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PSEUDOCEREALS AND THE POSSIBILITIES OF THEIR APPLICATION IN FOOD TECHNOLOGY

GENERAL CHARACTERISTICS OF AMARANTH

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Abstract: Amaranth (international name 'Amaranthus') is the so-called alternative plant, included into pseudocereals (pseudocereals). The seeds are characterized by a very favourable chemical composition as compared to the traditional bread grains. The dominant chemical component is starch with very small granules. They do not contain gluten proteins and thus they are designated for people suffering from coeliac disease. The protein includes exogenous amino-acids, which are deficit in traditional crops. Amaranth seeds are one of the richest natural sources of this component used in pharmacy and computer industry. It is a plant with very large, potential possibilities of application in broadly understood food technology. It pertains not only to seeds, but also leaves. The most popular products obtained from amaranth seeds are flour and the so-called 'popping', i.e. expanded seeds. It seems that the greatest possibilities of application of amaranth seeds and products obtained from them are in bakery and confectionary industries, although other branches should not be omitted, such as brewing or beer production.

Key words: pseudocereals, amaranth, general characteristics, chemical composition, nutritional value, technological application

Introduction

Pseudocereals are included into the so-called alternative plants, which in turn are defined as [1] a group of plants that due to the chemical content of their seeds, fruit or other parts (e.g.: leaves, stems, roots) as well as nutritious and pro-health qualities, can be used as an alternative to the commonly known species that are cultivated and industrially utilized on a large scale [1]. The term 'alternative plants' is not precise, however, it is approved and used all over the world.

Alternative plants include numerous species [1] and foremostly those which:

- provide and enhance the variety of either human food and animal feed,
- constitute renewable sources of industrial raw materials, including the energetic ones,
- possess a great ability to adjust to difficult and varying soil and climate conditions and due to that
- are perfect for recultivation of areas devastated by industry or municipal economy and additionally
- are fruitful.

Nowadays, the most commonly known alternative plants that have already been used for food production on a significant scale include, among others:

- topinambour,
- chokeberry,
- northern highbush blueberry (also called American blueberry),
- zucchini,
- summer squash,
- pattypan squash or
- camellia oleifera.

From the point of view of cereal technology, alternative plants are those, which seeds, due to their chemical content and predominantly the dominant concentration of starch, can be used as a substitute for traditional bread grains or grains in general. They are usually referred to as pseudocereals [1]. They are not, as traditional cereals, grasses and they are neither similar nor related to them [1]. The most significant pseudocereals and at the same time the group of alternative plants include:

- amaranth (Prince-of-Wales feather – *Amaranthus hypochondriacus*, purple amaranth – *Amaranthus cruentus*, tassel flower – *Amaranthus caudatus*),
- Quinoa – *Chenopodium quinoa*, *Chenopodium pallidicaule*, *Chenopodium album*,
- buckwheat (*Fagopyrum esculentum*),
- tartary buckwheat (*Fagopyrum tataricum*),
- panicgrass (*Panicum L.*) and even
- Triticale i.e. the first cereal fully bred by a human. It is a combination of wheat and rye.

From the enumerated pseudocereals, the two especially interesting and possessing wide perspectives of versatile and large utilization in production, are amaranth and quinoa.

General characteristics of amaranth

Amaranth (also called: kiwicha, amaranthus) is a plant that originated from Central America (Mexico and neighbouring countries) [2] and is, together with corn and bean, the basic crop. The grains provided foremostly flour for baking. They also served to prepare drinks, including alcohol [2–4]. Leaves and young shoots were treated as vegetables [2, 4].

In the Inca and Aztec beliefs, amaranth was a holy plant and thus it played a considerable role in all religious celebrations [2], but the Christians considered it as a proof of far-reaching paganism. Worshipping amaranth as a holy plant directly influenced the ban on its cultivation and consumption [2, 5].

Amaranth is classified into a dicotyledon class and amaranth family. Currently about 60 types and over 800 ecotypes of it are distinguished [2–4]. It is grown and valued all over the world beginning from Asia, through Europe and Africa and ending on both Americas. An incentive for cultivation is a very positive and desired, from nutritious point of view, chemical content of amaranth seeds. What is also significant is the fact that this plant is possible to be cultivated in various climate zones, from moderate to tropical, even 3000 m above sea level [6]. Amaranth is a C4 photosynthesis plant, which means that it can bind CO_2 with specific utilization of solar energy [3, 5, 7].

Amaranth is mainly grown for seeds, but also its leaves can be used. The typical seed species are [7]:

- *Amaranthus cruentus*,
- *Amaranthus caudatus* and
- *Amaranthus hypochondriacus.*

On the other hand, the species destined for leaves and less for seeds, i.e. species considered more as a vegetable than a seed, is [7]:

- *Amaranthus tricolor.*

Amaranth is also a flowering, ornamental plant, also known as a weed [1]. In this respect, one of the most well-known in the world and at the same time one of the most troublesome species is the red-root amaranth, i.e.:

- *Amaranthus retroflexus.*

The interest in cultivation and technological usage of amaranth is constantly increasing. Apart from the countries where this plant was traditionally grown, it appeared in new countries and regions of the world. The research on the chemical content of seeds as well as the most appropriate directions of their utilization in practice are conducted on wide scale.

Favorable chemical content and the resulting high nutritional value as well as great potential for practical usage caused that the UN/FAO nutritional experts recognized amaranth as the plant of the 21st century [8].

Structure and appearance of amaranth plant

Amaranth may take various forms, from wide-branching (bushy) to completely deprived of lateral shoots, with creeping stems (lying) up to almost ideally vertical, with various colors of leaves and stems (from various shades of red to green) as well as seeds, which can be white, yellow, brown or completely black [5]. Similarly, there is a great diversity of the plant's height, which can vary from 0.3 to 3.0 meters. Seed forms are generally 1.0 to 2.0 high and vegetable forms can take 0.3 to 1.0 m [3]. In Fig. 1, there is an inflorescence of purple amaranth and in Fig. 2, an inflorescence of tassel flower.

Amaranth is usually an annual plant with opposite or alternate leaf arrangements [3, 5]. Its inflorescences are single with unisexual or bisexual flowers. The characteristic feature of amaranth are thick and abundant inflorescences [3, 5]. One plant, especially among the seed forms, can produce over 500 grams of seeds and the vegetable forms, relatively pasture, produce much fewer seeds, but at the same time much more green matter, i.e. leaves [3]. Generally, it is a plant that adopts very well to the soil and climate conditions [3]. With little competition for the place, it easily produces lateral shoots that are densely leaved. With considerable number of neighboring plants, the number of lateral shoots is limited and generally one main shoot is produced with one inflorescent. Amaranth is a nitrogen-loving plant. When the content of this ingredient in the soil is satisfactory, the amount of green matter (leaves) is increasing rapidly, which has a great significance in cultivation of vegetable or pasture species [2].

Characteristics of amaranth seeds

Fig. 1: An inflorescence of purple amaranth (*Amaranthus cruentus*) [9].

Fig. 2: An inflorescence of tassel flower (*Amaranthus caudatus*) [9].

Fig. 3: Purple amaranth seeds [9]

Amaranth seeds are small, rounded and slightly flattened. Their size is proven by the weight of 1000 seeds, which fluctuates between 0.6 to 1.3 grams [10, 11].

The weight of 1000 seeds directly indicates their size but simultaneously the mutual proportions between the most significant components included in them, e.g. starch and protein [12]. It is a genetic feature, but greatly depends on the plants' conditions for growth e.g. climate, soil or fertilization.

Fig. 3 presents the general appearance of amaranth seeds and Fig. 4 [13] includes its longitudinal and cross sections together with its most important anatomical parts.

Amaranth seeds are rounded, slightly flattened and their embryo has a characteristic shape of a ring or a horseshoe and surrounds floury endosperm located inside. The external side of the seed has a thin, but at the same time quite resistant seed coat. It constitutes only 1% of the total weight of the whole seed. In the first research on amaranth utilization in food technology [15], after milling the seeds, the coat was not removed (sieved) and it did not significantly influence either the flour quality, especially color, or its granulation or excessive, noticeable roughness.

Directly under the seed coat, there is an embryo surrounding the floury endosperm [3, 5, 13]. The embryo is relatively big as it constitutes about 25% of the seed's total weight [16]. Floury endosperm, which is the largest part of the seed, is mainly composed of carbohydrates and predominantly the starch [2, 3, 13, 16], which appears in the form of very small (dimeter: $1 - 3\mu$m), polygonal granules (see Fig. 5). Due to its small sizes, it is popularly used in cosmetology as the so-called carrier for powder production and other products of the kind. The same role can be fulfilled in pharmacy and not to mention the industry of food concentrates.

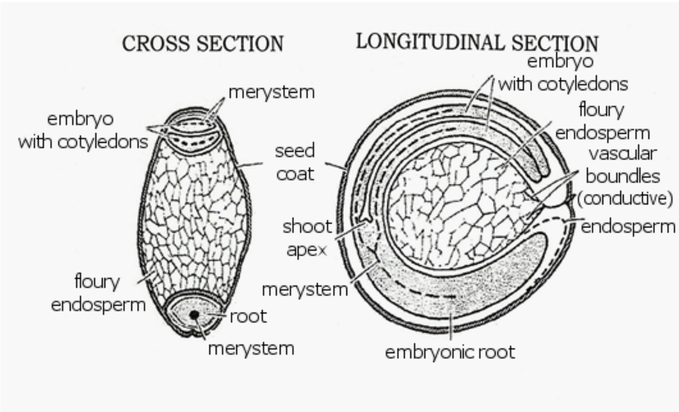

Fig. 4: Cross and longitudinal section of an amaranth seed (*Amaranthus cruentus*) [13, 14].

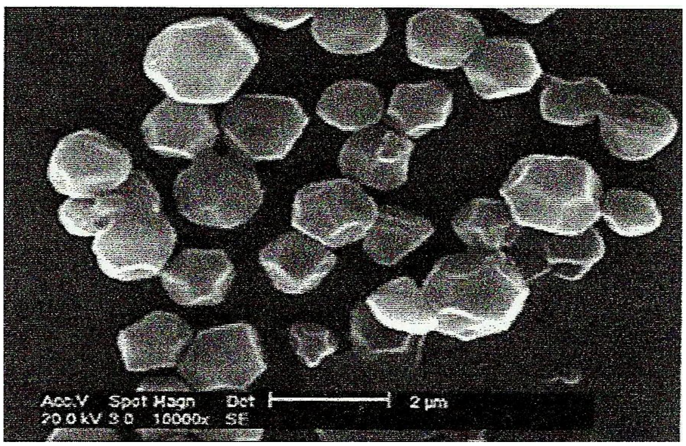

Fig. 5: Shape and size of amaranth's starch granules [13].

The most significant chemical components of amaranth seeds

Chemical content of amaranth seeds is similar to that of cereal grains and the most significant of them are: proteins, carbohydrates, fiber and mineral compounds (defined as ash). Their average content in amaranth seeds is presented in Table 1.

The fact worth noticing is the relatively high content of total protein, which is genetically determined and is directly dependent on the conditions in which the plant was growing, i.e. climate and soil conditions and especially the amount of nitrogen in the soil [10, 17].

The dominant chemical components are carbohydrates and among them the starch. The content of fat is 2-3 times higher than the average content of fat in a wheat or rye grain. It is also almost twice higher than in a corn seed and aligns with the fat content in an oat grain.

Chemical content of amaranth seeds is a genetic feature. It is proven by data presented in Table 1, which includes the content of the most significant chemical components of seeds of the three most popular species of amaranth (*A. cruentus*, *A. caudatus*, *A. hypochondriacus*) [10, 17, 18].

The highest total protein content and at the same time the lowest percentage of carbohydrates (mainly starch) is characteristic to the *Amaranthus caudatus* seeds. The reverse situation can be observed in the *Amaranthus cruentus* species.

The percentage of fats is almost identical and lies within 6 – 8% calculated on the dry matter. It is a quite high percentage, but not so high as not to cause trouble with fat absorption. Similar tendencies can be determined in relation to ash, i.e. the content of minerals. The percentage of fiber is more or less the same in *Amaranthus cruentus* and *Amaranthus caudatus* species, however, in the third compared type *Amaranthus hypochondriakus* it is about half lower.

When comparing the content of particular, basic chemical components in amaranth seeds with their percentage in the seeds of the four selected traditional grains (see Table 2), it can be noticed that amaranth seeds are much richer in the total protein, fat, raw fiber and minerals. The total amount of protein is almost 25% higher than in a wheat grain and almost 35% higher than in a corn seed. In the grains of rye and rice, these differences are even greater.

The only component that amaranth possesses less than the seeds of the selected grains, is the total amount of carbohydrates. When compared to wheat grains and corn seeds, amaranth contains respectively 9.7% and 9.2% less carbohydrates. It pertains mainly to starch as the content of simple sugars i.e. mono- and disaccharides is little. In amaranth seeds, it is between 3 and 5% [2] and in grains 1.9 – 2.1% [10]. When it comes to simple sugars, sucrose dominates – from 0.58 to 0.75 mg/100g [2].

Table 1: Comparison of chemical content of three types of amaranth [10, 14, 17].

Chemical component	*Amaranthus cruentus*	*Amaranthus caudatus*	*Amaranthus hypochondriacus*
	Content in % s.m.		
Total Carbohydrates	58,0 – 65,0	56,0 – 62,0	58,0
Total protein	13,2 – 18,2	17,6 – 18,4	17,9
Fat	6,3 – 8,1	6,9 – 8,1	7,7
Raw fiber	3,6 – 4,4	3,2 – 5,8	2,2
Total ash	2,8 – 3,9	3,1 – 4,4	4,1

Amaranth seeds, as compared to other useful plants, contain much more protein, which is particularly valuable from the nutritious point of view. Additionally, they are rich in amino acids in general and especially in exogenous ones [17–19]. The content of amino acids is presented in Table 3.

Among exogenous amino acids, high percentage of lysine (363 – 421 mg/g N) is especially precious. In this respect,

Table 2: Comparison of the content of basic chemical components in amaranth seeds (*A. cruentus*) as well as in wheat, rye, corn and rice [10,14,17].

Chemical component	Amaranth	Wheat	Rye	Corn	Rice
	Content in % s.m.				
Total carbohydrates	62,0	68,0	71,0	67,7	75,4
Total protein	15,7	12,0	9,0	10,3	8,5
Fat	7,2	1,9	1,9	4,5	2,1
Raw fiber	4,2	1,8	1,9	2,3	0,9
Total ash	3,3	1,9	1,7	1,4	1,4

Table 3: Amino acids content (mg/gN) in amaranth protein [14, 17].

Amino acid	Amaranth type:		
	Amaranthus cruentus	*Amaranthus caudatus*	*Amaranthus hipochondriacus*
Exogenous amino acids:			
Val (valine)	263	266	275
Thr (threonine)	236	225	246
Trp (tryptophan)	72	84	65
Phe (phenylalanine)	249	236	248
Met (methionine)	120	147	122
Lys (lysine)	421	371	363
Leu (leucine)	352	343	374
Ile (isoleucine)	226	223	241
Conditionally essential exogenous amin acids :			
Ser (serine)	420	393	459
Arg (arginin)	416	560	461
His (histidine)	159	157	161
Dispensable amino acids:			
Tyr (tyrosine)	214	217	186
Pro (proline)	244	252	334
Glu (glutamic acid)	982	1005	993
Asp (aspartic acid)	499	488	522
Gly (glycine)	480	445	565
Cys (cysteine)	127	121	138
Ala (alanine)	227	227	320

amaranth equals soya [8, 14, 17]. High content of lysine is very important as it is the so-called limiting amino acid in grains (wheat, rye and triticale). Moreover, amaranth protein includes a considerable amount of sulfur amino acids (methionine, cystine and cysteine). With this respect, amaranth greatly exceeds the majority of arable crops, not only grains [5]. In amaranth protein, the limiting amino acid is leucine, which in turn excessively appears in protein contained e.g. in corn, wheat or barley [5].

The identified differences in the content of particular amino acids in amaranth protein and in the protein of traditional grains clearly indicate the intentionality of composing and utilizing in production practice the mixture of amaranth and grains e.g. wheat, rye, triticale or corn.

Proteins contained in amaranth seeds reveal numerous features that are distinct from proteins included in seeds of traditional grains, soya or bean plants. It pertains either to functional properties (emulsifying abilities, creating and stabilizing foams, higher resistance to heating), but also, what is especially important, they reveal higher biological value [3, 5, 8, 10, 16, 18]. Arendt and Zannini [16] claim it is possible to obtain further, significant improvements in functional properties of amaranth proteins by their enzymatic, chemical or mixed (enzymatic-chemical) modification.

Biological value of amaranth protein compared to other selected animal and plant raw materials is presented in Table 4.

Table 4: Biological value of amaranth proteins in relation to other food products and raw materials [3].

Compared material/product	Biological value of protein (in %)
Chicken egg white	100
Amaranth seeds	75
Cow milk	73
Soya seeds	68
Barley grain	62
Wheat grain	56
Corn seeds	44
Amaranth seeds + corn seeds (1:1)	81

Biological value of amaranth proteins in relation to the value of chicken egg white is 25 percentage points lower and at the same time 2 percentage points higher than the biological value of cow milk proteins and 7 percentage points higher than the value of soya seeds proteins (very valuable proteins with amino acid content similar to meat proteins). According to Gontarczyk [3], the biological value of proteins is the result of beneficial amino acid content and mutual proportions of particular amino acids.

Similarly as with grains, so with amaranth seeds, they form the largest group of chemical compounds. The main component of carbohydrates is starch, which constitutes about 50 to over 60% in relation to the total seed mass or over 90% in relation to the carbohydrates included in the seed [3, 5, 8, 16, 17, 20]. The starch in amaranth seeds is located mainly in the endosperm.

An especially valuable feature of an amaranth starch granule is its small size (Fig. 5), which reaches from 1 to 3 μm.

A starch granule, similarly to grain starch, is composed of amylose and amylopectin and their mutual relation is from 5 : 95 to 22 : 78 and depends mainly on the amaranth type [2, 14]. There are also amaranth types that do not contain amylose at all [2].

The size of starch granules as well as their chemical content co-decide not only on their utilization, but influence also their chemical and physical properties [16]. One of such features is the ability of gelatinization, which happens in such a low temperature as 51 – 76°C (similarly to rye starch), but the obtained gruels reveal lower gelatinization than starch gruels of traditional bread grains [2].

Amaranth starch shows a relatively high ability of binding water that falls between 120 – 130% and greatly exceeds, in this respect, wheat and rye starch. It is considered that [14,16] higher water absorption of amaranth starch results from higher content of amylopectin. From the point of view of baking technology, it is a favorable feature as higher water absorption of a starch fosters higher water absorption of a cake baked with the addition of amaranth flour and this in turn influences the efficiency of baking products.

Other carbohydrates, which appear in seeds definitely in lower amounts than the starch, are: simple sugars, disac- and trisaccharides and their total content amounts to 3 – 5% [8, 14, 16]. The dominating ones are: sucrose, raffinose, glucose, galactose and maltose. The content of each of those varies, but lies between 0.24 to 0.75% [16].

Amaranth seeds are rich source of food fiber with highly positive influence on human digestive system. The general content of fiber ranges from 7.6 to 19.6% sm of seeds [3,8,16, 17,19]. It consists of two fractions: soluble and insoluble in water, with mutual proportion from 15 : 85 to 25 : 75, which means that the insoluble fraction constitutes the majority [3]. The insoluble fraction is composed predominantly of pectin and gum and the soluble one of cellulose and lignin. The amount of fiber, its content and mutual proportions of particular components depend directly on the amaranth type and indirectly on the conditions of its cultivation [3, 8,17].

The main components of amaranth seed fats are unsaturated fatty acids. Among them, the ones that appear in greatest amounts are: linoleic acid (62.0%) and oleic acid (20.4%). Unsaturated acids, including: linolenic, peanut and lignoceric appear in much smaller quantities, respectively: 1.1; 0.7 and 0.3% [3, 5].

The proportion of saturated fatty acids in amaranth seeds is much less and the most important of them are: palmitic (13.4%), stearic (2.6%) and myristic (0.1%) [3, 5, 8, 16].

High proportion of unsaturated fatty acids in oil from amaranth seeds is positive from nutritional and medical point of view [3, 8, 18].

Other important fatty components of amaranth seeds that should be enumerated are: tocopherols (vitamin E) and tocotrienols (vitamin E precursor), phytosterols (polycyclic alicyclic alcohol), phospholipids and glycolipids [8, 14,16,17]. Tocopherols and tocotrienols disclose antioxidant properties.

An especially important component of amaranth seed fat is squalene. It is an isoprenoid unsaturated hydrocarbon (6 double bonds) with the summaric formula $C_{30}H_{50}$. It occurs in all acids either animal or plant ones [20], but in very diversified quantities. For example, the amount of squalene in olive oil amounts to 0.5 – 0.6% and in amaranth seed oil – 6.1 – 6.3%, i.e. it is ten times higher than in olives [4]. In small amounts (0.12%), it also appears in female milk fat.

Currently, the oil obtained from the deep-sea sharks and whales' livers is considered a main source of squalene [3, 5, 14, 17, 21], but new sources of it are still constantly searched for and it provides new perspectives for amaranth utilization.

Squalene reveals many pro-health properties, which is the reason for such a great interest in it. It lowers cholesterol concentration (especially the bad LDL fraction) in the human organism, so it reduces the risk of atherosclerosis or coronary heart disease [3, 5, 16, 18, 21]. It also finds increasing application in oncology, especially in reducing unfavorable results of chemotherapy [18, 21]. It has been proven [18,21] that it strengthens the immune system and thus enhances natural immunity. It is used for drug production that prevents organism's aging processes and supports memory [2, 5, 21]. It is beneficial for skin and that is why it is used for cosmetic production (especially creams), protects the skin against aging as it improves its breathing, prevents from excessive dryness and protects against unfavorable environmental conditions, including the excessive UV radiation by absorbing it very strongly [8, 14, 16, 21].

Squalene is also used to protect memory surface of computer disks [5]. An exceptional similarity can be noticed – on the one hand, it enhances human memory and on the other hand, computer memory. Amaranth seeds contain numerous macro- and micronutrients. Macronutrients that are present in largest numbers are: phosphorus, potassium, magnesium, calcium and micronutrients are: iron, manganese and zinc [18,20]. In terms of macro- and micronutrients content, amaranth seeds greatly exceed traditional grains [17].

Amaranth is a rich source of numerous vitamins. It pertains especially to the following vitamins: C (ascorbic acid), E (α – tocopheryl), PP (i.e. B_3 – niacin) and B_6 (pyridoxine). It is most abundant in vitamin C (4,2 mg/100g of a product) and the rest of the vitamins appear from about two to seven times less frequently [16]. It also includes, but in lower amounts, the following vitamins: B_2 (riboflavin), B_1 (thiamine) and M (folic acid) and their quantities are respectively: 0.200; 0.116 and 0.082 mg/100g of a product [18].

In terms of vitamin content, amaranth seeds are very similar to grains, however, there are also quite significant differences, e.g.: the content of folic acid is almost twice higher in the amaranth [8, 16].

A certain disadvantage of amaranth seeds is that they include the so-called non-nutrients bearing the potential risk to human's health. Non-nutrients (anti-nutritive substances) are natural components existing in numerous food materials and products, especially of plant origin.

After consumption, they can cause disorders in metabolic processes, sometimes even illness symptoms resulting from, among others, restricting the proper usage of nutrients. Their presence causes the general reduction in nutritional value of food products [3, 20, 22].

Numerous substances considered non-nutritive were detected [3, 8, 17, 22, 23] in amaranth seeds, such as:

- Trypsin and chymotrypsin inhibitors,
- Phenolic compounds and among them saponin and tannin,
- Phytates and phytohaemagglutinin.

Their content is very diversified, often the same or lower than e.g. in grins or other food materials. They often have double effect and meaning, either negative as well as positive. They can e.g. enhance human immune defense or act as natural antioxidants [8, 17, 22].

It seems that the least desired non-nutritive substance in amaranth seeds are saponins [14] (saponin glycosides). They also exist in other food materials (e.g. potatoes, tomatoes or pepper). In an organism, they irritate digestive tracts and after passing to blood, they evoke hemolysis of red blood cells. Moreover, they hamper acetylcholinesterase enzyme, which causes disorders in transferring nerve impulses [20].

According to the research conducted by Jakuszew [23], who examined amaranth seeds in terms of saponin content and toxicity, there is no reason for fear as it was determined that [23]:

- amaranth seeds contain relatively low concentration (about 0.1% in sm) of triterpenoid glycosides (i.e. saponin) amount and moreover
- they reveal low toxicity as their lethal dose ranges from 1500 and 1750 mg per 1 kg of human body weight.

The cited author [23], taking into account the two conclusions mentioned above, claimed that saponin included in amaranth seeds do not constitute a real threat to human or animal life.

Similarly to other non-nutritive substances, saponin's activity can be desired e.g. due to foaming effect, which can be utilized in practice.

Summary

1. Amaranth is a well-known plant, which has been cultivated for ages and was re-discovered in the 70s of the previous century. It can be grown in every climate, from moderate to tropical, either in the lowlands or at altitudes of even 3000 m above sea level. It is a plant of C4 photosynthesis type, which means that it is able to bind CO_2 with specific utilization of solar energy. It reacts very well to nitrogen in soil, which influences the productivity of either seeds as well as the green matter (leaves). Due to its potential, it is recognized as the plant of the 21st century by the UN/FAO.
2. Amaranth seeds are characterized by a relatively high (up to 20%) content of protein with simultaneously lower percentage of starch. The protein possesses a favorable amino acid content and it pertains mainly to exogenous amino acids (including lysine). Amaranth proteins have a high biological value. The absorption of amaranth proteins is lower than the value of chicken egg white (assumed as 100%), but higher than the cow milk proteins. An especially favorable amaranth feature is a lack of gluten proteins.
3. Amaranth starch has numerous advantages i.e.: it has small sizes of granules, its digestion is easier and faster and it possesses high nutritious and energetic values. Due to its small sizes, it is utilized as the so-called carrier used in food concentrates, cosmetology, pharmacy.
4. Amaranth seeds contain much more fat and their exceptional feature is the presence of squalene. In this term, amaranth is the only rich and natural source of this component. Squalene finds application in medicine, pharmacy, cosmetic production and even in computer industry.

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