

## **GRAIN AMARANTH AS AN ALTERNATIVE AND PERSPECTIVE CROP IN TEMPERATE CLIMATE**

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### **Abstract**

#### **Grain Amaranth as an Alternative and Perspective Crop in Temperate Climate**

As a consequence of globalisation and industrialisation of agriculture, global food security has become increasingly dependent on only a handful of fertilisation and energy high demanding plant species. This involution has increased the vulnerability of agriculture, reduced genetic diversity, provoked some environmental problems and impoverished the human diet. The mentioned facts stimulate the retrieving of alternative crops into the production. The present paper briefly describes crop importance, botany, nutritional value and utilisation of grain amaranth (*Amaranthus* spp.), one of the alternative crops discussed in the book *Organic Production and Use of Alternative Crops*. The immediate objective of this paper is to present information gained as a result of a national project on grain amaranth.

#### **Key words**

grain amaranth, nutrition value, utilisation

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## 1. Introduction

Globalisation of agriculture and consequently its industrialisation seem inexorable, with negative side effects felt throughout the world. These effects include, but are not limited to, biased technological development of usage of only some, fertilisation and energy high demanding, plant species, monoculture production and in this way reduced genetic diversity in agriculture. As a consequence, global food security has become increasingly dependent on only a handful of crops. Even if humankind has, over time, used more than 10,000 edible species, today only 150 plant species are commercialized on a significant global scale, 12 of which provide approximately 80% dietary energy from plants and over 60% of the global requirement for proteins and calories are met by just four species; rice, wheat, maize and potato (FAO 2005).

The narrowing of the number of crops upon which global food security and economic growth depend has placed the future supply of food and rural incomes at risk. The mentioned facts with profound environmental consequences and concern for loss of crop varieties stimulate organisations and scientists worldwide in retrieving, researching and disseminating the knowledge in production and utilisation of neglected, disregarded, underexploited and new plant species, or so called alternative crops. Alternative crops are plant species that are used traditionally for their food, fibre, fodder, oil or medicinal properties. They have an under-exploited potential to contribute to food security, nutrition, health, income generation and environmental services. The present paper briefly describes the pseudocereal grain amaranth (*Amaranthus* spp.), one of the alternative crops which are suitable for growth in temperate climates and are discussed in the book *Organic Production and Use of Alternative Crops* (Bavec and Bavec 2006). The immediate objective of this paper is to present information gained as a result of a national project on grain amaranth; its production, nutritional quality and possible utilisation in our production environment.

## 2. Taxonomic classification and morphology

Grain amaranth belongs to the order *Caryophyllales*, amaranth family *Amaranthaceae*, sub-family *Amaranthoideae*, genus *Amaranthus*, and according to Sauer (1967), into the section *Amaranthus*. The genus *Amaranthus* includes approximately 60 species, most of which are cosmopolitan weeds (*A. retroflexus* L., *A. hybridus* L., *A. powellii* S. Watt., *A. spinosus* L.) and cultivated amaranth species which can be used as food grain, leafy vegetables, forage and ornamentals.

According to the utilization of cultivated amaranths for human consumption, species can be divided into grain and vegetable amaranths:

- Vegetable amaranth: most *Amaranthus* species have edible leaves, and several species (*A. blitum* L.; sin. *A. lividus* L., *A. viridis* L.; sin. *A. gracilis* Desf. and *A. tricolor* L.; sin. *A. gangeticus* L.) are already widely used as potherbs (boiled greens). Their mild spinach-like flavour, high yields, ability to grow in hot weather, and high nutritive value have made them popular vegetable crops, perhaps the most widely eaten vegetables in the humid tropics of Africa and Asia.
- Grain amaranth: belongs to a group of cereal-like grain crops or pseudocereals. The three principal species considered for grain production include:
  - *Amaranthus hypochondriacus* L. (sin. *A. leucocarpus* S. Watts, *A. frumentia*

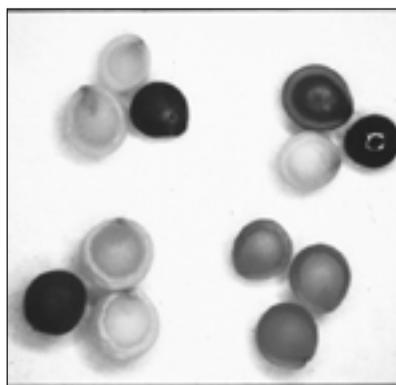
*ceous*) - prince's feather;

- *A. cruentus* L. sin. *A. paniculatus* L. - bush greens, red amaranth
- *A. caudatus* L. of two subspecies: subsp. *caudatus*; and subsp. *mante-gazzianus* Passerini syn.: *A. edulis* Spagazzini, named love-liebleeding and Inca wheat, respectively.

Grain amaranth is an annual herbaceous plant, one of the few C<sub>4</sub> dicots, with an erect stem and enormous inflorescence of various colours (Fig. 1a). Some anatomical characteristics of amaranth and its C<sub>4</sub>-photosynthesis pathway result in increased efficiency of using CO<sub>2</sub> under a wide range of temperature (from 25 to 40 °C), under higher light intensity, and moisture stress environments. All this contributes to the crop's wide geographic adaptability to diverse environmental conditions (Kigel 1994). The three grain species can be distinguished by inflorescence type and by some characters of pistillate flower structures: bract length, sharpness and position, as well as tepal and utricle shape, leaf morphology and gross plant morphology. The seed is lenticular and relatively small (0.9 to 1.7 mm diameter) with 1000-seed weights from 0.6 to 1 g (Sauer 1967; Kigel 1994). The colour of the seed in amaranth varies from white, gold, brown and pink to black (Fig. 1b).



(a)



(b)

Fig. 1: Grain amaranth varieties collection (a), grain amaranth seeds (b) amaranth seeds, 25-magnitude.

Source: Grobelnik Mlakar

### 3. Importance of crop in the past and in the present

In Pre-Columbian times, grain amaranth was one of the basic foods of the New World. It was nearly as important as corn and beans and was one of the principle items demanded as tribute. In the Codex Mendoza, a complex document on history, economy and ethnography of the Aztec, commissioned by the Spanish viceroy Antonio de Mendoza in around 1541-42, it is written that each year around 8,000,000 kg of *huautli* (mixture of amaranth and quinoa grain) was brought to Tenochtitlan, as an annual tribute paid to the emperor Montezuma 11. The quantity of *huautli* was comparable to tribute in maize and bean. The Indians used amaranth in beverages, sauces, porridges, they milled it into flour and prepared tortillas (also with maize flour), popped grains like maize, and for various medical uses. Besides in diet, amaranth had an important position also in Indians' religion. The grain was ground, mixed with water, honey, or even human blood and dough was then formed into the shapes of idols (*zoale*). Idols were paraded and consumed in a ritual manner as a symbol of communion with the gods. Because of the similarity between this communion ritual and Catholic Holy Communion, the Spaniards prohibited the cultivation and use of amaranth by legislative fiat. Besides this, the reason for the reduction in amaranth production was the introduction of new crops from Europe; small seed size may also be a reason for slow process of coming into modern use and practice (National Academy of Sciences 1984; Kauffman 1992; Schnetzler, Breene 1994).

Sauer (1967) reports the introduction of amaranth into Spain in 16<sup>th</sup> century, from where it had spread throughout the Europe. Around 1700s, it was known as a minor grain plant in central Europe and Russia and by the early 19<sup>th</sup> century it reached Africa and Asia. After that amaranth production in Europe declined and reduced to the state of an ornamental plant. Nowadays in Asia and Africa amaranth is mainly planted as a vegetable plant, and only in the Himalayan region of Asia it has been maintained as a minor cereal food.

The scientific plant name – *amaranth* signifies in Greek "immortal", "everlasting" or "non-wilting". The name could be poetically connected with a story of renaissance or "rediscovering" of amaranth crop. The first to draw attention to the nutritional value of amaranth was an Australian investigator Downtown (in 1973 he found out the high lysine concentration in grain of *A. edulis*). The interest for the crop was raised by the book Unexploited Plants with Promising Economic Value, which was published in the 1970s and presented cultivated grain amaranths as potential source of high quality proteins. Though quite small in comparison to other grains, amaranth has been extensively studied. There exists a surprisingly large volume of literature available, particularly on the nutritional qualities of amaranth, crop breeding, production and processing methods, development and commercialisation of new amaranth products. The strongest interest in amaranth (investigation and production) in Europe has been in Austria, Czech Republic, Slovak Republic, Germany, Hungary, Poland, Russia, Italy and Slovenia (Berghofer, Schoenlechner 2002).

### 4. Nutritional value and utilisation

A seed of grain amaranth is on average composed of 13.1 to 21.0% of crude protein; 5.6 to 10.9% of crude fat; 48 to 69% of starch; 3.1 to 5.0% (14.2%) of dietary fibre and 2.5 to 4.4% of ash.

Proteins have high digestibility (approx. 90%) and are rich with lysine – 0.34 g Lys/g N (which usually appears in grains as limiting amino acid). Amaranth seed is also a rich source of tryptophan and amino acids containing sulphur - these usually do not appear often enough in grains. This extremely balanced amino acid composition is the result of the fact that in amaranth 65% of proteins are found in the embryo and only 35% in the perisperm whereas in other grains amino acids in endosperm prevail (85% in average) and are poorer with essential amino acids. Amaranth's balanced amino acid composition is close to the optimum protein reference pattern in the human diet according to FAO/WHO requirements (Table 1). The combination of amaranth and maize flour (50:50) nearly reaches the perfect score of 100 on the nutritionist's scale and also the combination of amaranth and wheat flour increases the nutritional value of baked products (National Academy of Sciences 1984; Saunders, Becker 1984; Bressani 1989; Joshi, Rana 1991; Segura-Nieto et al 1994; Grobelnik Mlakar et al 2009).

Approximately 76% of fatty acids are unsaturated, the share of linoleic fatty acid is 25-62%, oleic acid 19-35%, palmitic acid 12 - 25%, stearic acid 2 - 8,6% and linolenic fatty acid 0.3 - 2.2%. The saturated/unsaturated fatty acid ratio ranges from 0.29 to 0.43. Amaranth oil has been reported to contain larger amounts (7-8% and 11%) of squalene (olive oil contains 1 % of squalene), which is often used and appreciated in cosmetics and medicine and produced from the liver of whales and sharks. Amaranth oil is a rich source of tocotrienols known to lower the LDL-cholesterol. Amaranth seed contains 0.27- 0.32 mg/g of sterols (Becker 1981; Plate Areas 2002).

Starch mostly contains amilopectin (93.6 - 95.2%). Amaranth starch granules are extremely small (0.8-2.5 µm) in comparison to the size of starch granules of other grains: rice 3-8 µm, wheat 3-34 µm, corn 5-25 µm. Smaller granules have a greater water-binding capacity, higher swelling power, lower gelatinization temperature and high resistivity to amylases. Due to the facts mentioned above, amaranth starch shows good gelatinization properties and freeze/thaw stability appreciated in food industry (Breene 1991; Lopez et al. 1994; Williams, Brener 1995; Bhandari, Singhal 2001; Pal et al 2001).

The seed of grain amaranth is a rich source of iron (72-174 ppm), calcium (1300-2850 ppm), natrium (160-480 ppm), magnesium (2300-3360 ppm) and zinc (36.2-40 ppm) as well as vitamin riboflavin (0.19-0.23 mg/100g of flour) and ascorbic acid (4.5 mg/100 gm of flour), niacin (1.17-1.45 mg/100 g of flour), thiamine (0.07-0.1 mg/100 g of flour) and other microelements (Becker et al 1981).

Amaranth – greens and grain have been used in a wide variety of food. Vegetable types (also leaves of grain one) are usually picked fresh, used as greens in salads or blanched, steamed, boiled, stir fried, or baked to taste. Cooked greens can be used as a side dish, in soups, as an ingredient in baby food, lasagne, pasta, pie, souflé, etc. Amaranth grain, mostly rolled or popped can be used in muesli and in granola bars. Grain can also be germinated for sprouts, malted for beer production, fermented or can serve as a starchy material in spirit production. Furthermore, amaranth, like maize and buckwheat, can be popped through intense, short and dry heat without addition of fat. Ground grain can be used as a flour ingredient in different mixtures for pancakes, bread, muffins, dumplings, crackers, cookies, pudding, etc. (Bejosano, Corke 1998; Early 1990; Berghofer, Schoenlecher 2002; Grobelnik Mlakar et al 2009).

Tab. 1: Essential amino acids in seeds of different grain amaranths and some other crops (g 100 g<sup>-1</sup> of protein).

Protein source	Amino acid									
	Trp	Met/ Cys	Thr	Isl	Val	Lys	Phe/Ty r	Leu	LAA <sup>A</sup>	EAA <sup>B</sup>
FAO/WHO (1973)	1,0	3,5	4,0	4,0	5,0	5,5	6,0	7,0		
Amaranth (average) <sup>a</sup>	1,3	4,4	2,9 (0,73) <sup>C</sup>	3,0 (0,75)	3,6 (0,72)	5,0 (0,91)	6,4	4,7 (0,67)	67	87
<i>A. cruentus</i> <sup>b</sup>	---	4,1	3,4 (0,85)	3,6 (0,90)	4,2 (0,84)	5,1 (0,93)	6,0	5,1 (0,73)	84	89
<i>A. cruentus</i> <sup>c</sup>	0,9 (0,90)	4,6	3,9 (0,97)	4,0	4,4 (0,88)	6,0	7,9	6,2 (0,88)	88	95
<i>A. cruentus</i> <sup>c</sup>	---	4,6	3,9 (0,97)	4,0	4,5 (0,90)	6,1	8,5	6,1 (0,87)	87	96
<i>A. caudatus</i> <sup>c</sup>	1,1	4,9	4,0	4,1	4,7 (0,94)	5,9	8,1	6,3 (0,90)	90	98
<i>A. hypochondriacus</i> <sup>d</sup>	1,82	0,6- Met (0,34)	3,3 (0,83)	2,7 (0,68)	3,9 (0,78)	5,95	8,42	4,2 (0,60)	34	78
<i>A. cruentus</i> <sup>e</sup>	1,4	4,1	3,4 (0,85)	3,6 (0,90)	4,2 (0,84)	5,1 (0,93)	6,0	5,1 (0,73)	73	91
Amaranth (average) <sup>a-e</sup>	1,3	4,5	3,5 (0,88)	3,6 (0,90)	4,2 (0,90)	5,6	7,3	5,4 (0,77)	75	91
Barley <sup>a</sup>	1,2	3,2 (0,91)	3,2 (0,80)	4,0	4,7 (0,94)	3,2 (0,58)	8,2	6,5 (0,93)	83	97
Buckwheat <sup>a</sup>	1,4	3,7	3,9 (0,98)	3,8 (0,95)	5,2	5,9	5,8 (0,97)	5,8 (0,83)	83	97
Maize <sup>a</sup>	0,6 (0,6)	3,2 (0,91)	4,0	4,6	5,1	1,9 (0,35)	10,6	13,0	35	86
Oat <sup>a</sup>	1,2	3,4 (0,97)	3,1 (0,78)	4,8	5,6	3,4 (0,62)	8,4	7,0	62	92
Rice <sup>a</sup>	1,0	3,0 (0,86)	3,7 (0,93)	4,5	6,7	3,8 (0,69)	9,1	8,2	69	94
Soya <sup>a</sup>	1,4	3,1 (0,89)	3,9 (0,98)	5,4	5,3	6,3	8,1	7,7	89	98
Wheat <sup>a</sup>	1,2	3,5	2,7 (0,68)	4,1	4,3 (0,86)	2,6 (0,47)	8,1	6,3 (0,90)	47	86

A - relative value of limited amino acid according to FAO/WHO requirements

B - relative value of essential amino acids according to FAO/WHO requirements

(C) - relative requirement recovery with 100 g of protein

Sources: a - Senft (1979); b - Betschart et al. (1981); c - Becker et al. (1981); d - Dodok et al. (1994); e - Sanchez-Marroquin et al. (1986).

Due to the stated unique seed composition, grain amaranth has certainly a potential to become a more considerable non-wheat material in composite flours used for fortified food production. Fortification is defined by the Codex Alimentarius as "the addition of one or more essential nutrients to a food, whether or not it is normally contained in the food, for the purpose of preventing or correcting a demonstrated deficiency of one or more nutrients in the population or specific population groups" (FAO 1996). The composite flour technology referred to the process of mixing wheat and non-wheat high protein components or used non-wheat mixtures (roots and tubers, legumes or other raw materials) as such in bread making, baking goods and pasta products (De Ruiter 1978). Effective wheat bread fortification by amaranth flour addition was demonstrated by many authors reviewed by Grobelnik Mlakar et al (2008). The reviewed authors recommend 10 to 15% amaranth flour or 1 to 3% amaranth albumin isolates of wheat flour supplementation to get bread of proper baking characteristics. Amaranth was recognized as gluten-free and is therefore suitable for diets of celiac disease patients (Thompson 2001).

## 5. Amaranth as a perspective crop in temperate climate – our own experience

The raised attention towards grain amaranth and its utilisation is also pointed out by projects carried out in Europe recently. In this sense, the Slovene national project funded by the Ministry of Higher Education, Science and Technology and co-financed by Žito-Intes, a Milling and Food Industry company, entitled "Investigation of some indefinite aspects of growth, composition and rheological properties of grain amaranth seed" was concluded in 2007. In the frame of the Cordis FP6, the project entitled "Adding Value to Holy Grain: Providing the Key Tools for the Exploitation of Amaranth, the Protein-Rich Grain of the Aztecs" is running since 2006. The objective of this project is to provide the tools for an extensive and sustainable exploitation of amaranth as a health-promoting food and its industrial use (IST World 2009).

In the above mentioned Slovene project, some indefinite and interacting effects of climatic and producing factors were investigated, such as soil texture, soil humidity, day length and sowing depth on early growth stages of grain amaranths. The study also discusses the effects of year (2001, 2002, 2005 and 2006), sowing date (beginning of 2<sup>nd</sup> decade of May and 2<sup>nd</sup> decade of June), nitrogen rate (defined according to mineral nitrogen amount at the time of sowing) and plant density (50 and 75 plants/m<sup>2</sup>) on yield, crude protein, and amino acid composition in the seeds of grain amaranth (*Amaranthus cruentus* "G6"). Furthermore, different blends containing amaranth flour, their pasting behaviour and dough rheological characteristics were also investigated. The baking properties of bread made with amaranth flour supplementation were also described. Some information and our own results obtained in the frame of this national project will be discussed below.

Amaranth grain yield strongly depends on environment, weather conditions, species, genotype, and production techniques, and varies in a wide range from 500 to 2,000 kg grain per ha. With appropriate varieties and production techniques yields of 1,500 to 3,000 kg grain per ha can be expected (Williams, Brenner 1995). Jamriška (1990) and Kaul et al (1996) reported amaranth grain yields in Europe between 2,000 and 3,800 kg ha<sup>-1</sup>.

According to trial results, the above ground biomass as well as grain yield were significantly influenced by the year of production, sowing date and nitrogen fertilisation, and ranged between 14,000 - 49,000 kg ha<sup>-1</sup> and 1,500 to 3,000 kg ha<sup>-1</sup>, respectively. Results suggested that a more appropriate sowing date is in May, and a stand density of 50 plants/m<sup>2</sup>. Averaged across years, amaranth yields and grain protein content increased linear to nitrogen fertilization. With selected cultivar "G6" above-ground biomass of 33,120 kg/ha, 1,748 kg/ha of grain with 14.7% of crude protein can be expected.

As part of the trial, which was set to optimize amaranth production practice, the grain amino acid pattern was studied to determine the effects of sowing date, plant density and nitrogen fertilisation. According to the results, plant density did not influence the amino acid pattern, nitrogen application influenced only valine concentration, and the most predominant interaction in the case of almost all amino acids was year x sowing date. The concentration of summarised essential amino acids varied, regarding vegetation period and sowing date, in the range of 33.31 to 34.59, lysine from 5.86 to 6.04, and methionine between 2.23 and 2.39 g 100 g<sup>-1</sup> protein. Leucine is shown to be the first limiting amino acid (Grobelnik Mlakar et al,

unpublished data).

With regard to crop agricultural advantage and its nutritional benefits, grain amaranth has certainly a potential to become a more considerable non-wheat material in composite flours. The main problem in the use of amaranth as a component replacing wheat in the blends arises from the fact that it does not contain gluten, and thus the addition into leavened and pasta products is limited. Additionally, amaranth has a distinct aroma and flavour described as spicy, slightly pungent with bitter aftertaste (Saunders, Becker 1984). According to our own experience in organically produced amaranth containing composite flours, their pasting and rheological properties strongly depend on the basic cereal used. Therefore, initial gelatinisation temperature and maximum viscosity increased with increasing replacement ratio of refined wheat flour with amaranth flour from 0 to 30%, while in the case of both spelt flours (refined and wholegrain) the values decreased by increased substitution. However, increasing levels of amaranth flour in the blends increased farinograph quality number, water absorption, development time, stability of dough and decreased degree of softening. A general observation derived from obtained extensograms was that the addition of amaranth strengthens the dough, mainly by decreasing its extensibility and, in the case of spelt flours, by increasing the resistance of dough to extension.

Considering the reviewed literature and results obtained in our own experiment, amaranth substitution of up to 20% is recommended to improve nutritional value, some rheological properties and to strengthen the dough (Grobelnik Mlakar et al, unpublished data). According to our own, yet unpublished data, breads made of wheat and refined spelt flours with 10% amaranth addition had the highest loaf volume and thus the highest specific volume, but further increases of amaranth rate in composite flours resulted in decreased values. Loaf volume as well as specific volume was not influenced up to 10% of substitution in the case of spelt wholegrain flour. Considering the sensory results obtained according to an official Slovene bread evaluation system and according to a 10-point liking scale evaluation procedures, the composite breads were generally graded as acceptable. Loaf form and appearance, loaf colour, appearance and property of crust and crumb of various composite breads were evaluated even superior in respect to controls (Grobelnik Mlakar et al, unpublished data).

## **6. Conclusion**

Due to some stated unique properties and versatile usage, grain amaranth - the holy grain of the Aztecs, has gained an increased attention since 1970s when it was re-discovered. Moreover, grain amaranth has some agricultural advantages and noted ability to grow successfully in adverse environmental conditions such as high irradiance, temperature and drought. The enumerated attributes confirmed with numerous, above all fundamental, scientific information ultimately govern its food, feed, as well as some industrial application potentials. Apart from more or less traditional dishes, where amaranth grain or young leaves could completely or partially replace common ingredients, produces have also the potential for application as an ingredient in food formulation. In such a manner amaranth grain in the form of flour, flakes, sprouts, or grain undergoing fermentation, popping, malting, extrusion cooking, nixtimitation, special compounds isolation, etc. might be exploited. Raised attention on grain amaranth and its utilisation is pointed out also by approved and funded projects carried out in Europe recently.

Food items like bread, biscuits and pasta are most consumed and therefore appropriate carriers for protein enrichment. Grain amaranth has been tested and by many authorities recognised as a gluten-free foodstuff suitable for incorporation into the diet for celiac disease patients. It contains high levels of fibres, calcium and iron, nutrients often difficult to get into a gluten-free eating plan. On the other hand, lack of gluten is a limiting factor for application of grain amaranth into the composite flour for leavened products. However, dough rheological properties and baking performance depend on the sort and quality of basic cereal used, and the baking quality of amaranth containing composite flour could also be improved by common used bread-making additives. Another fact limiting composite bread acceptance is a distinct aroma and flavour of amaranth grain. Deteriorative sensory effects occurred at higher substitution rates, while bread with amaranth addition in concentration up to 15 % is described as being nutty and pleasant tasting. Since amaranth containing breads are speciality breads, Lorenz (1981) proposed the application of standards other than those for wheat bread in their quality evaluation. However, consumer's food acceptance depends on sensory, but also on non-sensory factors. The non-sensory factors include not only aspects such as price and convenience of preparation, but also the production methods, consumer's attitudes, awareness of health and the environment, and product beliefs. Due to raised consumers' awareness of health and the environment, and due to product specialities, amaranth containing bread has, in authors' opinion, a particular possibility to be introduced on the market as being produced and processed in the organic way.

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## **GRAIN AMARANTH AS AN ALTERNATIVE AND PERSPECTIVE CROP IN TEMPERATE CLIMATE**

### ***Summary***

Globalisation of agriculture and consequently its industrialisation seem inexorable, with negative side effects felt throughout the world. These effects include, but are not limited to, biased technological development of usage of only some, fertilisation and energy high demanding plant species, monoculture production and in this way reduced genetic diversity in agriculture. The mentioned facts with profound environmental consequences and concern for loss of crop varieties stimulate organisations and scientists worldwide in retrieving, researching and disseminating the knowledge in production and utilisation of neglected, disregarded, underexploited and new plant species, or so called alternative crops. Besides the ecological advantages of their inclusion in production on agriculture, the alternative crops have, in principle, also a high nutritional value. Considering more than 30 alternative crops described in book *Organic Production and Use of Alternative Crops*, which are suitable for growth in temperate climates, the present paper discusses the grain amaranth, a pseudocereal with a rich history as a staple and sacred food of indigenous civilisations in South America. It was rediscovered in 1970s and is recently attracting increased interest from the agronomic, as well as nutritional and processing point of view. According to the information obtained in the scope of a national research project, grain amaranth is recognised as a perspective crop suitable for production of highly nutritive food also under our conditions.

