |

**Table 5.** The matrix of *p* values between dry biomass and dry grain yields.

| **Variety** | **Alegria** | **Amont** | **Golden** | **Mercado** | **Hopy Red Dye** | **Opopeo** |
|---|---|---|---|---|---|---|
| Alegria | - | 0.847 | 0.983 | 0.172 | 0.833 | 0.745 |
| Amont | 0.847 | - | 0.114 | **0.044** | **0.039** | **0.033** |
| Golden | 0.983 | 0.114 | - | 0.802 | 0.718 | 0.856 |
| Mercado | 0.172 | 0.044 | 0.802 | - | **0.046** | **0.031** |
| Hopy Red Dye | 0.833 | 0.039 | 0.718 | **0.046** | - | **0.024** |
| Opopeo | 0.745 | 0.033 | 0.856 | **0.031** | **0.024** | - |

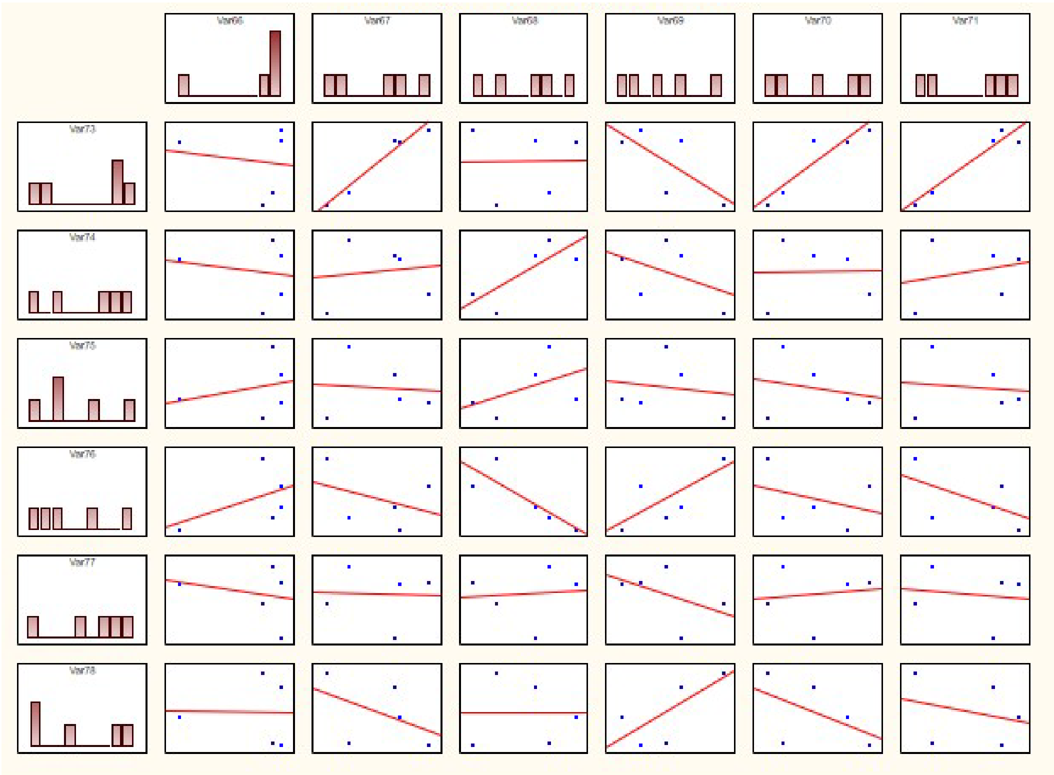

**Figure 1.** The Scatterplot Pearson simple correlation matrix between biomass and grain yields for varieties. Var 66, 73-Alegria, Var 67, 74-Amont, Var 68, 75-Golden, Var 69, 76-Mercado, Var 70, 77-Hopi Red Dye, Var 71, 78-Opopeo.

For emphasizing the influence of morphological traits (plant height and number of leaves) on biomass and grains yields, the multiple correlations were calculated for each analyzed *Amaranthus* sp. varieties (Table 6 and Table 7).

In Mercado, Hop Red Dye and Opopeo varieties, the dry biomass yield is moderately correlated with plant height and number of leaves, while in Amont, and Golden, weak correlations are seen (Table 6). In Alegria, a weak to moderate multiple correlations is observed between dry biomass yield, plant height and number of leaves. In all studied varieties, according to regression lines, the

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plant height has a negative influence on dry biomass yield, while the number of leaves positively influences the yield, but the multiple correlations are not significant.

For emphasizing the influence of morphological traits (plant height and number of leaves) on biomass grain yields, the multiple correlations were calculated for each analyzed *Amaranthus* sp. varieties (Table 6 and Table 7).

**Table 6.** The multiple regression analysis of dry biomass yield, plants heights and leaves number of varieties.

| Variety | N | Regression line | r | $r^2$ | p |
|---|---|---|---|---|---|
| Alegria | 10 | Y = 1008.021−0.078 × 1 + 0.347X2 | 0.343 | 0.117 | 0.882 |
| Amont | 10 | Y = 6304.343−0.227X1 + 0.216X2 | 0.223 | 0.049 | 0.950 |
| Golden | 10 | Y = 7563.559−0.084X1 + 0.5575X2 | 0.284 | 0.080 | 0.892 |
| Mercado | 10 | Y = 9418.051−0.159X1 + 0.493X2 | 0.431 | 0.186 | 0.813 |
| Hopy Red Dye | 10 | Y = 8266.946−0.146X1 + 0.501X2 | 0.478 | 0.228 | 0.771 |
| Opopeo | 10 | Y = 9195.162−0.258X1 + 0.556X2 | 0.419 | 0.175 | 0.805 |

In Mercado, Hop Red Dye and Opopeo varieties, the dry biomass yield is moderately correlated with plant height and number of leaves, while in Amont, and Golden, weak correlations are seen (Table 6). In Alegria, a weak to moderate multiple correlations is observed between dry biomass yield, plant height and number of leaves. In all studied varieties, according to regression lines, the plant height has a negative influence on dry biomass yield, while the number of leaves positively influences the yield, but the multiple correlations are not significant.

For emphasizing the influence of morphological traits (plant height and number of leaves) on biomass and grain yields, the multiple correlations were calculated for each analyzed *Amaranthus* sp. varieties (Table 6 and Table 7).

In Mercado, Hop Red Dye and Opopeo varieties, the dry biomass yield is moderately correlated with plant height and number of leaves, while in Amont, and Golden, weak correlations are seen (Table 6). In Alegria, a weak to moderate multiple correlations is observed between dry biomass yield, plant height and number of leaves. In all studied varieties, according to regression lines, the plant height has a negative influence on dry biomass yield, while the number of leaves positively influences the yield, but the multiple correlations are not significant.

**Table 7.** The multiple regression analysis of dry seed yield, dry biomass yield, plants heights and leaves number of varieties.

| Variety | N | Regression line | r | $r^2$ | p |
|---|---|---|---|---|---|
| Alegria | 10 | Y = 6498.799 + 0.218X1−0.104X2 + 0.249X3 | 0.406 | 0.165 | 0.969 |
| Amont | 10 | Y = 1734.297 + 0.086X1−0.522X2 + 0.685X3 | 0.608 | 0.369 | 0.891 |
| Golden | 10 | Y = 7452.531 + 0.363X1−0.525X2 + 0.721X3 | 0.686 | 0.471 | 0.305 |
| Mercado | 10 | Y = 3442.738 + 0.149X1−0.076X2 + 0.389X3 | 0.622 | 0.376 | 0.329 |
| Hopy Red Dye | 10 | Y = 2065.164 + 0.397X1−0.4734X2 + 0.371X3 | 0.693 | 0.480 | 0.143 |
| Opopeo | 10 | Y = 6939.331 + 0.462X1−0.53X2 + 0.334X3 | 0.797 | 0.636 | 0.718 |

### *3.3. The nutritional content and antioxidant activity of amaranth varieties*

According to Box-Plot diagram (Figure 2), dry matter content ranges between 12.90 g/100 g (Alegria) and 11.20 g/100 g (Amont). No significant differences are observed between dry matter contents among all Amaranthus sp. varieties.

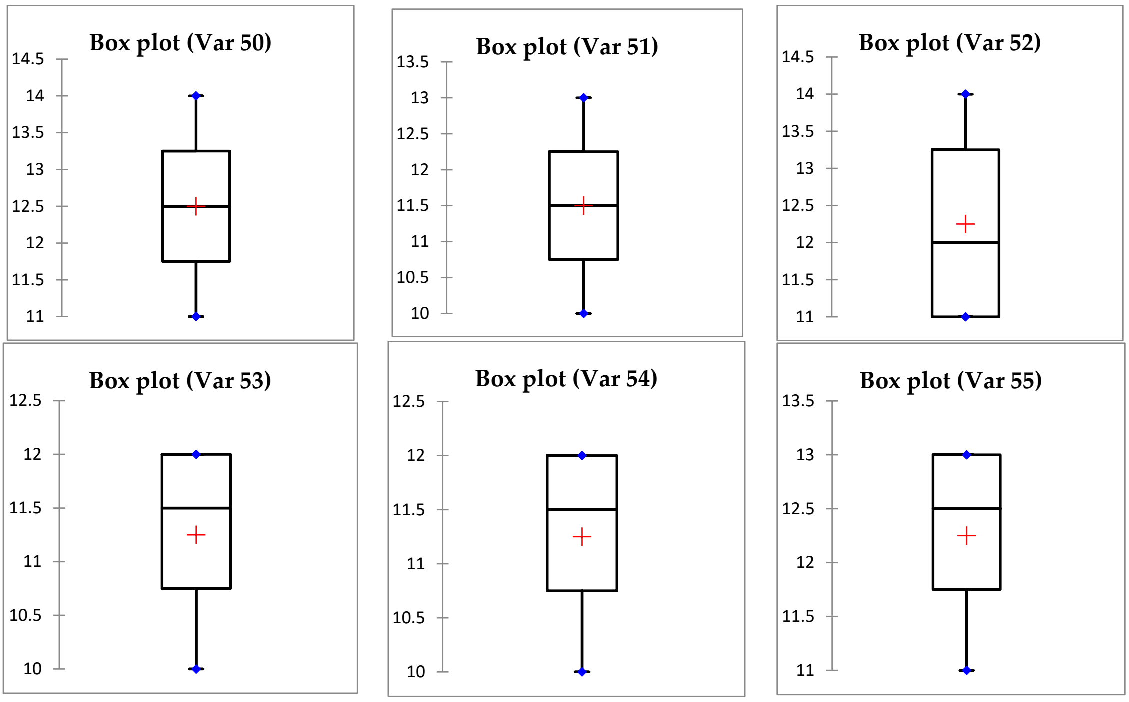


**Figure 2.** The Box-Plot diagrams for varieties dry matter (g/100 g). Var 50-Alegria, Var 51-Amont, Var 52-Golden, Var 53-Mercado, Var 54-Hopi red Dye, Var 55-Opopeo.

According to our study, crude protein ranges between 18.20 g/100 g dry matter, and 16.20 g/100 g dry matter (Table 8). No significant differences are observed between crude protein contents corresponding to five of six studied varieties. The exception is crude protein content identified in Alegria, which significantly differ from the contents of the other varieties. The crude fiber ranges between 20.40 g/100 g dry matter, and 14.20 g/100 g dry matter. No significant differences are observed between crude fiber contents corresponding to Golden, Mercado, Hopi Red Dye, and Opopeo. Differences are reported concerning crude fiber content, between Alegria, Amont and the other studied varieties. The highest mean crude fat content corresponds to Opopeo variety (10 g/100 g dry matter), and the lowest to Hopi Red Dye (6.80 g/100 g dry matter). The mean crude fat content from Amont, Golde, Mercado, and Hopi Red Dye differs significantly from those reported in Alegria and Opopeo. The mean crude ash ranges between 3 g/100 g dry matter (Alegria) and 2.20 g/100 g dry matter (Amont). No significant differences are seen between mean crude ash content corresponding to studied Amaranthus sp. varieties. The highest mean Nitrogen-Free Extracts content of 57.20 g dry matter is reported in Amont, and the lowest of 52.10 g dry matter, in Mercado. No significant differences are observed between mean Nitrogen-Free Extracts contents corresponding to Alegria, Golden, Hopi Red Dye and Opopeo varieties. Differences are identified between mean Nitrogen-Free Extracts contents corresponding to Amont and Mercado, on one hand, and between these means and those identified in the other four Amaranthus sp. varieties.

**Table 8.** The nutritional content of seven grains belonging to amaranth varieties (g/100 g dry matter).

| Variety | N | Crude protein | Crude fiber | Crude fat | Crude ash | Nitrogen-Free Extracts |
|---|---|---|---|---|---|---|
| Alegria | 10 | 18.20 ± 0.58ba | 20.40 ± 0.54a | 9.00 ± 0.95a | 3.00 ± 0.38a | 54.30 ± 0.92a |
| Amont | 10 | 16.20 ± 0.93ab | 14.20 ± 0.45b | 7.00 ± 1.12b | 2.20 ± 0.36a | 57.20 ± 1.031b |
| Golden | 10 | 16.60 ± 0.41b | 16.60 ± 0.86c | 7.20 ± 1.16b | 2.40 ± 0.51a | 55.70 ± 0.86a |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mercado | 10 | 17.60 ± 0.51ab | 17.20 ± 0.66c | 7.00 ± 0.71b | 2.50 ± 0.40a | 52.10 ± 0.67c |
| Hopi Red Dye | 10 | 16.90 ± 0.40b | 17.40 ± 0.80c | 6.80 ± 0.49b | 2.70 ± 0.62a | 55.60 ± 0.86a |
| Opopeo | 10 | 17.00 ± 0.71ab | 17.80 ± 0.62c | 10.00 ± 0.83a | 2.90 ± 0.33a | 53.00 ± 1.02ca |

* the differences between any two yield averages are significant, if their values are followed by letters, or groups of different letters.

The antioxidant activities of grains expressed as TPC differ in function of variety (Figure 3). Among the six *Amaranthus* sp. varieties, the highest means correspond to Alegria and Mercado varieties, with values of 0.43 mg GAE/g, and 0.41 mg GAE/g. The lowest mean of 0.19 g GAE/g corresponds to the Amont variety. No significant differences are observed between TPC identified in Golden and Hopi Red Dye varieties. Significant differences are reported between the other studied varieties on one hand, and between them, and Golden and Hopi Red Dye, on the other hand.

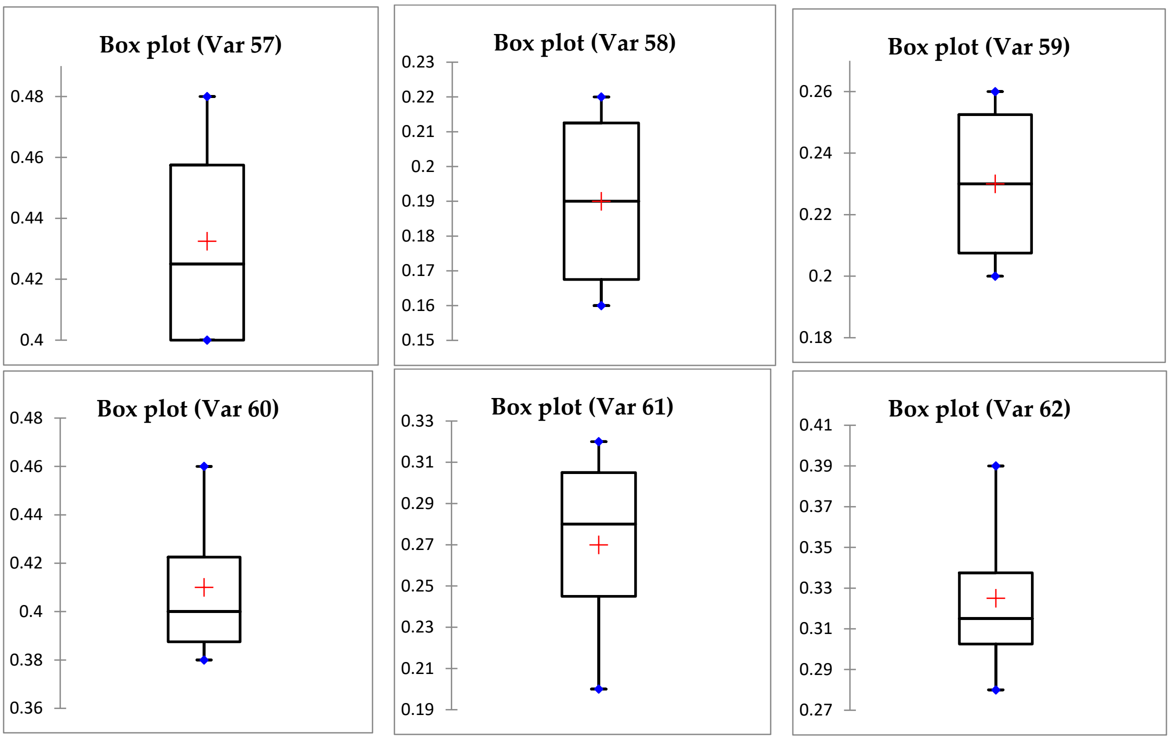


**Figure 3.** The Box-Plot diagrams for varieties TPC (mg GAE/g). Var 57-Alegria, Var 58-Amont, Var 59-Golden, Var 60-Mercado, Var 61-Hopi red Dye, Var 62-Opopeo.

## 4. Discussion

We find differences between morphological traits represented by plant heighth, and number of leaves, respectively. Also, productive traits as biomass and seed yields differ significantly among amaranth varieties. Differences in morpho-productive traits were also obtained by Dehariya et al. (2019) when different levels of inputs were administered to an A. tricolor culture [36]. They report plant heights ranging between 27.23–45.68 cm, number of leaves between 9.73–13.53, and dry biomass yields between 1,000.35–1807.90 kg/ha. These values are inferior to those obtained in our study (79.35–101.25 cm, 21.71–32, and 6,603.20–10,068.06 kg dry biomass/ha, respectively). The reason may be the different varieties used in our trial, meaning A. cruentus and A. hypochondriacus versus A. triclor. Our results concerning plant height frame within a narrower range, and mean plant heigths have lower values, compared to those reported by Baturaygil et al. (2021) in amaranth hybrids, between 109–253 cm [37], Bashyal et al. (2018) between 75.98–167.14 cm [38], and Génalis and Seguin

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(2008) in eight amaranth genotypes, between 143–168 cm [39]. The number of leaves (36.33–199.66) corresponding to results reported by Bashyal et al. (2018) is much higher [38] compared to values presented in our study. Interesting is that even though the above-mentioned studies present superior values of plant heights, and number of leaves, the reported dry grain yields ranging between 724.96–1183.58 kg grains/ha [37], and 432–979 kg grains/ha [38], are inferior to those obtained in our study. This finding suggests that A. cruentus and A. hypochondriacus have a high productive potential in cultivation conditions of our trial.

Like our findings, in a study performed on A. hypochondriacus genotype, in Southern Italy environmental conditions, Pulvento et al. (2021) identified a strong correlation between dry grains and dry biomass [40]. The study of the relationships between morph-productive traits provides insights into the complex relationships between morphological traits and yield in different amaranth varieties. According to the multiple correlations intensities, the multiple regression analysis shows that plants height and leaves number influence in a lower extent the dry biomass yield, compared with their influence together with biomass yield on dry grains yield. The observed variations in correlations highlight the importance of considering specific varieties and their unique characteristics when optimizing cultivation practices for dry biomass and seed yields. The acknowledgment of weak or moderate correlations also suggests that other factors beyond plant height and leaf number may contribute to yield variations in these varieties.

Amaranth grains constitute a well-balanced reservoir of bioactive substances [41]. Our findings provide a detailed analysis of various nutritional components and TPC in the grains, underscoring the diversity in nutritional composition among different amaranth varieties. In our study the dry matter content has lower values and rages in a narrower interval, 11.20–12.90 g/100 mg grains, compared to results reported by Baturaygil et al. (2021) in amaranth hybrids (9–24%) [37], but slightly higher compared to those reported by Oteri et al. (2021) in A. hypochondriacus, between 10.20–10.40 g/100 g dry matter [41]. The protein content ranging between 16.20–18.20 g/100 g dry matter is similar with values reported by Malik et al. (2023) between 12.70–19.80 g/100 g dry matter [42], Oteri et al. (2021), between 17.30–18.30 g/100 g dry matter [41], and Mekonnenet al. (2018) in A. caudatus varieties (16.64%) [43], but higher compared to those obtained by Haber et al. (2017), 15.75%, and USDA (2010), 13.56% respectively [1,10]. Our findings also emphasize higher values of crude fiber ranging between 14.20–20.40 g/100 g dry matter, compared with those obtained by Malik et al. (2023) between 2.40–5.80 g/100 g dry matter [42], Oteri et al. (2021) between 4.84–5.85 g/100 g dry matter [41], Mekonnenet al. (2018), of 11.33% [43], Haber et al. (2017), of 4.2% [10], and USDA (2010), 6.7%% respectively [1]. The fat content quantified in our study ranging between 7.00–10.00 g/g dry matter is similar with content reported by Haber et al. (2017), 7.2% respectively [10], and by Malik et al. (2023) between 1.70–10.30 g/100 g dry matter [42]. A mean of 3.3% ash content was observed in amaranth by Mekonnenet al. (2018), and Haber et al. (2017) [10,43], while Oteri et al. (2021) emphasize values between 3.26–3.54 g/100 g dry matter [41], Malik et al. (2023) between 2.20–3.50 g/100 g dry matter [42], which are slightly higher compared to those identified in our study between 2.20–3.00 g/100 g dry matter. Similar result of 2.88%, compared to our findings, is mentioned by USDA (2010) [1]

Studies suggest that red amaranth is notably abundant in polyphenols, particularly found in the seed coat [44]. The varieties with a superior red color index, such as A. cruentus and A. hypochondriacus, are significant reservoirs of phenolic and polyphenolic compounds, showing enhanced antioxidant activity. Our study shows a TPC in grains ranging within 19.23–43.17 mg GAE/100 g dry matter in A. cruentus, while other studies performed in the same variety emphasizes similar TPC values, of 30.48 mg GAE/100 g dry matter [45], or between 16–43 mg GAE/100 g dry matter [46]. Compared to TPC reported in our research in A. hypochondriacus ranging between 0.23–0.41 43 mg GAE/100 g dry matter, Oteri et al. (2021) and Gorinstein et al. (2007) [47] report similar values ranging between 24–43 mg GAE/100 g dry matter [41,46], and 15.40–41.40 mg GAE/100 g dry matter, respectively [45].

Amaranth high nutritional potential, also emphasized in this study, confirms its suitability for uses in human and animal nutrition, and in health industries, as raw matter for functional food production.

## 5. Conclusions

The research emphasizes differences concerning the analyzed morpho-productive traits within the studied Amaranthus sp. varieties. Among six these, Alegria has best performances in terms of number of leaves, biomass yield, seed yield, dry matter, nutritional content, and antioxidant activity. In varieties such as Mercado, Hop Red Dye, and Opopeo, there exists a moderate correlation between dry biomass yield and both plant height and number of leaves. Conversely, weaker correlations are observed in Amont and Golden varieties. Alegria exhibits weak to moderate correlations between dry biomass yield, plant height, and number of leaves. Interestingly, across all studied varieties, regression analysis indicates that plant height negatively impacts dry biomass yield, whereas the number of leaves positively influences yield. However, it's noteworthy that the multiple correlations observed are not statistically significant. These insights shed light on the complex interplay between morphological traits and yield outcomes in Amaranthus sp. varieties, suggesting the need for further investigation and nuanced understanding in optimizing yield potential and suitability for both human and animal nutrition. Our study underscores the nutritional richness and diversity present in amaranth grains, highlighting them as well-balanced reservoirs of bioactive substances. Through a comprehensive analysis, we have observed variations in nutritional components and total polyphenolic content (TPC) among different amaranth varieties. The article brings novelty within the current status of research in amaranth, because it emphasizes the yields, nutritional content, and interconditionalities between dry biomass yield and grain yields, of two amaranth species represented by seven varieties, in specific pedo-climate conditions.

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