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EXPLORATION OF THE BIOLOGICAL, PHARMACOLOGICAL AND NUTRACEUTIC PROPERTIES OF THE SPECIES *AMARANTHUS RETROFLEXUS* L.

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Abstract

The globalization of agriculture and its industrialization seems to be unceasing, with negative consequences such as loss of biodiversity and health risks perceived worldwide. These implications range from monoculture practices, which reduce genetic variation in agriculture, to biased technological development, which uses only a few species of energy-intensive plants. The limited variety of agricultural products raises concerns about the ability of major crops to address food insecurity and alleviate poverty. To meet such problems, exploitation of underutilized crop species is important for expanding the field of research and development. Millions of people around the world depend on thousands of different plant species to support their livelihoods, health and cultural traditions, namely, they provide food, medicine, fiber, fuel and other important resources that people rely on for survival.

***Key words**: biodiversity, underutilized crop species, nutraceutical potential*

INTRODUCTION

The study of morphological, anatomical and biochemical characters of the species *Amaranthus retroflexus* L - spontaneous flora represents a vast and complex field of botanical and ecological research. This plant, known as Common Amaranth, is an important component of the spontaneous flora and is widespread throughout the world, successfully adapting to a variety of environments and environmental conditions. Research deepens the knowledge about this species and is essential to understand its role in natural ecosystems, agronomic potential and impact on human health.

The morphological characteristics of the plant *Amaranthus retroflexus* L - spontaneous flora are essential for its identification and classification within the spontaneous flora.

Amaranthus retroflexus L., includes annual herbaceous plants, with heights ranging from 5 to 160 cm. The stem is usually erect (sometimes prostrate), green and typically densely pubescent. The leaf blade is rhomboidal, oval or lanceolate, glabrous (pubescent on the abaxial veins), the base being cuneate, the margins entire, and the lower veins very prominent, white-green. The tip is usually pointed and mucronate (figure 1).The structure of the inflorescence in *Amaranthus retroflexus* L. is quite complex, formed by green, erect, condensed spikelets. The terminal spikelet is usually equal to or shorter than the lateral spikelets. The flowers are small, usually green, unisexual and grouped in dense cymes, each presenting a central axis, with a terminal male flower followed by a pair of opposite lateral branches with female flowers. The cymes are arranged in spike-like structures. During the anthesis phase, new male flowers develop at the ends of the inflorescence branches, managing to pollinate the lower female flowers.

The tepals are five in number, spatulate, with an obtuse, truncate or emarginate apex. The fruit is circumscribed, elliptical, equal to or shorter than the perianth (Sarker et al., 2020).

Figure. 1. Morphological characters of the red-eared slider (author's photo*)*

The inflorescence structure described above is typical of self-pollinating plants. However, pollination is mainly carried out by the wind (anemophilous). The flowers lack nectar glands, and the pollen grains are small (18–28 μm), with 30–45 pores evenly distributed on their surface. The pollen grains also contain starch (up to 7.5%), protecting them against drying out. Reproduction is indirectly favored by insects. In Amaranth, flower development and seed production occur simultaneously, due to the high density of the inflorescence. Certain predators can accidentally pick up or carry the pollen grains, favoring their dispersal (Bajwa et al., 2017). The fruit is a circumscribed capsule containing one seed. The mature pericarp has two layers, between which there is a large intercellular space, filled with air, allowing the fruit to float (Hao et al., 2017). The seeds are subelliptical (1-1.5 mm diameter) and their surface is more or less smooth, resistant to water and chemical and physical atmospheric agents (Hanachi et all., 2022). Each plant can produce up to 100,000 seeds under optimal ecological conditions. The amount of seeds produced by a plant can be estimated by measuring the height of the plant and its diameter (Schafleitner et al., 2022). Biochemical research has highlighted the presence of a wide range of chemical compounds in this species (Tkaczewska, 2020).

These compounds include: saponins, flavonoids, tannins, alkaloids and other substances with biologically active potential. Studies on the chemical composition of different parts of the plant, such as: stems, leaves and seeds, have revealed significant variations in the content of compounds and their pharmaceutical potential (Das et al., 2018; Sandoval-Sicairos et al., 2020).

A particularly interesting aspect in the biochemistry of the species *Amaranthus retroflexus* L. is the nutritional composition of the seeds (Soriano-García, et al., 2018) Red amaranth seeds are rich in high-quality proteins, essential fatty acids, fiber, and minerals such as iron and calcium (Akin-Idowu et al., 2017). These nutritional characteristics make red amaranth seeds a valuable source of food for humans and animals and are the focus of extensive research in the field of nutrition and food security (Saubhik, 2016). Research on the morphological, anatomical, and biochemical characteristics of the species *Amaranthus retroflexus* L. is essential for a complete understanding of this plant in order to exploit its potential in various fields, including agriculture, ecology, and medicine (Ebrahimi et al., 2023; Schmid et al., 2023). These studies make significant contributions to the knowledge of biodiversity and the functioning of natural ecosystems and can serve as a basis for the development of new technologies and practical applications in the future (Meena et al., 2022). *Amaranthus retroflexus* L, popularly called red amaranth, has become an area of widespread scientific and industrial interest due to its biological properties, rich phytochemical composition and complex pharmacological activity (Christenhusz and Byng, 2016; Sarker 2022). In Romania, the plant is frequently used in pig feed, but it is a troublesome, invasive weed, especially in vegetable and garden crops (Morariu, 1952). Currently, in the case of the species *Amaranthus. retroflexus* L, research is focused on finding as many beneficial aspects from a medical point of view as possible.This plant was well known since the time of the Aztecs, Mayans and Incas and spread to various countries starting from the 16th-17th centuries, being used as a pseudo-cereal, vegetable, weed or agricultural crop (Sandra et al., 2021). Pseudo-cereals have been a staple food used since ancient times, even today serving as the basis of nutrition in the poorest parts of the world (Bhargava et al, 2019; Pirzadah et al., 2020). The edible parts of these plants are the seeds and are usually consumed in a similar way to cereals, being processed into flour (Bekkering et al., 2019; Das et al., 2022). The globalization of agriculture and its industrialization seems to be incessant, with negative consequences, such as biodiversity loss and health risks, perceived worldwide (Martinez-Lopez et al., 2020). These implications range from monoculture practices that reduce genetic variation in agriculture to biased technological development that uses only a few energy-intensive plant species (Jun-Hyoung Bang et al., 2021). Global food security now depends largely on a small number of crops, including maize, rice and wheat, which are the main cereals, providing more than half of the world's calories (Balakrishnan et al., 2022).

The limited variety of agricultural products raises concerns about the ability of major crops to address food insecurity and alleviate poverty. To address such issues, exploiting underutilized crop species is important to expand the scope of research and development. Despite their nutritional value and historical importance as staple foods in many societies, ancient crops rich in cereals, micronutrients and/or phytonutrients are currently neglected because they are cultivated in only a few niches of the global food system. Millions of people around the world depend on thousands of different plant species to sustain their livelihoods, health, and cultural traditions, namely, they provide food, medicine, fiber, fuel, and other important resources that humans rely on for survival (Srujana et al., 2019; Nazeer et al., 2022).These underutilized crops, such as red emmer and quinoa, have gained international relevance in the nutraceutical sector due to their high nutritional profile [69] compared to traditional cereals, which has led to increased research interest in them for potential use in functional foods and nutraceuticals (Miguel, 2018). Red emmer seeds have a high nutritional value The most important product obtained from red emmer is represented by cereals, a source of flour used in the bakery industry.The seeds are mainly used to produce flakes, flour, muesli, and oil (Carretero, 1990). The high quality of red emmer proteins indicates that it can be used individually or as a food fortifier in cereal mixtures (Peter and Gandhi, 2017). *Amaranthus retroflexus* L., is a weed species with rapid growth and spread in Europe. It has a good potential for metal accumulation and translocation, especially for: Al, Ba, Cu, Fe, Mn, Sr and Zn. The plant is widely distributed in metal-contaminated soils, suggesting a promising opportunity for metal phytoremediation, especially for phytoextraction (Nyonje et al., 2021).

The stems and leaves of red clover accumulate high concentrations of metals in contaminated sites, their accumulation rate varying significantly depending on the plant organs: Ba, Mn, Sr and Zn are found in high concentrations in the leaves, while Al, Cr, Cu, Fe and Pb in the roots (Wang et al., 2016). Among soil contaminants, heavy metals represent one of the most serious ecological problems worldwide. High concentrations of heavy metals can generate cytotoxic, genotoxic and mutagenic effects in living organisms (Segneanu et al., 2021). In recent years, interest in the use of plant raw materials, both in food and for therapeutic purposes, has increased considerably. Red clover leaves have 25% more protein, and the lysine content is higher, compared to the same amino acid in cereal caryopses, and methionine is also found in a higher proportion than in soybeans. There have been cases when treatment with styr tea has given very good results in the case of children suffering fromenuresis. In over 50 countries in the tropical region, red styr is a food source, being used in very large quantities. At each harvest, 10 tons of edible green mass can be obtained per hectare, the harvesting being staggered at an interval of 40 days.

Data on the chemical composition.

The main biological compounds found are: proteins, fats, carbohydrates, vitamins and minerals (Pamela et al., 2017; Muhali Olaide Jimoh et al., 2019; Roth-Nebelsick et al., 2019; Park et al., 2020; Sarker et al., 2020). The protein content (~18%) of red styr seeds depends on the plant variety, climate, soil conditions and fertilization method (Sarker et al., 2019; Sarker et al., 2020). Red yeast rice protein has a relatively high amount of sulfur-containing amino acids, a process rarely found in legume crops (López et al., 2019; Phoswa and Mokgalaboni, 2023). The protein content of red clover seeds (Fisayo Ajayi et al., 2021) is relatively close to the guidelines recommended by the World Health Organization (WHO), due to its balanced amino acid profile (Bajwa et al., 2017). The WHO recommends a daily intake of 0.75 g of protein per kilogram of body weight for adults (Ramkisson et al., 2020). Amino acids: Red clover is rich in essential amino acids and has a near-optimal protein composition that is similar to that found in cow's milk (Oteri et al., 2021). (Table 1.1), (Jan et al., 2023). Most cereals generally lack essential amino acids such as lysine and are rich in valine, leucine and isoleucine (Shahidi et al., 2015) , while red millet is rich in lysine (5.2–6.1 g/100 g protein) (Yang et al., 2021), has a balanced amino acid composition and meets the human dietary requirements for most of the essential amino acids: alanine, valine, leucine, arginine, phenylalanine, methionine, tryptophan, isoleucine and serine, suggesting that it is a pseudocereal that can be used as a nutritious cereal substitute (Wang et al., 2016; Flieger et al., 2021; Süleyman and Keskin 2022).

To understand In order to fully understand the antioxidant activity of *Amaranthus retroflexus* L, further studies were needed to gain a deeper understanding of the internal structure of the leaf, which is composed of two epidermises, an upper and a lower one, as well as the mesophyll. The stomata of this species open in response to light in the morning, due to a photoactive reaction, and their degree of opening is maximum in sunny conditions, when CO_2 penetration is intense, managing to facilitate both the photosynthesis process and leaf transpiration at a high intensity. The fixation and preservation techniques used in this study allowed for the detailed observation of the internal structure of the leaf.This knowledge contributes to a better understanding of the anatomy and physiology of this species, which can be useful in various fields such as agriculture, botany and ecology (Sărăcin et al., 2023). In addition to the antioxidant effects, which have been demonstrated, it seems that *Amaranthus retroflexus* L. has a crucial role not only in providing antioxidants, but also in combating fungal infections, as evidenced by the study conducted by Bahrami-Teimoori et al., (2017), in which it was found that *Amaranthus retroflexus* L. may have the ability to synthesize silver nanoparticles, with effective antifungal activity, especially against plant fungi: *Macrophomina phaseolina* and *Fusarium oxysporum*, known for their negative impact on crop yield and quality.The findings of this study could be adopted for several applications in the field of plant protection. Further studies are underway to investigate the treatment of plants damaged by pathogenic fungi by

AgNPs derived from *Amaranthus retroflexus* L. However, further research is needed to investigate whether the application of AgNPs to soil could cause unwanted damage to beneficial bacteria, as it is well known that nanoparticles have potent antibacterial activity (Bahrami-Teimoori et al., 2017).

Table 1.1. Nutrient components of red clover (adapted from Jan N. et al., 2023).

Pseudo-cereals	Components	Values
Amaranthus retroflexus L.	Protein	15,2%
	Fat	8%
	Fiber	3,1-5%
	Carbohydrates	67,3%
	Magnesium	2300-3360 mg/kg
	Calcium	1300-2850 mg/kg
	Sodium	160-480 mg/kg
	Iron	72-174 mg/kg
	Zinc	36,2-40 mg/kg

Starch is the main carbohydrate found in the plant, at a rate of 45%–65% (Lomonosova et al., 2021). Compared to staple cereals such as maize, wheat and sorghum, red emmer is distinguished by a higher protein content of 14.0–15.5%, a lower fat content of approximately 7.5%, and a higher percentage of carbohydrates, ranging from 60% to 68%.

Vitamins: Among leafy green vegetables and cereals, *Amaranthus* species are recognized as a storehouse for essential vitamins such as vitamin B_6, vitamin C, folic acid, as well as carotene, which is a precursor of vitamin A (Tharun et al., 2012; Dinu et al., 2017; Lăcătușu et al., 2018; Gianni et al., 2020; Famuwagun et al., 2020; Grundy et al., 2020).

Fiber is an important group of compounds present in seeds, in both soluble (pectins) and insoluble parts. Lignin, cellulose and hemicellulose (the insoluble fraction) have a beneficial role in the digestive system (Jimenez-Aguilar et al., 2017).

Lipids: the nutritional value of the seeds is mostly represented by lipids (~7%), (fig.1) (Baraniak and Kania-Dobrowolska 2022; Streyczek, 2023). Of the unsaturated fatty acids present, the most important are: linoleic acid, which constitutes approximately 62%, followed by oleic acid (~20%), linolenic acid (~1%) and arachidonic acid (Peter Ifeoluwa Adegbola et al., 2020; Roth-Nebelsick and Krause, 2023). The seeds also contain saturated fatty acids in smaller quantities, such as: palmitic acid (~13%), stearic acid (~2.6%) and myristic acid (~0.1%) (Sarker, 2020).

Red clover oil is rich in unsaturated fatty acids, tocopherols, phytosterols and squalene (Jyoti Jaina and Ramachandra, 2018) compounds that have been shown to have benefits for hair and skin health (Nazeer and Firincioglu, 2022).

Minerals: In addition, the seeds are an excellent source of minerals, representing an average of 3.3% of their total mass (Piga et al., 2021);

Calcium, potassium and magnesium levels are quite high. Iron and phosphorus are found in the highest amounts. In addition, red clover has a lower ash content, between 2.5% and 3.1% (Shahidi and Zhong, 2015)

Polyphenols: Red clover seeds and leaves are also a small source of polyphenols, saponins, hemagglutinins, nitrates and oxalates (Orsango et al., 2020).

Pigments: Betacyanins are part of the category of red or purple betalain pigments, with betanidin being an important one. These compounds are identified in different species of red yeast rice.

Data on the pharmacological action of the species.

Many species of the genus are medicinally important and have properties: antiallergic, anticancer, antihypertensive and antioxidant. The astringent effect of the plant depends on the presence and activity of betacyanins (Li et al., 2015), the content of saponins, protoalkaloids and betacyanins. Red yarrow seed oil exhibits hypolipidemic, anti-atherosclerotic, hypotensive and antioxidant activity (Nyonje et al., 2021) Therefore, its consumption may lead to inhibition of the development of diet-related diseases (Mechela et al., 2019; Zhao et al., 2020; Firouzeh et al., 2024).

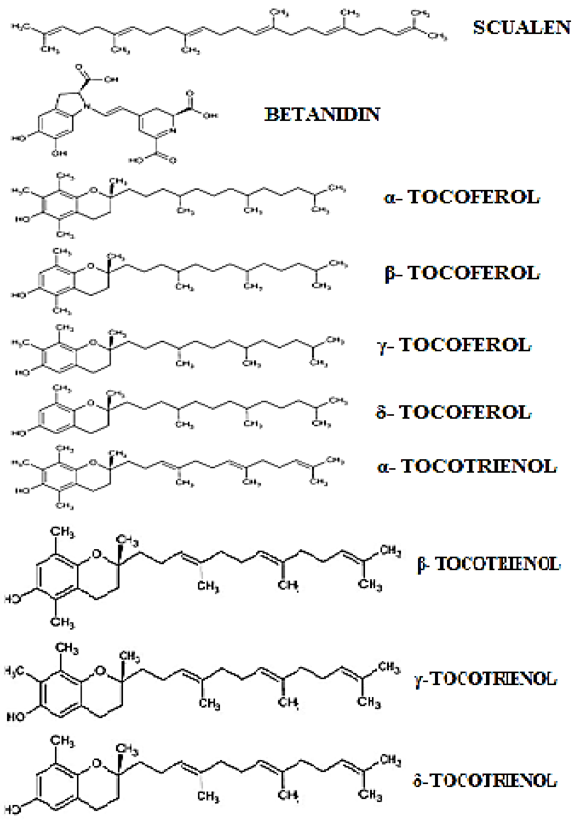

Figure. 1. Chemical structure of selected compounds from red sedge oil (adapted from Baraniak J. et al., 2022)

It also contributes to the regeneration, nourishment and strengthening of the epidermis, acting as an antioxidant (Ayşe and Filik, 2021; Jimoh et al., 2022). The hepatoprotective activity of red yarrow is attributed to the oil and extracts of the plant (Yang et al., 2021). Enriching the diet with red clover oil regulates the lipid profile and has a protective effect on the liver (Debalin et al., 2021). It modulates the physicochemical properties of lipids and cell membranes of hepatocytes, which it stabilizes, acting as a hepatoprotective agent (Schmidt et al., 2023). A very important property of red clover oil is its resistance to oxidation (Sarker et al., 2016; Akanji et al., 2021).

Squalene has antioxidant and hepatoprotective properties, regulates cholesterol levels and helps eliminate toxic substances from the body (Sarker et al., 2016; Hsiao et al., 2021; Jamka et al., 2021; Oteri et al., 2021). Diseases in which treatments with extracts of *Amaranthus retroflexus* L. are recommended.

Amaranthus retroflexus L. is one of the plants that has attracted particular attention, being recognized as an important natural source of biologically active compounds, which can contribute to reducing the risk of chronic diseases. Red newsprint has been used for the treatment of: diarrhea, gastric ulcers and in cases of pharyngitis, as well as in excessive menstruation, skin problems such as acne and eczema (Karamac et al., 2019) against atherosclerosis, including high blood pressure, diabetes, cancer and cardiovascular disorders (Luo et l., 2016; Mamun et al., 2016); tuberculosis, as well as as an antiseptic, antifungal and anti-inflammatory preparation. The substantial iron content of red sorghum seeds makes them potentially effective in combating iron deficiency anemia (House et al., 2020). Due to its rich nutritional composition, certain products derived from this plant are also used in the cosmetic industry. This oil is suitable for all skin types, providing hydration, soothing irritations, accelerating wound healing and having antimicrobial properties (Ayala-Niño et al., 2019). In addition, this underutilized cereal is safe for patients with celiac disease, due to the lack of gluten content (Moszak et al., 2018; Piga et al., 2021; Woomer and Adedeji, 2021). Extracts obtained from red sorghum during the vegetation and early flowering period, due to the high content of hydroxycinnamic acid derivatives, may be a valuable source of antioxidants (Amorati and Valgimigli, 2018; Jimoh et al., 2020). Consumption of processed bread enriched with red sorghum by children in underdeveloped countries decreased the prevalence of anemia and also increased the average hemoglobin concentration (Orsango et al., 2020). A detailed analysis showed that the risk of iron deficiency anemia decreased significantly from 35% to 15%, in a group of children treated with red yeast rice (Korres, 2018).

CONCLUSIONS

Worldwide, the demand for plant raw materials required for the phytopharmaceutical industry is continuously increasing, therefore it is evident that, in addition to the *Amaranthus retroflexus* L. species, other medicinal plant species with higher qualitative indices (active ingredient composition) are being identified and exploited, compared to cultivated medicinal plant species. *Amaranthus retroflexus L*. is widely distributed in metal-contaminated soils, suggesting a promising opportunity for metal phytoremediation, especially for phytoextraction.

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