Chapter

Functional Value of Amaranth as Applied to Sports Nutrition

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Abstract

Amaranth can be beneficial to health and sports, with multiple applications owing to varied concentration of phytochemical; the concentration of these compounds depends on the part or by-product employed. For example, as a food supplement, amaranth oil (rich in squalene) can exert cardiovascular properties, while amaranth extract (rich in nitrites) can increase nitric oxide production (therefore improving endurance performance). On the other hand, as a functional ingredient, its gluten-free flours (containing fibre) can act as probiotics, whereas its proteins (with a peculiar amino acid profile) support muscle recovery. The few clinical results with athletic population suggest it can contribute to improved aerobic metabolism, but there is insufficient clinical data to draw any conclusion. Further research warrants elucidation of amaranth phytochemicals as promising ergogenic aids in sports by high-quality human clinical trials with both standardised products and ingredients in athletic population.

Keywords: amaranth, sports nutrition, clinical trial, functional food, athletic performance, recovery, ergogenic aid

1. Introduction

The field of sports nutrition studies how food and other dietary supplements can improve performance and general health status of physically active subjects, or athletes (both recreational and professional). Usually, recreational physical activity aims to obtain the healthy benefits which can include improved mood and movement in daily physical activities, aesthetic reasons and maintenance of health status. On the other hand, competitive athletes (especially elite athletes) pursue to peak performance.

For this reason, the first category of subjects would prefer including functional foods and change their overall diet by healthier choices (whatever definition is in their minds), while competitive subjects might prefer a combination of nutritional strategies with promising dietary supplements. Surveys vary much to this respect, but statistics estimated that between 40 and 100% of athletes typically uses supplements such as sports foods, medical supplements, ergogenic supplements and functional foods (super foods) [1, 2]. Amaranth is a pseudo-cereal which has many edible parts like seeds and leaves and by-products (like amaranth oil, flour and powder) which has been attributed to many health benefits.

The area of sports nutrition studying all these aspects is an emerging field which shows some evidence showing efficacy for active compounds, while others still need further quality research to draw reliable initial conclusions. This chapter reviews the existing literature of amaranth applied to the sports field and discusses the potential application of amaranth and its derivate products to sports and their functional value supported by the existing clinical and empirical data.

2. Existing literature of amaranth in the sports field

The number of published research articles of amaranth with physically active human population is still scarce. The few studies found (through Google Scholar and PubMed search engines) at the time of writing this article are summarised in **Table 1**. Two of the three articles found employed amaranth oil, while the other employed a different product (amaranth drink instead of amaranth oil). To our best knowledge, only one of the studies assessed amaranth supplementation in an exercise test, while the other two studies used athletic population to measure aerobic metabolism parameters and cardiovascular parameters (heart rate variability). Furthermore, the only trial with an exercise test administered an amaranth drink, while most of the clinical literature addresses the functional properties of amaranth oil—without a single clinical trial with exercise tests in athletic population to our best knowledge. Due to the small amount of exercise test-related data, it is not feasible to obtain strong conclusions of the contribution of amaranth products to sports, according to various guidelines to assess the level of clinical evidence [3, 4].

3. Prospective applications of functional value of amaranth to exercise

There is a good *rationale* to employ amaranth in the sports field. The following chapter discusses the potential application of the functional value of amaranth and its by-products supported by the existing clinical and empirical data of previous studies.

3.1 Amaranth sports performance and metabolism

3.1.1 Amaranth impact on aerobic metabolism

Among amaranth products, the most studied by its functional properties is perhaps amaranth oil. Amaranth oil possesses large quantities of polyunsaturated fatty acids (PUFAs) especially linoleic acid (LA) (38.2%) (the most important FA in the omega-6 family) and oleic acid (33.3%) [5]. Action of PUFAs on heart rate variability was previously linked to omega-3 fatty acids (FAs) [6] translated in heart rate recovery after exercise partly attributed to incorporation in myocardial cells, affecting cardiovascular performance [7–9]. However, amaranth oil has a small quantity of alpha-linolenic acid (ALA) (compared to other seeds like walnuts and flaxseed oil [10] which are the one addressed to improve performance in sports [11]).

In spite of this fact, amaranth oil was studied in athletes showing activation of aerobic metabolism (important in long distances and low- to medium-intensity sports), concomitant with clinical biomarkers showing an improved utilisation of oxidation waste products (lipid peroxidation products), showing improved heart rate variability (HRV) [12], which is related with a better physical performance condition [13, 14]. This happened also in another study also for the group patients with diabetes mellitus 2 [15] later confirmed by studies in unhealthy subjects (duodenal peptic ulcer patients) [16].

Title	N	Trial design	Test	Supplementation protocol	Outcome/s
The influence of an amaranth-based beverage on cycling performance: a pilot study [28]	6 trained cyclists (5 men and 1 woman)	Randomised, counterbalanced, cross-over trial	2 time trials (TT): 10 minutes of warm-up, 32.20 km, 10 minutes of recovery, and 5 km	Periodic intake of 150 ml of an amaranth based (52.48 kcal/100 ml) or commercial drink (24 kcal/100 ml) rich in carbohydrates, every 10 minutes through the first TT and recovery time	↓ Time to complete 1st TT Trend to decreased time to complete 2nd TT ($p = 0.06$) No significant changes in rate or perceived exertion (RPE), muscular power during the TT or haematocrit
Activation of aerobic metabolism by amaranth oil improves heart rate variability both in athletes and patients with type 2 diabetes mellitus [15]	36 patients with diabetes mellitus type 2 (DM) (20 male and 16 female) 24 national level athletes (16 male and 8 female)	Comparative study	Heart rate variability (HRV) (standing and orthostatic test) Aerobic metabolism (by lipid peroxidation/antioxidant activity and blood haemoproteins)	1 ml of concentrated amaranth oil (*Amaranthus cruentus*) obtained by vacuum CO2 cold extraction, at least 2 hours before meal, for 28 ± 2 days in the DM group and 22 ± 2 days for athletes	In the athlete group: ↑ HRV Haemoglobin ligands were redistributed ↑ levels of oxidative destruction products Moderate strength correlations of HRV with aerobic metabolism found
Study of aerobic metabolism parameters and heart rate variability and their correlations in elite athletes: a modulatory effect of amaranth oil [12]	68 (36 competitive male athletes and 32 healthy males)	Comparative study	HRV and autonomic profile Oxidative stress (catalase activity, superoxide dismutase, oxidatively modified proteins) Middle mass molecules Haemoglobin (Hb) and its ligands (oxyHb-, carboxyHb, sulfHb and metHb)	1 ml of concentrated amaranth oil (*Amaranthus cruentus*) obtained by vacuum CO2 cold extraction, at least 2 hours before meal, for 21 consecutive days	↑ HRV in both groups ↓ HbO_2 percentage ↑ HbCO, HbS and MetHb Moderate correlation of HRV with some aerobic metabolism and oxidative damage markers was found

Table 1.
Summary of studies that used Amaranth in physically active population. Search was conducted through Google Scholar and PubMed search engines.

Another mechanism in which amaranth can contribute to aerobic performance is through participation in the nitric oxide pathway, thanks to its nitrate and nitrite composition. Dietary nitrate is firstly converted to nitrite by the oral microflora [17, 18] and then can enter into the system. A study with healthy human subjects supplemented with 2 g of amaranth extract showed a significant increase in plasma nitrate and nitrite, lasting up to 8 hours after administration [19].

Nitric oxide (NO) is important in physiological processes that may enhance exercise performance [20–22]. Some studies showed amaranth extract capacity to increase nitrite and nitrate in plasma, which is expected to increase the production of nitric oxide [19] (previously seen in cell cultures [23] and animal models [24]). Nitric oxide has been linked to improved endurance performance by reducing the oxygen cost during exercise, increasing the efficiency of energy production [25] (through an increase in mitochondrial efficiency [26] and ATP turnover functions [27]). Nitric oxide dietary supplements are widely consumed among athletes, and therefore future employment of amaranth extracts in new powder sports products (like pre-workouts) could be enticing if its efficacy is clinically validated.

3.1.2 Amaranth and carbohydrate metabolism

Amaranth components and ingredients can be used both as an ergogenic aid or a healthy food depending on the glycaemic index (GI) (the speed at which glucose appears in the bloodstream). High-glycaemic index foods have been attributed to higher conversion in triglycerides (fat) but may be of interest when, after a workout, our aim is to provide a fast source of carbohydrates to quickly restore muscle glucose stores (glycogen). Previous work stated that after exercise, a transitory physiological phenomenon called "metabolic window" (also referred as "anabolic window") occurs, so that utterly every carbohydrate (glucose) is synthesised to muscle glycogen and therefore stored the "healthy way" (not converted into fat).

A study with women showed that a snack with extruded amaranth presented a significantly higher GI (107) and insulinemic response than white bread, which can be recommended to athletes with this purpose as a post-workout snack [29]. amaranth starch has low viscosity and high solubility, greater than wheat and corn starches, with little content in resistant starch which provides a high glycaemic ingredient that can be dissolved in high concentrations in water, with high digestibility [30] which can be used efficiently in post-workout drinks to quickly restore glycogen stores. However, outside this metabolic window, the interest could be to avoid high GI foods, so they are not concomitantly synthesised as lipids, which can increase our fat stores (mainly as fat tissue under the skin).

Replacement of some traditional products with amaranth-based products can represent a healthier option, when they present a low GI, as in amaranth-based breakfast cereals. However, the format employed is the most determinant factor for its GI, showing higher values for a popped amaranth (105.2) than a regular cereal (74.1) but significantly lower for amaranth cereals (45.9) [31]. This is in line with a study with diabetic patients in which a diet with different amaranth proportions (grain, popped amaranth and amaranth-wheat flour) showed that its employment can represent a low or high GI [32]. This should be taken in consideration by athletes to decide when to use each product.

Apart from amaranth nutritional properties as an ingredient, amaranth oil can also improve carbohydrate metabolism as a food supplement. Previous studies with animal models showed that amaranth grain and oil can exert a hypoglycaemic effect in diabetic [33, 34] and in postmenopausal women (n = 90) when administered with amaranth leaf powder [35], showing a decreased fasting blood glucose level.

However, further research is needed to clarify its role in athletic population and if these clinical markers are translated in improvement of physical and/or biochemical markers and health condition.

3.2 Recovery and health maintenance of the athlete

3.2.1 Cardiovascular system health

The main benefit associated with amaranth in cardiovascular health is through amaranth oil (very likely its high squalene content). Squalene is an unsaturated hydrocarbon ranging from 2.4 to 8.0% [36, 37], which has a similar structure to beta-carotene, and is an intermediate metabolite in the synthesis of cholesterol [38].

Animal models showed a decrease in total level of cholesterol by amaranth grain [39, 40] and also of triglycerides, LDL cholesterol [41] and VLDL [33] in addition to the fatty acid composition of the membranes of erythrocytes by amaranth oil [42] later confirmed in human patients after taking 600 mg of squalene [43]. This was also found in a study with a larger number of patients (n = 125) with amaranth oil intake from 3 to 18 ml daily (3 ml provides 100 mg of squalene) for 3 weeks, showing a dose-dependent relation with also reduced systolic and diastolic blood pressure [44].

In addition to its oil, other bioactive peptides have been found in amaranth with interesting applications to cardiovascular health. For example, globulin 11S [45] showed a potential to modulate the angiotensin system [through inhibition of angiotensin-I-converting enzyme (ACE)] tested to be resistant to gastrointestinal hydrolysis in a simulated digestive environment [46], suggesting resistance to peptic hydrolysis by human digestion. Seed protein hydrolysates also showed antihypertensive effect in vivo [47], which was also the case for amaranth oil in pulmonary arterial hypertension, although a lot of clarification is required to this respect [48]. Other in vitro studies showed that the pure peptides of amaranth inhibit cellular markers associated with the development of atherosclerosis [49] (a disease strongly linked to coronary artery disease [50]).

Apart from its regular edible parts, amaranth leaf powder also showed a different action to cardiovascular markers by increasing haemoglobin levels after administration of 9 g daily (for 3 months) in postmenopausal women [35], in line with the effect of amaranth oil, which showed a shift in haemoglobin ligands in athletes [15]. A combination of amaranth edible parts (seeds, oils and flours) as part of the diet, combined with supplements of its bioactive compounds (as per its leaves and peptides), seems to be linked to the cardiovascular physiology to some extent.

The cardiovascular system is also comprised of the blood vessels, whose inner tissue (endothelium) health status is a determinant and plays an important factor in the energetic chain, due to its role in the interchange of nutrients and oxygen. To this respect, NO is an important signalling molecule that can improve endothelial function and, as previously discussed, can be enhanced by the dietary intake of nitrite present in amaranth extracts [19]. It should be noted that NO is usually produced during exercise in absence of dietary supplementation [51] and that improvements in endothelial function are not only dependent on the cells of the arteries but also by the bone marrow whose main stimulator is also the NO produced by exercising [52]. However, the growth factor which is important during the first stages of training adaptation becomes significantly reduced after significant angiogenesis has occurred [53], and therefore, external sources (like in amaranth extracts) that can improve the endothelial function are of high value to preserve its health integrity.

3.2.2 Amaranth fibre as a probiotic for health and athletic performance

Probiotics and gut microbiota health are becoming popular among athletes and general population. Intense and strenuous exercise can impact gastrointestinal health status [54], while on the other hand, recent publications suggest that probiotics and gut microbiota are related to improved exercise performance [55]. Probiotics are an early field of study in sports nutrition, which can directly interact with gut microbiota and interact with the mucosal immune system and immune signalling to a variety of organs and systems [56].

Dietary fibre can serve as food for the microbiota, and to this respect, amaranth is a good source. Fibre from amaranth seeds is 78% insoluble (mainly composed of pectic substances: galacturonic acid, arabinose, galactose, xylose and glucose) and 22% soluble (mainly xyloglucans and arabinose-rich pectic polysaccharides) [57].

While clinical studies in humans are still missing to prove the effects of amaranth fibre to human microbiota, an in vitro study (emulating human intestinal ecosystems) suggests it has a probiotic effect, as it exerts some properties to specific culture of probiotic cultures [58], and a prebiotic effect (by increasing *Bifidobacterium* spp. and *Lactobacillus/Enterococcus*) as confirmed in human faeces [59] (and in vitro [60]). Apart from possible influence of amaranth fibre to microbiota, the fibre content can help to relieve common gut problems derived from the disturbance of mucosal surfaces because of prolonged or intensive exercise [61], which can be a beneficial side effect.

In addition, amaranth protein is surprisingly a source of dietary fibre with prospective applications to sports nutrition, since protein concentrate powders are widely used among athletes in protein shakes, being the main product consumed by muscle builders. The soluble dietary fibre content or amaranth protein concentrate powder is notably higher [12.90 g/100 g on dry weight (dw)] than in its flour (4.29 g/100 g dw) also with higher content of insoluble fibre (20.69 g/100 g dw against 5.54 g/100 g) [62]. This kind of amaranth product would provide large amounts of fibre for the development of gut microbiota, being also a source of vegetable protein. Clinical studies with protein and probiotics (whey + probiotics) showed improved recovery (diminished exercise-induced muscle damage) in recreationally trained males [63], as well as an improved strength restoration [64], compared to only protein (whey: probably the most widely used protein powder). Further research should be carried to study if this behaviour is mimicked when vegetal proteins (like amaranth's) are used, compared to that of milk (whey).

3.2.3 Antioxidant effect linked to sports

Polyphenols (the most abundant antioxidants in plants) have shown to improve athletic performance from large improvement to moderate impairment [65], while a meta-analysis showed an average improvement of 1.90% (95% CI 0.40–3.39) when at least supplemented by 7 days. They also have been blamed to impair training adaptations due to its antioxidative effects by chronic supplementation [66–68] which may hamper the development of antioxidant endogenous enzymes, while a recent review states that acute administration just before or during exercise can have beneficial effects [69]. Different parts of amaranth contain fractions of a variety of antioxidants which could be employed.

Amaranth sprouts are rich in red-coloured betacyanins—a subclass pigment belonging to the betalain family (and therefore a polyphenol)—with known antioxidant [68] and anti-inflammatory properties [70] in vitro [35], which at the same time can be applied to improve performance in sports. Betacyanins are also present in other red-coloured plants like beet [71, 72] still requiring studies in humans to clarify its bioavailability, which suggests being low [73].

In addition, amaranth seeds and sprouts showed antioxidant flavonoids (such as rutin) and phenolics (like gallic acid, *p*-hydroxybenzoic acid and vanillic acid), while sprouting makes the appearance of *p*-coumaric and syringic acid (related with light exposure) [74].

Clinical studies showed that supplementation with amaranth leaf powder in postmenopausal women showed a significant increase in the endogenous antioxidant enzymes superoxide dismutase and glutathione peroxidase with decrease in the marker of oxidative stress malondialdehyde [35]. These are developed as a consequence of oxidation provoked by training in physical exercise, but more research is required to assess any possible contribution of the described antioxidants of amaranth ingredients to trained athletes (which presumably have developed this endogenous antioxidant system to its highest) and its link to sports performance outcomes.

3.2.4 Amaranth protein, muscle recovery and improved body composition

Early studies suggested that amino acid composition of amaranth grain protein had leucine as the limiting amino acid [75] (later confirmed in post-prandial analysis of children [76]), while it is pretty rich in lysine [62] and tryptophan [76] being suitable to combine with other cereals and provide a more balanced amino acid profile [77]. On the other hand, latter studies suggest that they are especially rich in the essential amino acids threonine and tryptophan [78] and that leucine and lysine are not the limiting amino acids in pseudo-cereals [79] (contrary to cereals) which are not true cereals from a botanical view and have nutritionally been considered as a mix of rice and beans. Protein in amaranth seeds is mainly in the embryo (instead of the endosperm) [80] showing also variation in their composition between species [81, 82]. Proteins have been appointed as the macronutrient with the most satiating effect [83] which can cause an improvement in body composition thanks to an increased satiety [84].

Protein powders which are popular among athletes can also include diverse forms like concentrates (the most common and cheap) or isolates (with virtually no carbohydrate fraction) and additionally be hydrolysed (with its proteins partly broken into smaller peptides and even amino acids). Protein hydrolysates of whey have shown to increase the insulin concentration due to a mechanism independent of gastric emptying, which can improve muscle repair by its accentuated anabolic response. Amaranth protein hydrolysate releases biopeptides which were investigated for its antihypertensive properties [47]. Studies in humans warrant further research in this field to study the same response in insulin of blood pressure in healthy and physically active population.

3.2.5 Employment of amaranth for gluten-free diets and vegan diets

Nutritional strategies through special diets are a common resource used by athletes to reduce fat mass, increase muscle mass and improve health [85]. Among these diets we find raw food diets, gluten-free diets and vegan diets [86].

To this respect, amaranth is a gluten-free alternative source of carbohydrates which can be used in gluten-free diets [87]. Amaranth can be cooked in water, extruded (appearance is of pellet form, which could be used as breakfast cereals (for a picture see [88])), toasted, incorporated into flakes [89, 90] or pastas and baked into bread, biscuits and cookies, resulting in gluten-free bakery foodstuffs [91]. Some work has been done to try to develop grain amaranth-based nutrient-rich snack bars [92]. In Mexico, *Amaranth cruentus* cultivars are used to manufacture cookies called "Alegria" [93] (in which amaranth is used in the form of popcorn) and a commercial drink called "atole" made from milled and roasted amaranth seed, which contains large amounts of sugar. In Asia, the Indian diet find amaranth grain as an alternative to wheat, easy to incorporate into the traditional cuisine [94].

On the other hand, amaranth protein is suitable for vegan diets of athletes, whose requirement in protein can be markedly high [86, 95] and whose nutritional value was previously discussed (see *3.2.4 Amaranth protein, muscle recovery and improved body composition*).

4. Further research in the sports field of amaranth

4.1 Clinical trials with amaranth and athletic population require more research

Nutraceuticals are an area of recent research in which substances not traditionally associated with nutrients or drugs show physiological effect on the body [96]. The nutraceutical era is an emerging opportunity to find the inherent nutritional value in biology (like the functional value of amaranth discussed in this book) and requires an additional effort in its research to conduct robust and controlled clinical trials to throw light on the knowledge field. Compared to the research conducted in pharmacy, nutrition, nutraceuticals and dietary supplements in the sports nutrition field require clinical studies with good trial design and standardised products and ingredients. Uncontrolled factors, as the regular diet of subjects participating in a clinical trial, can contain one or different functional molecules that can affect the results of the trial, so its study as stand-alone substances is not so easy (and in fact is better controlled in clinical trials with patients staying in a hospital room). The following section focuses on some of the aspects that should be taken in consideration to conduct further high-quality research with amaranth.

4.2 Fluctuation in the nutritional value of amaranth plants should be considered

Natural ingredients and by-products from plants are subject to a natural fluctuation in their composition and nutritional value (which can affect their functional effect) due to external factors or conversions until they are manufactured a final ingredient or product. These are some of the empirical data found in the literature when assessing the functional value of amaranth products used in clinical trials:

4.2.1 External factors during crop growth

External factors during the growth of the crop, its manufacturing and conversion until a final product is created can affect the nutritional value of amaranth:

- The lipidic content (which includes squalene) shows great variations depending on the species and genotype [37, 97] as well as the different parts of the seed [98].

- Stress and other external crop factors can influence their nutritional value [99] and in consequence its clinical outcomes.

- Enrichment with selenium of *Amaranthus cruentus* improved its anti-inflammatory effect in rat models, very likely due to its increased content in betacyanins and selenium which significantly decreased inflammatory interleukin 6 production [100].

- Sunlight exposure of *Amaranthus tricolor* showed more development of red-fleshed cultivars with greater exposure to direct sunlight, with an increased quantity of antioxidants like polyphenols [101].

- Stress like climate changes and harsh conditions can affect seed's morphology and nutritional value, which showed globulins paralogs and precursors in wild species, which could be a genetic source for improving the nutritional quality of amaranth seed [102].

- Amaranth sprouting showed increased vitamin content (significantly in biotin, folic acid and especially riboflavin (vitamin B2) and ascorbic acid (vitamin C) [103]) and decreased lipid and phytic acid content, which also is specie dependent [104].

- Amaranth contains varying amounts of vitamin C depending on the species and part used, with around 69–288 mg/100 g in the grains and 62–209 mg/100 g [105], which is suggested to have an important role in the defence of exercise-induced oxidative stress [106].

4.2.2 Manufacturing and storage can also affect its nutritional and functional values

Manufacturing of amaranth to final product is also an important stage in the consecution of a dietary supplement for administration in clinical trials. Amaranth oil is extracted by squeezing amaranth grain, which can be extracted by cold extraction (considered as a gold standard in the manufacture of virgin oils)—which should be a well-controlled process to assure integrity maintenance of the oil—or solvent extraction (which requires further purification). On the other hand, amaranth flours can be converted to breakfast cereals by puffing or extruded, both processes that can affect its integrity, which is also affected by heat if, for example, used in bakery.

These are some of the facts found in literature which found how extraction technologies can affect amaranth bioactives and their functionality:

- Processing of amaranth may result in losses in protein content [107] as later confirmed by a study which abolished the sensitization potential of albumins with hypoallergenic properties in rats [108].

- Heating can affect antioxidant capacity [109], and phytic acid content has shown to be significantly decreased after undergoing a low-cost extrusion process.

- Storage conditions, as shown in a study which stored amaranth leaves, showed a reduction in beta-carotene of up to 85.0% [110] and a decrease in lysine of 4.8 and 9.6% in cracker and biscuits, respectively, after 4 months of storage [111].

- Extrusion improved anti-inflammatory effect of bioactive peptide hydrolysates studied afterwards in rat models [112], while other studies state that antioxidant capacity (phenolic content) decreased on the favour of an improved digestibility (tested in vivo) [113].

- Puffing to convert amaranth seeds into popped amaranth (breakfast cereal-like product)—probably the most popular breakfast amaranth product [114]—can influence its nutritive value by decreasing the unsaturation of PUFAs, mainly linoleic acid (from 46.8 to 27.0%) with increased squalenes (by 15.5%) [115].

- In children, post-prandial amino acid analysis after the intake of toasted, popped or flaked amaranth consumption caused significant falls in leucine and threonine, suggesting that these were first- and second-limiting essential amino acids [76].

4.3 Standardised amaranth ingredients

Natural fluctuation is difficult to control, but there is an alternative solution to control the active ingredients in a dietary ingredient or supplement: Standardisation

Standardisation consists with describing a set of technical standards to guarantee constant qualitative and quantitative parameters and therefore its safety, quality and efficacy [116]. According to the same authors, these are some of the problems associated with nutraceuticals (not happening in synthetic drugs):

1. They are a mixture of many constituents.

2. The active ingredient/s is/are in some cases unknown.

3. Selective analytical methods or reference compounds (standard samples) may not be commercially available.

4. Plant materials are chemically and naturally variable.

5. Chemo-varieties and cultivars exist.

6. The source and quality of the raw material are variable.

Therefore, further research should focus on proper analysis of the composition of the product used for the trials, and pursue to guarantee, that the target compound is found in enough amounts, and not other compounds which might affect the outcomes of its experiments. Application of manufacturing processes to isolate active compounds like squalenes (by fractionation and distillation), as shown in a study [117], may allow the isolation of them for its further clinical study.

5. Conclusions

1. Amaranth still requires further investigation in athletes and physically active healthy subjects to study its functional effect on sports performance. The few results suggest it can activate the aerobic metabolism.

2. Clinical results with human and animal population and in vitro assays suggest physiological mechanisms that can contribute to aerobic performance through

activation of NO pathways, as a source of high and low glycaemic index carbohydrate, possible activation of gut flora (probiotic) which can be translated to athletic performance, antioxidant effect and employment of its protein and/or biopeptides.

3. Maintenance of athlete's health can be obtained through amaranth properties on cardiovascular health, as a probiotic for gut microbiota, as a source of dietary antioxidants and as a suitable ingredient for special diets like gluten-free diets (of its flours) and vegan diets (as a vegetal protein).

4. Further research should consider amaranth natural fluctuation of its nutritive value by external factors and control its composition by thorough analysis or employment of standardised products and supplements.

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