

Nutrition value and use of grain amaranth: potential future application in bread making

Silva GROBELNIK MLAKAR*, Matjaž TURINEK, Manfred JAKOP, Martina BAVEC, Franc BAVEC

University of Maribor, Faculty of Agriculture and Life Sciences, Pivola 10, 2311 Hoče, Slovenia

Due to described agricultural advantages, unique nutritional properties and versatile usage, grain amaranth (*Amaranthus* spp.) has gained increased attention since 1970s when it has been re-discovered. The present paper briefly describes crop importance, botany and chemical composition, including new findings on nutritive value and properties of grain amaranth processed as food. Especially the rheological properties of composite flours containing amaranth and their suitability for making fortified bread are discussed. 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 and feed also under our conditions.

Key words: grain amaranth, nutrition value, utilisation, bread making

INTRODUCTION

Amaranth is one of the few multi-purpose crop which can supply grains and tasty leafy vegetables of high nutritional quality as a food and animal feed, and additionally, because of attractive inflorescence colouration, amaranth can be cultivated as an ornamental plant. Although the crop was one of the staple foods in the pre-colonized South American civilizations, the cultivation and knowledge fell into oblivion and thus nowadays it could be classified as a new, forgotten, neglected and alternative crop of great nutritional value. The poor nutritional values of the few, but most produced, crop species in the world today and consecutively occurred genetic erosion of cultivated land are some of the reasons for renewed interest in alternative crops. The use of alternative crops would result in product competitiveness, rich nutritional value, tradition, locality and special quality (Bavec and Bavec 2006). Raised attention towards grain amaranth and its utilisation is also pointed out by projects carried out in Europe recently. In this sense a Slovene national project funded by the Ministry of Higher Education, Science and Technology and co-financed by Žito-Intes, company of Milling and Food Industry, entitled "Investigation of some indefinite aspects of growth, composition and rheological properties of grain amaranth seed" was concluded in 2007. In the frame of Cordis FP6 a 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).

The objective of this paper is to briefly describe crop importance, botany and chemical composition, and review the

currently available literature on nutritive value and properties of grain amaranth processed as food. The paper discusses in particular the rheological properties of amaranth containing composite flour and its suitability for making fortified bread which could be identified as one of the scopes for future amaranth application.

IMPORTANCE

In Pre-Columbian times grain amaranth was one of the basic foods of the New World. It was nearly as important as maize and beans and was one of the principle items demanded as tribute. 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 medicinal uses. Besides in the diet, amaranth had an important position also in Indians' religion. Idols made of amaranth dough (zoale) were paraded and consumed in a ritual manner as a symbol of communion with the gods. Because of ritual similarity to Catholic Holy Communion, Cortez banned all cultivation by legislative fiat in 1519. Additional reason for the dramatic reduction in amaranth production was the introduction of new crops from Europe and besides this also the small seed size contributed to slow down the process of amaranth coming into modern use and practice (National Academy of Sciences 1984, Kauffman 1992, Schnetzler and Breene 1994). However, Sauer (1967) reports the introduction of amaranth in the 16th century into Spain, from where it had spread throughout Europe. Around 1700s it was known as a minor grain plant in central Europe and Russia and by the early 19th century it reached Africa and Asia. After that amaranth production in Europe declined and was reduced to the state of an ornamental plant. Nowadays in Asia and Africa amaranth is mainly planted as a vegetable plant, and has been maintained as a minor cereal food only in the Himalayan region of Asia.

The scientific plant name in Greek "amaranth" means "immortal", "everlasting" or "non-wilting". The name could also be poetically connected with a story of renaissance or »rediscovery

*Correspondence to:

Tel.: +386-2-3209082

Fax: +386-2-6161158

E-mail: silva.grobelnik-mlakar@uni-mb.si

ering« of the amaranth crop. The first who drew attention to the nutritional value of amaranth was Australian investigator Downtown who, in 1973, found out the high lysine concentration in grain of *Amaranthus edulis*. Interest for the crop was raised by the book *Unexploited tropical plants with Promising Economic Value* (National Academy of Sciences 1975) which presented cultivated grain amaranths as a potential source of high quality proteins. Soon afterwards the first genetic investigations were started in India and on California-Davis University. The stimulus for the amaranth production and marketing in USA was initiated by the Rodale Foundation and the Rodale Research Center in the mid-1970s, where they started with breeding, development of crop production, commercialisation and marketing. In 1982 the Board on Science and Technology of the US National Academy of Science selected grain amaranth as a research area and nine grant programmes were awarded until 1989. The research conducted in those programmes is reported in the papers collected in the special issue of *Food Reviews International*. The interest stimulated the establishment of the American Amaranth Institute which promotes and supports amaranth production, science, and marketing. They hold an annual meeting and have published the journal *Legacy* since 1988 on an occasional basis (Kauffman 1992, Stallknecht and Schulz-Schaeffer 1993).

Though quite small in comparison to other grains, amaranth has been extensively studied and nowadays a surprisingly large volume of available literature exists, particularly on the nutritional qualities of amaranth, crop breeding, production and processing methods, development and commercialisation of new amaranth products (Article Citation Database 2009). The strongest interests in amaranth investigation and production in Europe have been present in Austria, Czech Republic, Slovak Republic, Germany, Hungary, Poland, Russia, Italy, and Slovenia (Berghofer and Schoenlechner 2002).

BOTANY

1. Taxonomic classification and origin

Grain amaranth belongs to the order *Caryophyllales*, the amaranth family *Amaranthaceae*, sub-family *Amaranthoideae*, to the genus *Amaranthus*, and according to Sauer (1967), into the section *Amaranthus*. The genus *Amaranthus* includes approximately 60 species, most of which are cosmopolitan weeds associated with difficulties in cultivation practices after soil disturbance and seed exposure to light (*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 utilisation of cultivated amaranths for human consumption, species can be divided into grain and vegetable amaranths.

Grain amaranth belongs to a group of cereal-like grain crops or pseudocereals. According to the definition proposed by Shewry (2002), pseudocereals are dicotyledonous species which are not closely related to each other or to the monocotyledonous true cereals. The name is deriving from their production of small grain-like seeds and the group comprises three crops, amaranth (*Amaranthus* spp., *Amaranthaceae*), qui-

noa (*Chenopodium quinoa*, *Chenopodiaceae*) and buckwheat (*Fagopyrum esculentum*, *Polygonaceae*). All contain main major groups of 11S globulin storage proteins with smaller amounts of 2S albumins, and 7-8S globulins appear in buckwheat and amaranth. The cultivated grain amaranths differ from their wild and weedy relatives by bearing pale, rather than black seeds, which are superior for many cooking uses. According to Sauer's taxonomic key (1967) three principal species of genus *Amaranthus*, originating in South America, are considered for grain production:

- *A. hypochondriacus* L. (sin. *A. leucocarpus* S. Watts, *A. frumentaceus*) - prince's feather;
- *A. cruentus* L. sin. *A. paniculatus* L. - bush greens, red amaranth and
- *A. caudatus* L. of two subspecies: subsp. *caudatus*; and subsp. *mantegazzianus* Passerini syn.: *A. edulis* Spagazzini, named love-liebleeding and Inca wheat, respectively

Within each grain species there are several grain types or races defined by their common branching pattern, height, inflorescence size and form, days to maturity, seed size and colour, and other morphological characteristics (Kauffman 1992, Espitia-Rangel 1994, Brenner et al. 2000).

Most *Amaranthus* species have edible leaves, but several species are known as vegetable amaranths; *A. blitum* L. (sin. *A. lividus* L.), *A. viridis* L. (sin. *A. gracilis* Desf.) and *A. tricolor* L. (sin. *A. gangeticus* L.). Their mild spinach-like flavour, high yields, ability to grow in hot weather, and high nutritive value have made them popular vegetable crops (boiled greens), perhaps the most widely eaten vegetables in the humid tropics of Africa and Asia (Schnetzler and Breene 1994). Prakash and Pal (1991) reported amaranth greens high in protein (14 to 43 g kg⁻¹ in fresh matter), lysine (40 to 56 g kg⁻¹) and carotenoids (60 to 200 mg kg⁻¹). According to authors' oxalates and nitrates concentration in fresh matter varied from 4.1 to 9.2 g kg⁻¹ and from 3 to 16.5 g kg⁻¹, respectively. Compounds are generally associated with forage and vegetable application, and they strongly depend upon genotype and fertilisation practice (Williams and Brenner 1995).

2. Morphology

Amaranth is a dicotyledonous, herbaceous plant with an erect stem and enormous inflorescence. It is a one of a few C₄ dicots and belongs into group of NAD-malic enzyme-type of C₄ metabolism. Some anatomical characteristics of amaranth and its C₄-photosynthesis pathway result in increased efficiency of using CO₂ under a wide range of temperature (from 25°C to 40°C), under higher light intensity, and moisture stress environments. All this contribute to the crop's wide geographic adaptability to diverse environmental conditions (Kigel 1994).

2.1 Roots

Root morphology, growth, development and distribution in the soil, as well as its responses to availability of nutrients and water, have been barely investigated in amaranths. In *A. retroflexus* the root system of plant growth without com-

petition develops rapidly, reaching nearly its maximum extent (2.4 m depth and 1.8 m spread) after only 10 weeks of growth. This fast development of the root system may contribute to the competitive ability of grain amaranths, too (Kigel 1994).

2.2 Stem

The stem measures from 0.5 to 3.5 m in height, is simple or branched, depending on species, genotype and growth conditions, but mainly on plant density. One of the main breeding objectives of grain amaranth is to reduce plant height to less than 1.5 m, and select genotypes with a less degree of branching (Kauffman 1992).

2.3 Leaves

Leaves are of various shapes: elliptic, rhombic, ovate, lanceolate or rhombate-ovate, with acute, obtuse or acuminate leaf tips, of green, red or silver colour. Because of anthocyanin (amaranthine) colouration, entirely red plants and plants with reddish or silver spots on the leaves also exist (Williams and Brenner 1995).

2.4 Inflorescence

Grain amaranth has a large, more or less branched inflorescence. *A. hypochondriacus* and *A. caudatus* have an erect inflorescence, inflorescence of *A. cruentus* is semi erect, and the inflorescence of *A. caudatus* is lax, long and dropping. The growth of inflorescence and its branches is indeterminate and hence can reach long lengths except for *A. caudatus* subsp. *mantegazzianus* which has a determinate or club-shaped inflorescence. Inflorescence can be of various colours: yellow, green, purple, orange, pink, violet, brown and two-coloured inflorescence (Williams and Brenner 1995). Amaranth is a monoecious plant. The flowers are unisexual with a pentamerous organisation. Each of flowers has a bract of purple, orange, red or gold colour, and is developed on branched flower clusters named glomerules (a glomerulus (sing.) is a basic unit of inflorescence and is described as a dichasial cyme). The first flower in each glomerulus is staminate (male) while the following are all pistillate (female). The crop is mainly anemophilous, up to 90 % pollination occurs on the same crop, but in some genotypes and circumstances the rate of cross-pollination can increase up to 30 %. In individual glomerulus, the male flower flowers before female flowers do, therefore female flowers are pollinated by pollen from other glomerulus (Sauer 1967, Joshi and Rana 1967, Kigel 1994). Three amaranth 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 (Sauer 1967).

2.5 Seed

Amaranth seed is borne in an utricle, which is classified as dehiscent, semi-dehiscent, or indehiscent type (grain shattering depends on the type of utricle). The colour of the seed in amaranth varies from white, gold, brown and pink to black. Seed is lenticular and relatively small (0.9 to 1.7 mm diameter)

with 1000-seed weights from 0.6 to 1 g (Kigel 1994). Selection in the past was directed toward larger plant size, larger inflorescences with higher seed production, and selection of mutant forms in which the normal black changed to a better flavoured white or light-coloured seed with superior nutritional quality. However, the size of seeds was not increased by Indians. Nowadays, one of the goals for amaranth breeding is to increase seed size. Larger seeds would improve seedling vigour, ease of handling and popping. However, increasing seed size could have a negative effect on reducing seed protein if it comes from the increase of endosperm portion only. Several breeding approaches to improve seed size are possible: seed selection (it was shown as not successful), crossing (wild species are a potential source of genes for larger seeds), and artificial polyploidy. Tetraploids are shorter with thicker stems, and with 42 % to 159 % larger seeds (Stallknecht and Schulz-Schaffer 1993, Brenner et al. 2000). Wild amaranth species and some vegetable accessions express seed dormancy. The cultivated and especially white-seeded grain amaranth lack dormancy and will generally germinate in 3 to 4 days at 21°C or above (Stallknecht and Schulz-Schaffer 1993).

The morphology of *A. cruentus* grain has been described in detail by Irving et al. (1981). The embryo is campylotropous i.e. encircles the starch-rich perisperm like a ring; it is large and accounts for about 25 % of the grain weight. The main seed storage tissue is perisperm (diploid in chromosome number), and not endosperm like in other cereals. The seed coat is smooth and thin, thus it is not necessary remove it. These differences in the morphological structure compared to cereals and amaranth small seed size have a significant influence on amaranth grain processing.

One of the most pronounced difficulties in commercial amaranth production is mechanical harvesting. The plants do not dry down uniformly and sufficiently at maturity to permit combine harvest before a killing frost. After that, the plants dry down within ten days if dry weather conditions prevail. Harvesting should be done as soon as possible to reduce wind damage and grain shattering (Weber 1987), and cereal harvesters may successfully be used (Majewski et al. 1994). 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 and Brenner 1995). According to Jamriška (1990) and Kaul et al. (1996) grain yields in Europe ranged between 2,000 in 3,800 kg ha⁻¹.

CHEMICAL COMPOSITION AND NUTRITION VALUE

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. The proximate composition is inconsistent among and within the species, and the range of reported data derived from different sources is shown in Table 1.

Table 1. Proximate seed composition of grain amaranth species (g 100 g⁻¹ on dry basis) reported in literature

	A. cruentus	A. hypochondriacus	A. caudatus	A. hypochondriacus x A. hybridus
Crude proteins (Nx5.85)				
Average	17.1	15.7	15.5	16.3
Range	13.8-21.5	15.0-16.6	13.1-21.0	16.0-16.5
No. of observation	19	6	14	3
Lysine (g 100 g protein ⁻¹)				
Average	5.3	5.5	5.9	
Range	4.9-6.1	4.9-6.0		
No. of observation	7	2	1	
Crude fat				
Average	7.7	6.7	7.1	8.9
Range	5.6-8.1	6.1-7.3	5.8-10.9	8.0-9.6
No. of observation	10	5	26	3
Crude fibre				
Average	3.9	4.9	3.9	
Range	3.1-4.2	4.9-5.0	2.7-4.9	
No. of observation	5	2	5	
Carbohydrates				
Average	65.9	67.9	70.8	62
Range	63.1-70.0		63.7-76.5	61.3-63.1
No. of observation	9	1	9	3
Ash				
Average	3.2	3.3	3.1	3.1
Range	3.0-3.8	3.3-3.4	2.5-4.4	3.1
No. of observation	9	2	10	3
Squalene (% in oil)				
Average	4.6	2.7	5.2	
Range	2.2-6.9	1.9-4.6	3.8-6.7	
No. of observation	10	8	2	

Sources: Becker et al. (1981); Sanches-Marroquin et al. (1986); Lyon and Becker (1987); Pedersen et al. (1987); Singhal and Kulkarni (1988); Ayorinde et al. (1989); Gorinstein and Moshe (1991); Prakash and Pal (1992); Bressani et al. (1993); Dodok et al. (1994); Zheleznov et al. (1997); Marcone and Yada (1998); Leon-Camacho et al. (2001); Berganza et al. (2003)

Proteins have high digestibility (approx. 90 %) and are rich with lysine (4.9 to 6.1 g 100 g protein⁻¹) which usually appears in grains as a limiting amino acid. This high lysine concentration is complemented with elevated levels of sulphur amino acid content (2 to 5 %), which is higher than that measured in the most important legumes (1.4 % on average), such as peas, beans and soybeans (Gorinstein and Moshe 1991). 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 % on average) and are poorer with essential amino acids (Senft 1979, Betschart et al. 1981). Amaranth's balanced amino acid composition is close to the optimum protein reference pattern in the human diet according to FAO/WHO requirements (Table 2). 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 (Academy of Sciences 1984, Saunders and Becker 1984, Bressani 1989, Joshi and Rana 1991, Segura-Nieto et al. 1994). Leucine, isoleucine, valine, the limiting amino acids in amaranth, are not considered

Table 2. Essential amino acids in seeds of different grain amaranths and some other crops (g 100 g⁻¹ of protein)

Protein source	Amino acid									
	Trp	Met/Cys	Thr	Isl	Val	Lys	Phe/Tyr	Leu	LAAA	EAA ^B
FAO/WHO (1973)	1.0	3.5	4.0	4.0	5.0	5.5	6.0	7.0	-	-
Amaranth (average) ^a	1.3	4.4	2.9 (0.73) ^C	3.0 (0.75)	3.6 (0.72)	5.0 (0.91)	6.4	4.7 (0.67)	67	87
<i>A. cruentus</i> ^b	-	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> ^c	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> ^c	-	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> ^c	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> ^d	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> ^e	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) ^{a,e}	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 ^a	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 ^a	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 ^a	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 ^a	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 ^a	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 ^a	1.4	3.1 (0.89)	3.9 (0.98)	5.4	5.3	6.3	8.1	7.7	89	98
Wheat ^a	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

Sources: ^aSenft (1979); ^bBetschart et al. (1981); ^cBecker et al. (1981); ^dDodok et al. (1997); ^eSanches-Marroquin et al. (1986)

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

a serious problem since they are found in excess in most common grains, and therefore, amaranth is well suited for blending with cereals.

The stated balanced amino acid composition of amaranth is also supported by our own work. As a part of four-year trials, which were set to optimize amaranth production practice in NE part of Slovenia, 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 is 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⁻¹ protein. Leucine is shown to be the first limiting amino acid (Grobelnik Mlakar et al. unpublished data).

Amaranth was recognized as gluten-free and is therefore suitable for diets of celiac disease patients (Fasano and Catassi 2001, Thompson 2001).

Amaranth grain has higher lipid content than most cereal grains. Approximately 76 % of fatty acids are unsaturated; the share of linoleic fatty acid is 25 to 62 %, oleic acid 19 to 35 %, palmitic acid 12 to 25 %, stearic acid 2 to 8.6 % and linolenic fatty acid 0.3 to 2.2 %. The saturated/unsaturated fatty acid ratio ranged from 0.26 to 0.31 in oil of grain amaranth and from 0.33 to 0.36 in oil of vegetable, ornamental genotypes and weedy species. Amaranth oil has been reported to contain large amounts of squalene (2 to 7 % or even more than 8 % in refined oil). The compound is often used and appreciated as a lubricant for fine electronic instruments, in cosmetics and medicine, and is commercially obtained from the liver of whales, sharks, and some other marine species (from 33 to 64 % in oil) or is industrially synthesised. Among other alternative plant sources the olive, wheat germ and rice bran oils contain squalene in the 0.1 to 1.7 % range (Becker et al. 1981, Leon-Camacho et al. 2001, Berghofer and Schoenlechner 2002). Squalene is a highly unsaturated hydrocarbon, a triterpene, known as the obligatory biochemical precursor of sterols. According to the studies reviewed by Kopicová and Vavreinová (2007), the nutritional standpoint of squalene consumption is contradictory; results of some investigations indicate increased LDL-cholesterol level in blood plasma of humans and hamsters, while others claim that a high squalene diet does not raise the levels of triacylglycerols and cholesterol in blood serum, whereas the concentrations of faecal cholesterol and its non-polar derivatives, as well as of bile acids, increase dramatically. However, the antibacterial properties of squalene, its antioxidative and anti-tumor effects in carcinogenesis are scientifically demonstrated and accepted. Amaranth seed contains sterols in concentrations from 0.27 to 0.32 mg g⁻¹ (Leon-Camacho et al. 2001), phospholipids concentration in amaranth oil is relatively low (around 5 %), and contents of tocols varies from 191 mg kg⁻¹ (Becker 1994) to 2,000 mg kg⁻¹ in oil (Berghofer and Schoenlechner 2002).

Amaranth starch mostly contains amilopectin (88.9 to 99.9 %) and is thus classified as “waxy type” starch with some unique characteristics (high viscosity and gelatinisation at higher temperature) in comparison to normal starches with amylase contents between 17 and 24 %. Amaranth starch granules are extremely small (0.8 to 2.5 µm) in comparison to the size of starch granules of other grains as rice (3 to 8 µm), wheat (3 to 34 µm) and maize (5 to 25 µm). Smaller granules have a greater water-binding capacity, higher swelling power, lower gelatinisation temperature and high resistance to amylases. Due to the facts mentioned above, amaranth starch shows good gelatinisation properties and freeze/thaw stability appreciated in food industry (Breene 1991, Lopez et al. 1994, Williams and Brenner 1995, Pal et al. 2001). However, broad genetic diversity in physical properties of starch within and among amaranth species, and variation in all other constituents (proteins, lipids, minerals) which have an influence on starch functional properties, need to be taken into account

when selecting genotypes for particular processing purposes.

According to an extensive study carried out by Becker et al. (1981), seed of grain amaranth is a rich source of iron (72 to 174 mg kg⁻¹), calcium (1,300 to 2,850 mg kg⁻¹), sodium (160 to 480 mg kg⁻¹), magnesium (2,300 to 3,360 mg kg⁻¹) and zinc (36.2 to 40 mg kg⁻¹) as well as vitamin riboflavin (0.19 to 0.23 mg 100 g⁻¹ of flour) ascorbic acid (4.5 mg 100 g⁻¹), niacin (1.17 to 1.45 mg 100 g⁻¹), and thiamine (0.07 to 0.1 mg 100 g⁻¹).

On the average pale-seeded amaranths contain 8 % of dietary fibre and black coloured 16 % with soluble fibre rate of 30 to 40 % and 18 %, respectively (Schnetzler and Breene 1994). Tosi et al. (2001) reported 14.2 % of dietary fibre in the *A. cruentus* flour (8.1 % soluble, 6.1 % insoluble). With different milling, sifting and pneumatic classification procedures used, authors achieved fractions of flour with increased share of dietary fibre from 32.1 to 70.8 %.

Seed of grain amaranths contain some antinutritional factors which can have a nutritional impact or can limit their food application. Content in light coloured seeds is lower or comparable to the quantity of growth inhibitors in common grain (trypsin inhibitor, phytates, saponins, and tannins), or are heat labile as lectins (Souci et al. 1994, Berghofer and Schoenlechner 2002).

UTILISATION AND APPLICATION

Amaranth grain has been used in a wide variety of food. From the whole grain tasteful soups, stews, sauces, porridges, and soufflés can be prepared, boiled grains can be used as rice and kus-kus. When amaranth grains are boiled, the starch is leaching out and is gelatinised. This causes the cooking water thickening and pronounced porridge structure formation. It often occurs that the embryo encircled gelatinous perisperm is separated during cooking.

Amaranth grain can also be germinated for sprouts and malted for beer production (traditional beer chicha in Peru), and fermented (as compound for ogi – traditional product of lactic fermentation of cereal porridges in Africa, or could be used instead of soy in shoyu). It can serve as a starchy material in spirit production and from the grain or green material protein concentrates and flours can be produced. Amaranth grain could be a suitable high protein material for maize supplement in nixtamalization or lime cooking, the process which is used for tortilla production. Furthermore, amaranth, like maize and buckwheat, can be popped through intense, short and dry heat without addition of fat. Amaranth grain, mostly rolled or popped can be used in muesli and in granola bars. Grain can be ground and used as a flour ingredient in different mixtures for pancakes, bread, muffins, dumplings, crackers, cookies, puddings, etc. (Bejosano and Corke 1998, Early 1990, Berghofer and Schoenlechner 2002). Vegetable types (also leaves of grain types) 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, casserole, lasagne, pasta, pie, soufflé, etc.

Due to amaranth's extremely small seed size in comparison to common grain, and its morphological particularity,

it is not possible to apply cereal milling equipment for production of flour fractions. Among different mills and milling procedures tested, the modified Strong-Scott barley pearler (Betschart et al. 1981) and a modified stone mill (Becker et al. 1986) proved to be the most suitable for production of amaranth flour fractions with different chemical compositions. After five successive passes through the pearler, the seed coat-germ parts were entirely abraded, leaving a spherical intact starchy perisperm. The cumulative quantity of seed coat-germ fraction was 25.5 %, which could be expressed as a flour extraction rate of 74.5 %. Crude protein, fat, dietary fibre, minerals as well as vitamins concentrations in the obtained seed coat - germ fraction were 2 to 3 times higher in comparison to whole grain. Efficient flour separation of the bran-germ and perisperm fractions was also obtained by a stone mill with gap distance set at 0.75 to 0.50 mm and increased spindle speed. Seed moisture is found to be a crucial factor influencing fractionated stone milling.

1. Amaranth containing composite flours in leavened products

With the intention to reduce the prevalence of protein-energy and micronutrient malnutrition, which prevails in lesser developed countries and is the gravest threat to the world's public health and the biggest contributor to child illness and mortality, much research in last decades has been devoted to develop procedures for the production of fortified food. 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). Food items like bread, biscuits and pasta are mostly consumed and therefore appropriate carriers for protein enrichment. In this field of fortified cereal based food products the FAO/UN launched its "Composite Flour Program" already in 1964. 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. The program's objective has been to find a new and possible replacement for wheat and to find mixtures formulations having a composition that combine optimal nutritive value with appropriate processing characteristics. An additional advantage of the Composite Flour Program would be a decline in the need for imported raw materials and stimulation of cultivation and processing of staple tropical crops in developing countries (De Ruiter 1978).

With regard to crop agricultural advantage and its nutritional benefits the 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 and Becker 1984).

Some research and our own experiences with blends containing amaranth flour and the resulting pasting behaviour, dough rheological characteristics, and their suitability for bread making will be discussed below.

1.1 Pasting behaviour and dough rheological characteristics of amaranth-containing composite flours

Pasting characteristics of slurry and especially rheological properties of dough are important in order to predict the dough behaviour during mechanical handling in the bread making process, and affect the quality of the resulting loaf. Above mentioned properties are, in case of wheat, routinely examined with tests and devices such as: Falling number, Brabander amylograph, farinograph, extensograph, and others. The Brabander amylograph is a standard instrument worldwide for measuring the gelatinization characteristics and enzyme activity (α -amylase) of flour. On the resulting viscosity curve (amylogram), initial gelatinisation temperature (T_i), gelatinisation peak temperature (T_g), time to maximum viscosity (Time) and maximum viscosity (MV) are recorded. Falling number is a rapid test for enzyme activity measurement. It is defined as the time in seconds required for a viscometer stirrer to fall a measured distance through a hot aqueous flour undergoing liquefaction due to alpha-amylase activity. The Brabander farinograph and extensograph tests are among the most commonly used flour quality tests of decisive importance for the milling and baking industries. The farinogram results are used as parameters in formulation to estimate the amount of water required to make dough, to evaluate the effects of ingredients on mixing properties, to predict processing effects, including mixing requirements for dough development, tolerance to over-mixing, and dough consistency during production. Extensograph is used for measuring the stretching properties of dough after certain time of proofing, in particular the resistance to extension and the extensibility. The force exerted is measured and recorded as a curve or extensogram from which the flour quality, baking properties and rheological optimum in case of flour additives adjustment is evident (Nikolić 1996).

Among studies on composite flour containing amaranth there are only some on dough rheological characteristics, and are resumed below. Lorenz (1981) evaluated amylographic and farinographic properties of composite flours in which 3, 5, 10 and 15 % of wheat was replaced with flour of *A. hypochondriacus*. Initial gelatinisation temperature of wheat-amaranth blends gradually increased and peak viscosities decreased as amaranth replacement level in the blend increased. Reported farinogram water absorption increased while development time and stability decreased with increasing level of replacement. On the contrary, higher dough development time and stability was reported by Silva-Sánchez et al. (2004) in treatments where wheat flour was supplemented with 1% amaranth albumin isolate (relative to wheat flour quantity). The rheological test based on farinograms showed that wheat flour substituted with 1 % amaranth albumins improves dough de-

velopment time (8.3 minutes in comparison to control of 7.4 minutes) and mixing stability (11.1 minutes in comparison to control of 10.9 minutes), however, less water was required to get the optimum dough development. Alveogram results provided by the authors suggested and baking test (discussed afterwards) approved the improvement of dough properties and bread crumb characteristics when albumin isolates are added. Similarly Oszvald et al. (2009) reported the beneficial effects of amaranth albumin to wheat supplementation even in concentration from 1 % to 5 % relative to the protein content of the wheat (i. e. about one tenth of the protein used in the aforementioned study). Positive effects on dough development time, strength and stability were evident in case of both investigated supplementation approaches; by simple amaranth albumin to flour addition and, at a significantly higher level, by its incorporation (albumin addition followed by dough chemical reduction/oxidation). Authors demonstrated that amaranth albumins are able to interact with the glutenin type subunits of the wheat storage proteins through free disulfide bonds and thus the initial reduction of the amaranth albumins is not required for incorporation. In the research of Tosi et al. (2002) where hyperproteic whole amaranth flour and hyperproteic defatted amaranth flour were added to wheat flour in concentration of 4, 8 and 12 %, the increased share of amaranth flour in the mixture slightly changed farinograph; water-binding capacity and time of dough development increased, while dough stability slightly decreased. Contrary, Sindhuja et al. (2005) reported a small reduction in water absorption capacity when amaranth flour (*A. gangeticus* L.) substituted wheat at 0 to 35 % levels in the composite flour for sugar snap cookies production.

According to our own experience on 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 (Grobelnik Mlakar et al. unpublished data).

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.

1.2 Bread quality

The results of rheological tests conducted before the baking, indicate flour baking quality, but only the loaf characteristics are the final evidence of baking performance. Physical

evidence of baking performance is routinely determined by measures as the loaf weight, volume and specific loaf volume or volume index. Volume of a cooled loaf is assessed by the rape or millet seed displacement method and specific loaf volume is determined as the ratio of loaf volume to its weight. However, irrespective of nutritive values and loaf appearance the acceptance of any product is a function of its sensory qualities. For bread sensory analysis factors such as taste, texture, aroma, crust and crumb colour, appearance and acceptability are evaluated by trained or untrained panels and according to standard bread evaluation or point hedonic scale procedures. Among studies on composite flour containing amaranth there are only few reports on their bread baking performance and sensory characteristics, and they are resumed later in the paper.

Beside amilographic and farinographic properties already mentioned, Lorenz (1981) also discussed the bread making potential of wheat-amaranth composite flours. With increased amaranth substitution levels from 0 to 20 % (in 5 % increments) the proofing time gradually increased while bread specific volume and total bread scores, obtained by standard bread evaluation, decreased. Significant deteriorative effects occurred at higher substitution rates, while bread with amaranth addition in concentrations of up to 15 % is described as being nutty, pleasant tasting, the texture not as silky and was preferred over the flavour of the white bread control. Replacement of 15 and 20 % of wheat flour resulted in darker bread crumb measured by Hunter colour difference meter and evaluated as questionable by panel one day after baking. Similarly, Tosi et al. (2002) in the previously mentioned research with hyperproteic wholegrain and hyperproteic defatted amaranth flour addition, reported a decrease in loaf volume and specific volume as well as in bread score values. The hyperproteic wholegrain amaranth flour has, probably due to the presence of oil, a better performance and acceptance and can substitute up to 8 % wheat flour. Substitution levels of more than 4 % for hyperproteic defatted amaranth flour produced an unacceptable detrimental effect in bread quality revealed by scoring. Increased level of amaranth flour in the mixture enhanced protein (from 12.2 to 16.8 %) and lysine concentration. The latter compound increases almost twofold for acceptable bread. Ayo (2001) evaluated baked products in which grain amaranth flour replaced wheat flour at levels from 0 to 50 %. Resulted water absorption capacity had a high positive correlation with the percentage of amaranth in composite flour. The author explained the relationship with amaranths starch granules' extremely small size and its unique structure. Enhanced water binding capacity and an increase in the percentage of moisture in resulted composite bread measured by the author, may also lead to the idea of prolonged product's shelf-life, although the staling process depends on many other factors and is not examined on amaranth containing bread so far. Measured specific volume of composite loaf decreased from 3.29 to 1.91 ml g⁻¹ due to gluten dilution and was significantly affected above 20 % of amaranth addition. Furthermore, the sensory attributes evaluated by an untrained panel using nine-point hedonic

scale, decreased; odour significantly at levels above 15 %, taste at 10 % and above, crumb colour was unchanged, and texture remained unchanged up to 10 % of added amaranth. Overall acceptability decreased from 6.6 to 4.0; significantly at 20 % amaranth addition and above. According to results of Burisová et al. (2001) the sensory quality of composite bread slowly decreases with increasing the rate of amaranth, but it is more pronounced with substitution levels higher than 15 %. Authors also reported that the increase in fermentative gas amount might be caused by higher saccharides concentration and improved bread porosity for products where amaranth substituted wheat flour at levels of 10 and 15 %. Baking tests carried out by Silva-Sánchez et al. (2004) have shown that amaranth albumin isolates addition at 1 % concentration improves the volume of the loaf (880 cm³) in comparison to sole wheat flour bread (830 cm³). Additionally, the crumb showed much better characteristics and no holes were detected as found on control loafs. Albumin addition in concentration of 3 % was found not to change loaf volume as well as bread flavour and colour, although the crumb was better than the control.

Effective wheat bread fortification by popped amaranth addition was demonstrated by Bodroža-Solarov et al. (2008) in a study where popped amaranth supplementation of up to 20 % contributed to the increased content of zinc (from 7.21 to 12.59 mg kg⁻¹), magnesium (from 137.80 to 396.90 mg kg⁻¹), calcium (from 80.79 to 219.04 mg kg⁻¹), squalene (from 3.50 to 43.0 mg 100 g⁻¹) and protein (from 12.6 to 13.9 %). Consequently, by increasing amaranth levels in the bread samples, water absorption, loaf weight and bread yield increased, whereas specific loaf volume decreased from 3.54 ml g⁻¹ of control to 2.73 ml g⁻¹ already at 10 % of popped amaranth addition. Authors reported altered, but completely acceptable sensory characteristics of popped amaranth supplemented bread, especially with doses from 10 to 15 %.

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 procedure, 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).

2. Amaranth as feed

The suitability of amaranth grain (raw and processed) or green parts as feed has been so far tested in trials on rats, lambs, rabbits, ruminants, pigs, hens and broiler chickens. Utilisation of amaranth grain as a high-quality row material in feed mixtures is especially interesting after the occurrence of bovine spongiform encephalopathy and consecutive prohibi-

tion of meat-and-bone meals in the nutrition of all farm animal species in Europe. Reviewing all available information is out of scope of this paper; however, the results on feed intake, feed conversion and live weight gains considerably varied, mainly according to antinutritive compounds derived from various amaranth species and genotype used, within-species differences in animal responses due to natural variation and age, feed formulation and processing method used (Saunders and Becker 1984, Schnetzler and Breene 1994, Punita and Chaturvedi 2000, Roučková 2004, Zralý et al. 2004, Písaříková et al. 2005). Due to amaranths' rapid growth rate, high protein content, and reports on generally greater bypass protein or rumen undegraded intake protein (UIP) of some grasses because of their C₄ anatomy, amaranth could potentially be a good source of UIP in the diet of polygastric species. Although in China some amaranth species are being cultivated solely for use as forage for cattle (Kauffman 1992), the potential of amaranths as forage has not been fully studied. However, forage quality of various amaranth accessions at different harvest dates was evaluated by Sleugh et al. (2001). When most of the forage quality parameters studied (neutral detergent fiber, acid detergent fiber, acid detergent lignin, in vitro dry matter digestibility, crude protein and undegraded intake protein) are taken together, it can be concluded that amaranth has good to excellent forage quality at certain stages of development. Of all the quality parameters evaluated, nitrate concentration remains a major concern. The observed nitrate concentrations may be too high for these accessions to be used as fresh forage for livestock before 84 days after planting. Ensiling the forage can be an alternative for reducing nitrate concentration and improving its digestibility. In available literature there is only one study examining the ensiling ability of sole and amaranth combined with other forages. From this study Kadoshnikov et al. (2001) resume that *A. lividus* and *A. mantegazzianus* are more appropriate for ensilage among amaranths, *A. cruentus* is not suitable for silage by itself, but ensiling should be done in combination with other forage plants, such as maize and sorghum (in proportion of 1:1 or 1.5:1), and that the best time to cut amaranth for ensiling is the fruiting period.

Proposed amaranths' silage suitability has been just recently studied at the Faculty of Agriculture and Life Sciences, University of Maribor. For this purpose trials have been conducted to examine crop performance of amaranth-maize and amaranth-sorghum grown together in different row intercropping patterns, and their feed and biogas producing silage quality.

CONCLUSIONS

Due to some stated unique properties and versatile usage, grain amaranth – the new crop – has gained increased attention since 1970s. This re-discovered crop has some agricultural advantages and noted ability to grow successfully in adverse environmental conditions such as high irradiance, temperature and drought. We can conclude that attributes confirmed with numerous, above all fundamental, scientific information ultimately govern its food, feed, as well as some industrial ap-

plication potentials. Food items like bread, biscuits and pasta are most consumed and therefore appropriate carriers for protein enrichment. Grain amaranth has been tested and recognised by many authorities as a gluten-free foodstuff suitable for incorporation into the diet for celiac disease patients. On the other hand, lack of gluten is a limiting factor for application of grain amaranth into the composite flour for leavened products. Another fact limiting composite bread acceptance is a distinct aroma and flavour of amaranth, described as spicy, slightly pungent with bitter aftertaste. However, consumer's food acceptance not only 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 environmental, and product beliefs. Due to raised consumer's awareness of health and the environment, and due to product specialities, amaranth containing bread has, in authors' opinion, particular possibility to be introduced on the market as being produced and processed according to standards of organic agriculture.

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