



Why Millet, Quinoa, and Amaranth Should Be Considered the Grains of the Future?

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ABSTRACT

The consequences of climate change on the performance of grain and cereal crops are profound and multifaceted, affecting crop yields, nutritional quality, and food security. The impacts are particularly severe for vulnerable populations, exacerbating hunger, malnutrition, and socio-economic challenges. Addressing these challenges requires a comprehensive approach, including investment in climate-resilient agricultural practices, improved infrastructure, and effective policies to support food security and sustainable development. By understanding and mitigating the impacts of climate change on agriculture, we can work towards a more secure and sustainable future for global food systems. The increasing demand for sustainable, nutritious, and resilient food sources is steering global attention towards ancient grains. Millet (*Pennisetum glaucum*), quinoa (*Chenopodium quinoa*), and amaranth (*Amaranthus spp*), often termed "super grains," offer unique advantages that make them prime candidates for addressing future food security. This dissertation explores the nutritional, agricultural,

environmental, and economic aspects of millet, quinoa, and amaranth, highlighting why they should be considered the grains of the future.

Keywords: Ancients' grains, sustainability, nutrition quality, climate changes, alert for the future

INTRODUCTION

Climate change, driven by increased levels of greenhouse gases, is causing significant changes in global weather patterns. These changes have profound impacts on agricultural systems, particularly grain and cereal crops, which are fundamental to global food security. This dissertation explores how climate change affects the performance of these crops and the subsequent implications for population hunger.

As the global population continues to grow, the pressure on food systems to provide adequate nutrition sustainably is intensifying. Traditional staple grains such as wheat, rice, and corn dominate global agriculture but face challenges such as climate change, soil degradation, and nutrient deficiencies. Ancient grains like millet, quinoa, and amaranth are gaining recognition for their resilience, nutritional benefits, and potential to diversify agricultural systems. This dissertation will delve into the reasons these grains are poised to become essential components of future food systems.

EFFECTS OF CLIMATE CHANGE ON GRAIN AND CEREAL CROPS

Temperature Extremes

Higher average temperatures can accelerate crop maturation, potentially reducing the growing period and resulting in lower yields. For example, a study published in *Nature Communications* indicated that for every degree Celsius increase in temperature, the global yields of wheat, rice, and maize could decrease by approximately 6%, 3.2%, and 7.4%, respectively. The heat stress, crops such as wheat and maize are particularly sensitive to high temperatures during critical growth stages like flowering and grain filling. Heat stress can lead to poor pollination, reduced grain size, and lower yields. The frequency and intensity of heatwaves are increasing, causing severe damage to crops. Heatwaves can cause irreversible damage to plant tissues, reduce photosynthetic efficiency, and increase water loss through transpiration. According to Renato Rodrigues from *-Planeta Campo-* (Pastrana-Pastrana, et. al, (2025), the heavy rains and devastating floods that hit *Rio Grande do Sul* in May 2024 brought an unprecedented tragedy to the region. Flooded cities, thousands of homeless people and significant economic losses marked the event that left a trail of destruction and suffering. Given this catastrophic scenario, a crucial question arises: how are extreme weather events like this related to climate change? Climate change, a widely studied and discussed phenomenon, refers to significant changes in weather patterns over time, largely attributed to human activities, such as greenhouse gas emissions and deforestation. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2021, NASA, 2020) reinforces the gravity of this situation, highlighting that global warming has been occurring at an unprecedented rate in recent years. The report indicates that extreme weather events such as heat waves, heavy rains and cyclones are becoming more frequent and intense due to human-caused climate change.

Water Availability

Prolonged periods of drought lead to a significant reduction in soil moisture, critical for crop growth. The Intergovernmental Panel on Climate Change (IPCC) projects that many regions will experience more frequent and severe droughts. Drought stress affects various physiological processes in plants, such as photosynthesis, nutrient uptake, and growth. For instance, maize yields can drop by 20-30% during severe drought conditions. Increased rainfall and extreme weather events can lead to flooding and waterlogged soils, negatively affecting root development and oxygen availability to plants. Crops like rice can tolerate temporary flooding, but prolonged waterlogging can lead to yield losses. Cereals like wheat and maize are particularly vulnerable to waterlogging, (World Bank. 2014; Weng, et al. 2021; Schnitkey, et al, 2019; Schnitkey, et al. 2021).

Changes in Precipitation Patterns

Erratic Rainfall, changes in precipitation patterns, with more erratic and unpredictable rainfall, can disrupt planting schedules and crop growth cycles. Water Stress, both excessive rainfall and extended dry periods can create water stress conditions for crops, affecting yields and quality (Jägermeyr, et al, 2021; Miller, et al, 2021).

Increased Incidence of Pests and Diseases

Warmer Temperatures, higher temperatures can increase the survival and reproduction rates of pests, leading to more frequent and severe pest infestations. Geographical spread, pests and diseases can spread to new areas previously unsuitable due to climate barriers. For example, the fall armyworm, traditionally found in the Americas, has spread to Africa and Asia, devastating maize crops. Higher humidity and warmer temperatures favour the growth of fungal diseases like rusts and blights. For example, wheat rust diseases can cause significant yield losses if not controlled, (Hanson, et al. (2022).

Soil Degradation

Increased rainfall intensity can lead to soil erosion, reducing soil fertility and its ability to support healthy crop growth. In addition, loss of topsoil, soil erosion can remove the nutrient-rich topsoil layer, leading to decreased soil productivity over time. Nutrient Leaching, for excessive rainfall, heavy rains can cause nutrient leaching, where essential nutrients are washed away from the soil, leading to nutrient deficiencies in crops Myers, S., et al. (2021).

CO₂ Concentration

Photosynthesis enhancement, higher atmospheric CO₂ levels can enhance photosynthesis and potentially increase crop yields, a phenomenon known as CO₂ fertilization. This effect is more pronounced in C3 crops like wheat and rice than in C4 crops like maize and sorghum. Increased CO₂ can lead to nutrient dilution, where crops have lower concentrations of essential nutrients like protein, zinc, and iron, potentially reducing their nutritional quality (NASA, 2020).

ABOUT MILLET, QUINOA AND AMARANTH NUTRITIONAL SUPERIORITY

In figure 1. The grains of millet, quinoa and amaranth are shown.

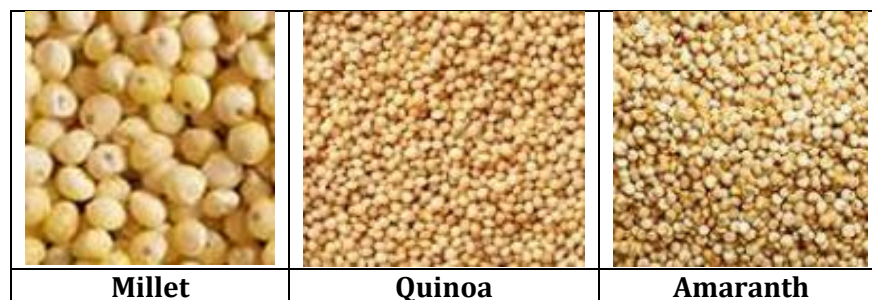


Figure 1: Millet, quinoa and amaranth grains.

Millet is a group of small-seeded grasses, including pearl millet, finger millet, and foxtail millet. It is a staple in many parts of Africa and Asia due to its nutritional benefits. Millet is high in fiber, vitamins (especially B vitamins), and minerals such as magnesium, phosphorus, and iron. It has a higher protein content compared to rice and corn, with a well-balanced amino acid profile, particularly rich in methionine. Millet is naturally gluten-free, making it suitable for people with celiac disease or gluten sensitivity, (Balakrishnan, et al, 2022).

Quinoa native to the Andean region has been cultivated for thousands of years and is celebrated for its exceptional nutritional profile. Quinoa contains all nine essential amino acids, making it a complete protein source, which is rare among plant foods. It is high in dietary fibre, promoting digestive health and aiding in the prevention of chronic diseases (Mozaffarian & Wu (2011). Is rich in vitamins (especially E and B complex) and minerals such as iron, magnesium, potassium, and zinc, (Palombini, et. al, 2013).

Amaranth, another ancient grain, was a staple in the diets of the Aztecs and other ancient civilizations in Central and South America. Amaranth has a high protein content, with a well-balanced amino acid profile, including lysine, which is typically low in other grains. It is an excellent source of calcium, iron, magnesium, phosphorus, and potassium. Amaranth contains antioxidants such as squalene, which have potential health benefits, (Schmidt, et. al, 2023).

AGRICULTURAL RESILIENCE

Drought Tolerance, millet is highly drought-tolerant, capable of growing in arid and semi-arid regions with minimal water requirements. This makes it a valuable crop for regions prone to water scarcity. Quinoa thrives in a range of climatic conditions, from arid regions to high altitudes, demonstrating resilience to drought and poor soil conditions. Amaranth is known for its adaptability to various growing conditions, including drought-prone areas, making it a versatile crop, (Spehar, 2007).

Soil Health and Biodiversity, millet contributes to soil health by improving soil structure and fertility. Its deep root system helps in soil aeration and water retention. Quinoa's ability to grow in saline and marginal soils makes it a suitable crop for reclaiming degraded lands and enhancing soil biodiversity. Amaranth is a fast-growing crop that requires minimal inputs, reducing the need for chemical fertilizers and pesticides, thereby promoting sustainable farming practices, (Spehar, 2006; Weng, et al. (2021).

ENVIRONMENTAL BENEFITS

Low Input Requirements, millet, requires less water, fertilizer, and pesticides compared to conventional staple crops, reducing the environmental footprint. Quinoa grows well without heavy reliance on chemical inputs, which helps in maintaining soil and water quality. Amaranth, minimal input requirements make amaranth an environmentally friendly crop, contributing to sustainable agriculture.

Carbon Sequestration, millet's extensive root system can contribute to carbon sequestration, helping mitigate climate change. Quinoa cultivation can contribute to carbon sequestration, especially when integrated into agroforestry systems. Amaranth's rapid growth and biomass production can aid in carbon sequestration, enhancing its role in climate-smart agriculture. In this regard, (Spehar, & Santos, 2002; Spehar, 2006) in the Brazilian Cerrado Biome, adapted varieties of quinoa and amaranth, with the aim of protecting the soil and at the same time verifying their adaptation in this environment that is very different compared to their natural habitat, in the Andean Region. In this sense, the Brazilian Cerrado, a unique biome on the planet, currently has two varieties of quinoa and amaranth adapted to this region with excellent results in terms of their nutritional quality, Gehring, et al. (2021).

ECONOMIC AND SOCIAL IMPACT

Livelihoods and Food Security, millet cultivation supports the livelihoods of smallholder farmers in arid and semi-arid regions, contributing to food security and economic stability. Quinoa, the global popularity of quinoa has created market opportunities for farmers in the Andean region, improving their livelihoods and economic prospects. Amaranth cultivation provides income opportunities for farmers in developing regions, enhancing food security and reducing poverty, (UNFCCC, 2015).

Market Potential, millet increasing consumer awareness of millet's health benefits is driving demand in health food markets, creating new economic opportunities. Quinoa's status as a "superfood" has led to its inclusion in various health and wellness products, expanding market potential. Amaranth's nutritional benefits are driving its incorporation into health foods, gluten-free products, and nutritional supplements, increasing market demand, (Sustainable Agriculture Research & Education Program, 2022).

CULINARY VERSATILITY

Diverse Culinary Applications, millet used in traditional porridges, flatbreads, and as a rice substitute, millet offers diverse culinary applications. Quinoa, versatile in salads, soups, pilafs, and as a base for various dishes, quinoa's culinary flexibility is well recognized. Amaranth can be used in cereals, porridges, baked goods, and as a thickening agent in soups and stews, highlighting its culinary adaptability (Tobias-Espinoza, et al, 2024).

PROMOTING DIETARY DIVERSITY

Millet, incorporating millet into diets can enhance dietary diversity and provide essential nutrients that are often lacking in staple-based diets. Quinoa's inclusion in meals adds nutritional variety, promoting a balanced diet. Amaranth's use in various dishes enhances dietary diversity, contributing to better overall nutrition (Ascheri, et al, 2002).

CHALLENGES AND FUTURE DIRECTIONS

Overcoming agronomic challenges, research and development, investing in agronomic research to improve yield, disease resistance, and pest management for millet, quinoa, and amaranth. Developing improved varieties through breeding programs to enhance resilience and productivity. Promoting awareness and adoption, consumer education: Increasing awareness of the health benefits and culinary uses of these grains through education and marketing campaigns. For other way, policy support, encouraging policy support for the cultivation and consumption of these grains through subsidies, incentives, and inclusion in food security programs, Myers, et al. (2021).

SUSTAINABLE SUPPLY CHAINS

Value Chain Development, strengthening value chains from production to market, ensuring fair prices for farmers and consistent quality for consumers including sustainability Certifications, promoting certifications that ensure sustainable and ethical production practices, enhancing market appeal. Consequently, millet, quinoa, and amaranth are poised to become the grains of the future due to their exceptional nutritional profiles, agricultural resilience, environmental benefits, and economic potential. As the world faces increasing challenges related to food security, climate change, and health, these ancient grains offer viable solutions for sustainable and nutritious food systems. By investing in research, promoting awareness, and supporting sustainable practices, millet, quinoa, and amaranth can play a pivotal role in ensuring a healthy and sustainable future for global food systems, (Pennington, et al, 2023; National Research Council, 2010).

Comparison of Nutrients of Millet, Quinoa and Amaranth, as Contribution to Health

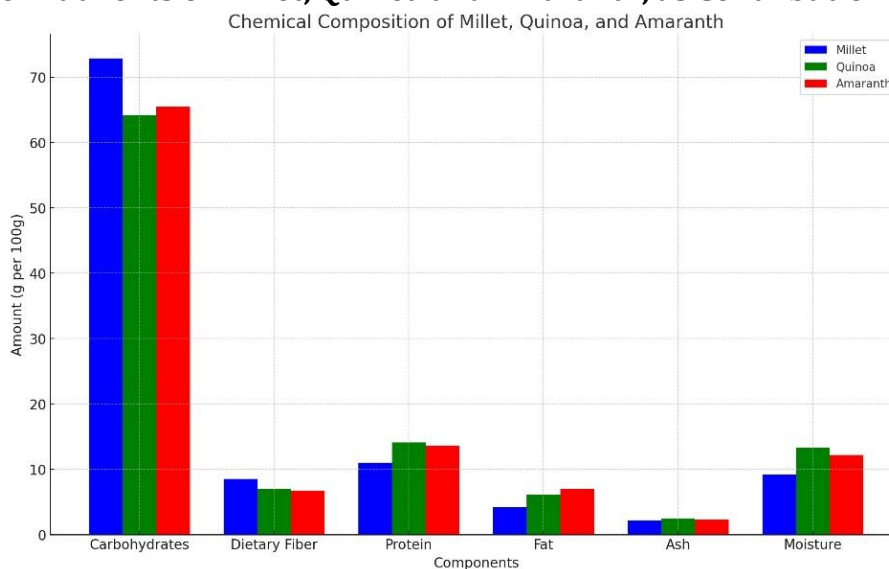


Figure 2: Bar chart showing the proximal composition of millet, which details the amounts of carbohydrates, dietary fibre, protein, fat, ash, and moisture per 100 grams.

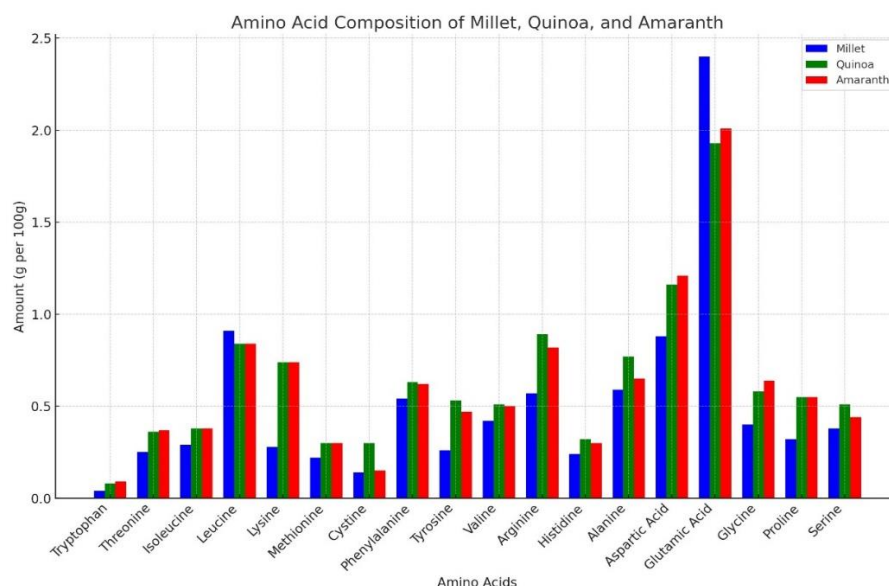


Figure 3: Bar chart showing the amino acid composition (g/100 g grain) of millet, amaranth and quinoa grains.

The bar chart above presents the amino acid composition of millet, quinoa, and amaranth grains. Here is a detailed analysis of the trends observed in the amino acid composition for amaranth and quinoa:

Quinoa is a pseudocereal native to the Andean regions of South America, especially in Peru, Bolivia, Ecuador and Colombia. More than 5,000 years ago, quinoa was a staple food for pre-Columbian civilizations, including the Incas. Known as the "golden grain" or "chisaya mama" (mother of all grains) by the Incas, quinoa was revered not only for its nutritional value, but also for its ability to grow in adverse conditions, such as high altitudes, poor soils and cold climates. On the other hand, amaranth (genus *Amaranthus*) is another pseudocereal with a long history of cultivation in Latin America. Like quinoa, amaranth was an essential crop for ancient civilizations, including the Aztecs and the Incas. The Aztecs, in particular, considered amaranth a sacred food, using it in religious rituals and as an important source of sustenance. They called amaranth "huautli" and considered it as valuable as corn.

NUTRITIONAL VALUES

Quinoa is often referred to as a superfood due to its exceptional nutritional profile. It is rich in high-quality protein, containing all nine essential amino acids, which is unusual for plant-based foods. Additionally, quinoa is a good source of fibre, magnesium, iron, B vitamins, vitamin E, and several antioxidants. It is naturally gluten-free, making it an excellent alternative for people with celiac disease or gluten intolerance. As for its molecular structure, quinoa protein is unique among pseudocereals due to its high-quality protein profile. It contains storage proteins, primarily albumin and globulin, which make up approximately 35% and 37% of total protein, respectively. Unlike many other grains, quinoa is a complete protein source, meaning that it contains all nine essential amino acids in balanced proportions for human needs – histidine,

isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine-. This is rare among plant-based foods (Balakrishnan, & Schneider, 2022; Feitosa, et. al, 2024).

Albumins and globulins are the main proteins in quinoa. Albumins are water-soluble and globulins are salt-soluble. These proteins are relatively small, with a globular structure that facilitates their digestion and absorption. Prolamins and glutelins, although present in smaller quantities in quinoa, are more common in cereals such as wheat, barley and rye. The prolamins and glutelins in quinoa are gluten-free, making quinoa suitable for gluten-free diets. The average composition described in the literature for millet, quinoa and amaranth is presented in Figure 2. Nutritional values per 100g of cooked quinoa: calories, 120 kcal, proteins, 4.1g, carbohydrates, 21.3g, fats, 1.9g, fibre, 2.8g.

Amaranth also has an impressive nutritional profile. Considered as an excellent source of protein, with a high content of lysine, an essential amino acid that is limited in many other cereals. In addition, amaranth is rich in fibre, calcium, magnesium, phosphorus and iron. Like quinoa, it is naturally gluten-free. As for the molecular structure of amaranth protein, a pseudocereal known for its nutritional value, especially for its protein profile. Amaranth proteins are of high quality, containing all the essential amino acids – histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine – in significant quantities, which is also unusual for foods of plant origin, as is the case with quinoa. In its molecular structure, amaranth proteins are predominantly globulins and albumins, which represent about 65% of the total proteins. These proteins are soluble in water and saline solutions, facilitating their digestion. Prolamins and glutelins are present in smaller quantities in amaranth compared to other cereals, and are insoluble in water, but soluble in alcohol solutions and dilute acids/bases (Schmidt, et. al, 2023).

HEALTH BENEFITS

Quinoa protein offers a number of health benefits. Standing out among plant-based proteins, it is highly digestible, facilitating the efficient absorption of amino acids by the body. This helps ensure that nutrients are used effectively for the maintenance and repair of body tissues. Promotes muscle health. Due to its high-quality protein content, quinoa can help build and maintain muscle mass. This is beneficial not only for athletes, but also for individuals seeking to improve or maintain their body composition. Supporting metabolic health, through the intake of high-quality proteins, is associated with better control of appetite and satiety, which can help with weight control and the prevention of metabolic diseases such as obesity and type 2 diabetes. On the other hand, it promotes cardiovascular benefits, which together with its other nutrients, such as fibre, antioxidants and healthy fatty acids, can contribute to the reduction of LDL (bad) cholesterol and the improvement of cardiovascular health. When comparing with other reference proteins, such as milk casein, egg, soy and wheat, it can be seen that, in the case of casein, it has completed essential amino acids and is also highly digestible, with a PDCAAS score of 1.0 (Protein Digestibility-Corrected Amino Acid Score). In this comparative case, quinoa is on par with casein, although it may have slightly lower digestibility due to the presence of fibre and antinutrients. In the case of the comparison with egg, it has completed essential amino acids and very high digestibility, PDCAAS score: 1.0. Egg is often considered the gold standard protein due to its amino acid profile and high digestibility. Quinoa

protein is of comparable quality in terms of amino acids, but egg has slightly higher digestibility. When compared with soy, it has completed essential amino acids. Digestibility, high, PDCAAS score: 1.0. Soy is one of the few plant sources of complete protein and is highly digestible. Quinoa is similar to soybeans in terms of amino acid profile, making it an excellent option for those seeking complete plant-based proteins. Among cereals, compared to wheat, it has incomplete essential amino acids (low lysine), moderate to high digestibility, PDCAAS score: 0.40-0.50. Quinoa, therefore, surpasses wheat in terms of amino acid quality and digestibility, being a much more complete and balanced protein source.

Among its health benefits, amaranth protein offers a number of benefits, making it a valuable food in the human diet. This is because it is a complete source of protein, containing all nine essential amino acids. This is particularly important for vegetarians and vegans, who may have difficulty obtaining complete proteins from other plant-based sources. Additionally, amaranth proteins are highly digestible, meaning that the body, improving the efficiency of nutrition, easily absorbs the amino acids. Similar to quinoa, amaranth supports muscle health, building and maintaining muscle mass. This can be beneficial for athletes and individuals who want to improve their body composition. In addition, due to its high-quality protein profile, amaranth helps with metabolic health benefits. High-quality protein intake is associated with improved appetite control and satiety, which can help with weight control and the prevention of metabolic diseases such as obesity and type 2 diabetes. As for cardiovascular health, amaranth proteins, along with other nutrients such as fibre and antioxidants, can help reduce LDL (bad) cholesterol levels and promote cardiovascular health (Tang Yao & Tsao Rong, 2017).

On the other hand, immune support is benefited, since the presence of essential amino acids helps to strengthen the immune system, promoting the production of antibodies and other proteins essential for the immune response. As a result, amaranth protein stands out for its complete amino acid profile and high digestibility, being comparable to high-quality proteins of animal origin and other reference plant proteins. Health benefits include supporting muscle, metabolic and cardiovascular health, in addition to helping maintain the immune system. Compared to other proteins, amaranth is one of the best sources of plant-based protein available, making it a valuable and nutritious addition to a balanced diet, especially for those following vegetarian or vegan diets. Nutritional values per 100g of cooked amaranth: calories, 102 kcal, proteins, 3.8 g, carbohydrates, 19.5 g, fats, 1.6 g, fibres: 2.1g (Su, et.al, 2015; Lauritzen, et.al, 2001; Calder, 2009; Calder, 2010; Aguiar et. al, 2021).

Trends in amaranth and quinoa, tryptophan, both quinoa and amaranth have higher levels of tryptophan (0.08 g/100g for quinoa and 0.09 g/100g for amaranth) compared to millet (0.04 g/100g). This amino acid is essential for the production of serotonin and melatonin, important for mood regulation and sleep. Threonine, quinoa (0.36 g/100g) and amaranth (0.37 g/100g) have slightly higher threonine content compared to millet (0.25 g/100g). Threonine is crucial for protein synthesis and central nervous system function. Isoleucine, both quinoa and amaranth contain 0.38 g/100g of isoleucine, which is higher than millet's 0.29 g/100g. Isoleucine is important for muscle metabolism and immune function. Leucine, millet has the highest leucine content at 0.91 g/100g, whereas quinoa and amaranth both have 0.84 g/100g. Leucine is essential for protein synthesis and muscle repair. Lysine, quinoa and amaranth have

significantly higher lysine content (0.74 g/100g for both) compared to millet (0.28 g/100g). Lysine is a limiting amino acid in many grains, but it is abundant in quinoa and amaranth, making them valuable for complete protein diets. The methionine content is higher in quinoa and amaranth (0.30 g/100g) compared to millet (0.22 g/100g). Methionine is crucial for metabolism and detoxification. Cystine, quinoa has 0.30 g/100g and amaranth has 0.15 g/100g, both higher than millet's 0.14 g/100g. Cystine plays a role in protein structure through disulphide bonds. Phenylalanine and tyrosine, quinoa and amaranth both have higher phenylalanine (0.63 g/100g for quinoa and 0.62 g/100g for amaranth) and tyrosine (0.53 g/100g for quinoa and 0.47 g/100g for amaranth) compared to millet. These amino acids are precursors for neurotransmitters. Valine content is similar in quinoa (0.51 g/100g) and amaranth (0.50 g/100g), higher than in millet (0.42 g/100g). Valine is important for muscle metabolism and tissue repair. Arginine, both quinoa (0.89 g/100g) and amaranth (0.82 g/100g) have significantly higher arginine content compared to millet (0.57 g/100g). Arginine is important for immune function and hormone secretion. Histidine, quinoa (0.32 g/100g) and amaranth (0.30 g/100g) contain more histidine compared to millet (0.24 g/100g). Histidine is important for growth and tissue repair. Alanine, aspartic acid, and glutamic acid, quinoa and amaranth both have higher levels of alanine, aspartic acid, and glutamic acid compared to millet. These amino acids play crucial roles in energy metabolism and neurotransmitter regulation. Glycine and proline, amaranth has higher glycine (0.64 g/100g) and proline (0.55 g/100g) compared to quinoa (0.58 g/100g glycine and 0.55 g/100g proline) and millet. Glycine is important for collagen synthesis, and proline is critical for maintaining healthy skin and connective tissues. Serine content is similar in quinoa (0.51 g/100g) and amaranth (0.44 g/100g), higher than in millet (0.38 g/100g). Serine is important for protein synthesis and cell function. Overall, both quinoa and amaranth exhibit superior amino acid profiles compared to millet, particularly in essential amino acids like lysine, methionine, and threonine. This makes them valuable additions to diets, especially for vegetarians and those seeking complete protein sources. The higher levels of these essential amino acids contribute significantly to their nutritional value, supporting various physiological functions and promoting overall health (Repo-Carrasco & Serna, 2011; Ranhotra, et.al, 1993; Bressani, & García-Vela, 1990; Abugoch, 2009).

WITH REFERENCE TO FATTY ACIDS

Essential fatty acids (EFAs) are lipids that cannot be synthesized by the human body and therefore must be obtained through the diet. The two main EFAs are linoleic acid (an omega-6) and alpha-linolenic acid (an omega-3). These fatty acids are essential for several physiological functions and play a crucial role in the body's metabolism. They can be converted into other bioactive compounds in the body, such as arachidonic acid (ARA) from linoleic acid, and eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) from alpha-linolenic acid. A comparative table highlighting the special fatty acid composition of millet, quinoa, and amaranth, along with a few other common foods is showed in Table 1.

According whit Table 1, Millet, quinoa, and amaranth are excellent sources of polyunsaturated fatty acids, particularly Omega-6. Quinoa stands out for its higher Omega-3 content, while amaranth offers the highest amount of monounsaturated fats. These grains, alongside chia and

flaxseeds, contribute significantly to a balanced intake of essential fatty acids, which are crucial for maintaining heart health, reducing inflammation, and supporting overall well-being.

Table 1: Comparative with other grains highlighting the special fatty acid composition of millet, quinoa, and amaranth.

Food Item	Saturated Fatty Acids (g)	Monounsaturated Fatty Acids (g)	Polyunsaturated Fatty Acids (g)	Omega-3 Fatty Acids (mg)	Omega-6 Fatty Acids (mg)
Millet	0.8	0.8	2.6	30	2600
Quinoa	0.7	1.0	3.3	180	2500
Amaranth	1.5	2.0	2.9	135	2750
Brown Rice	0.4	0.5	0.9	20	370
Oats	1.2	2.1	2.5	65	2100
Chia Seeds	3.3	2.3	23.7	17,552	5,859
Flaxseeds	3.7	2.2	28.7	22,813	5,911

Source: Dados adapted from: Mozaffarian, & Wu, 2011; Lauritzen, 2001; Feitosa, 2024; Bressani, & García-Vela, 1990; Balakrishnan, 2022).



Figure 4: Mindmap diagram illustrating the main lipophilic bioactives in quinoa and amaranth seed.

Among the functions and benefits of EFAs, we have, in cardiovascular health AGEs are known for their benefits to cardiovascular health. Studies show that adequate intake of omega-3 is associated with a reduced risk of cardiovascular disease. They help to lower blood triglyceride levels, reduce blood pressure and prevent cardiac arrhythmias. For brain development and

function, omega-3 fatty acids, especially DHA, are important structural components of the brain and retina. They are essential for brain development during pregnancy and childhood and are associated with cognitive function throughout life. Regarding the inflammatory and immune response, omega-6 and omega-3 have opposing roles in inflammation. While arachidonic acid (a derivative of omega-6) can promote inflammation, omega-3 derivatives, such as EPA and DHA, tend to be anti-inflammatory. An adequate balance between omega-6 and omega-3 is crucial for the regulation of the inflammatory response and immune function. In this regard, for mental health, there is evidence that omega-3 fatty acids may have beneficial effects on mental health. Studies suggest that omega-3 supplementation may help reduce symptoms of depression and anxiety. When it comes to skin health, EFAs are essential for skin health, helping to maintain the integrity of the skin barrier and hydration. A deficiency in EFAs can lead to dry, flaky, and dermatitis-prone skin. Dietary recommendations for EFAs vary between different organizations, but a balanced intake of omega-6 and omega-3 is generally recommended with an omega-6 to omega-3 ratio typically between 2:1 and 4:1. In Figure 3, is the mind map diagram illustrating the main lipophilic bioactives in quinoa and amaranth seeds.

Tocopherols and tocotrienols are vitamin E homolog. All four tocopherol isoforms (α , β , γ and δ) have been detected in quinoa and amaranth seeds. With γ -tocopherol (47–53 mg/kg dry weight (dw)) to be the most abundant followed by α -tocopherol (17–26 mg/kg (dw)), β - and δ -tocopherols in trace amount (<5 mg/kg DW). The most common tocols in amaranth seeds were α -tocopherol (1.40–31.6 mg/kg) and β -tocotrienol (0.53–43.86 mg/kg), δ -tocotrienol (0.06–8.69 mg/kg), and δ -tocopherol (0.01–48.79 mg/kg) (Calder, 2009; Calder, 2010; FRamzo & Downs, 2021; Innis, 2007; Lauritzen, 2001; Mozaffarian, & Wu, 2011; Ranhotra, et al, 1993).

THE SAPONIN ISSUE

Saponins are chemical compounds naturally present in the outer layer of quinoa grains. These compounds can have some adverse effects on human consumption, but they also offer benefits. Here is a breakdown of the effects of saponins and how these problems can be addressed. Saponins give quinoa grains a bitter taste, which can be unpleasant for many consumers. The solution is simple; washing quinoa before cooking is a common practice to remove saponins. Rinsing the grains under running water in a fine sieve until the water runs clear usually removes most of the saponins. In some people, saponins can cause gastric irritation or digestive discomfort. In addition to washing, complete removal of saponins can be achieved through the industrial hulling process, where the outer layer of the grains is removed. Purchasing pre-washed or industrially pre-treated quinoa can minimize these effects. It is very common to sell quinoa already washed, dried and packaged. Regarding antinutrients, these can interfere with nutrient absorption, acting as antinutrients. The large reduction through washing and cooking not only removes saponins, but also helps reduce other antinutrients present in quinoa, such as phytates (Stikic, et al, 2012; Jarvis, et al, 2017; Kuljanabhagavad, 2008; Medina-Meza, 2016; Gupta, 2010).

BENEFITS OF SAPONINS

Despite the negative effects, saponins also have some potential benefits. For example, saponins have antimicrobial and antifungal properties that help protect quinoa grains from pests and diseases during growth. They also have antioxidant effects, which can contribute to overall

health by reducing oxidative stress in the body. Another important aspect is related to hypocholesterolemic effects. Studies suggest that saponins can help reduce blood cholesterol levels, providing cardiovascular benefits. Therefore, the saponins in quinoa may have some adverse effects, such as a bitter taste and potential digestive irritation, but these effects can be mitigated by simple methods such as washing and cooking. In addition, saponins offer potential health benefits, including antioxidant and hypocholesterolemic properties. By following proper cooking practices, consumers can enjoy the nutritional benefits of quinoa without the negative effects of saponins (Medina-Meza, et al, 2016).

THE COMMERCIAL ISSUE FOR THESE GRAINS

In recent years, quinoa has experienced a significant increase in global demand due to its superfood status. This increase in popularity has led to quinoa being cultivated in countries outside its traditional range, such as the United States, Canada, and several European nations. Quinoa is now marketed in a variety of products, from whole grains to flours, flakes, cereal bars, pastas, and beverages. While amaranth has not achieved the same global popularity as quinoa, it is also gaining recognition as a superfood. Amaranth is marketed in similar forms to quinoa, including whole grains, flours, flakes, and processed products such as cereal bars and breads. Growing awareness of its nutritional qualities is increasing demand and production in many parts of the world.

There are several aspects to highlight their current importance. In terms of nutrition and health, the inclusion of quinoa and amaranth in the modern diet offers a number of health benefits, including improved weight control, support for digestive health, and prevention of chronic diseases and improved overall health due to their high nutrient and antioxidant content. They are particularly valuable for vegetarians, vegans and people with food intolerances, due to their high protein content and absence of gluten. Another important aspect concerns sustainability. The production of quinoa and amaranth contributes to agricultural sustainability. Both pseudocereals are adaptable to diverse climatic conditions and soils, requiring less water and pesticides compared to many other cereals. This adaptability makes them valuable crops for regions with difficult growing conditions, helping to promote food security. Complementing the above, researchers at EMBRAPA in Brazil have adapted varieties of quinoa (BRS Piabiru) and amaranth (BRS Alegria) to the Cerrado region of the country, which constitutes a unique biome on the planet. These two varieties had similar results regarding the nutritional quality of those cultivars produced in the Andean regions of Peru and Bolivia (Spehar et al., 2007; Spehar & Santos, 2002; Spehar, 2006). Thus, the cultivation and commercialization of quinoa and amaranth have a significant impact on the local economies of the Andean regions and other production areas. The growing demand for these pseudocereals has provided farmers with new income opportunities, helping to improve living standards and reduce poverty in rural areas. In general, in the Andean regions, mainly in Peru and Bolivia, the cultivation areas are relatively small, due to the topography of these high regions, between 1,500 and 2,500 meters above sea level, implying small production volumes, generally related to family farming. Because of the value of the pseudocereal, these farmers sell practically all of their production, leaving almost nothing for their own consumption, meaning that the capital raised is used to purchase other products, not always related to good nutrition, causing serious nutritional deficiencies among them. In any case, quinoa and amaranth have a long and rich history as staple foods in ancient

Latin American civilizations. Today, their global popularity reflects not only their exceptional nutritional value, but also their importance in promoting sustainability and food security. The commercialization of these superfoods and the growing variety of derived products highlight their continued and growing relevance in the global food scene. Taking highly nutritious and stable foods to space missions, for example, can be crucial due to space and weight restrictions and the need to provide a balanced diet for astronauts.

Quinoa and amaranth, due to their exceptional nutritional profile, are excellent candidates for this purpose. Here are the reasons and justifications for including these processed products in space missions, including their high nutritional value, since quinoa is rich in complete proteins, containing all nine essential amino acids. In addition, it provides vitamins B and E, magnesium, iron, fibre and antioxidants. The presence of high-quality proteins is crucial for maintaining muscle mass and the overall health of astronauts during long-duration missions. Amaranth, on the other hand, is also an excellent source of protein and contains high levels of lysine, in addition to being rich in fibre, calcium, magnesium, phosphorus and iron. Its nutrient-rich composition can help meet strict dietary requirements. Both are naturally gluten-free, making them safe for people with celiac disease or gluten intolerance, in addition to being easily digestible and less likely to cause gastrointestinal discomfort, an important aspect in a zero-gravity environment, when used by astronauts. Stability and long shelf life: quinoa and amaranth, when properly processed, have a long shelf life without the need for refrigeration. This is crucial in places where fresh food storage is limited and food preservation is a major concern. Culinary versatility, they can be processed into various forms, such as flours, flakes and cereal bars, providing a variety of textures and culinary possibilities. This versatility helps to maintain a varied and interesting diet, which is important for the psychological well-being of consumers. On the other hand, the ease of preparation of products derived from quinoa and amaranth, since they can be easily rehydrated or consumed directly, facilitates the preparation of meals in an environment where resources and time are limited. Considering their high caloric and nutritional density, in critical situations where every gram count, these pseudocereals can be essential. Quinoa and amaranth offer a large amount of nutrients in small portions, maximizing nutritional value within weight restrictions.

The main scientific and practical justifications for considering these grains, for example, in the maintenance of bone and muscle health. Due to the rich content of proteins, calcium and magnesium of both pseudocereals, which is essential for the maintenance of bone and muscle health, especially in a microgravity environment where the loss of bone and muscle mass is a constant concern. They are also considered important in the prevention of nutritional deficiencies, due to the variety of vitamins and minerals present in quinoa and amaranth. On the other hand, the complex carbohydrates present in quinoa and amaranth provide sustained energy, essential for physical and cognitive activities. Dietary diversity and the consumption of nutritious foods can have a positive impact on the mood and well-being of the consumer, contributing to the morale of students, for example. The levels of antioxidants and other nutrients present can help to strengthen the immune system, which can be compromised by inadequate nutrition in deprived populations. Millet, like pseudocereals, has different forms of consumption. Figure 5 shows different forms of commercialization.

For other way, millet is a versatile grain that is widely used in human nutrition and is sold in a variety of forms. Below are some of the most common forms in which millet is sold, in addition to its whole grain and processed forms. Figure 5 show different uses for millet.

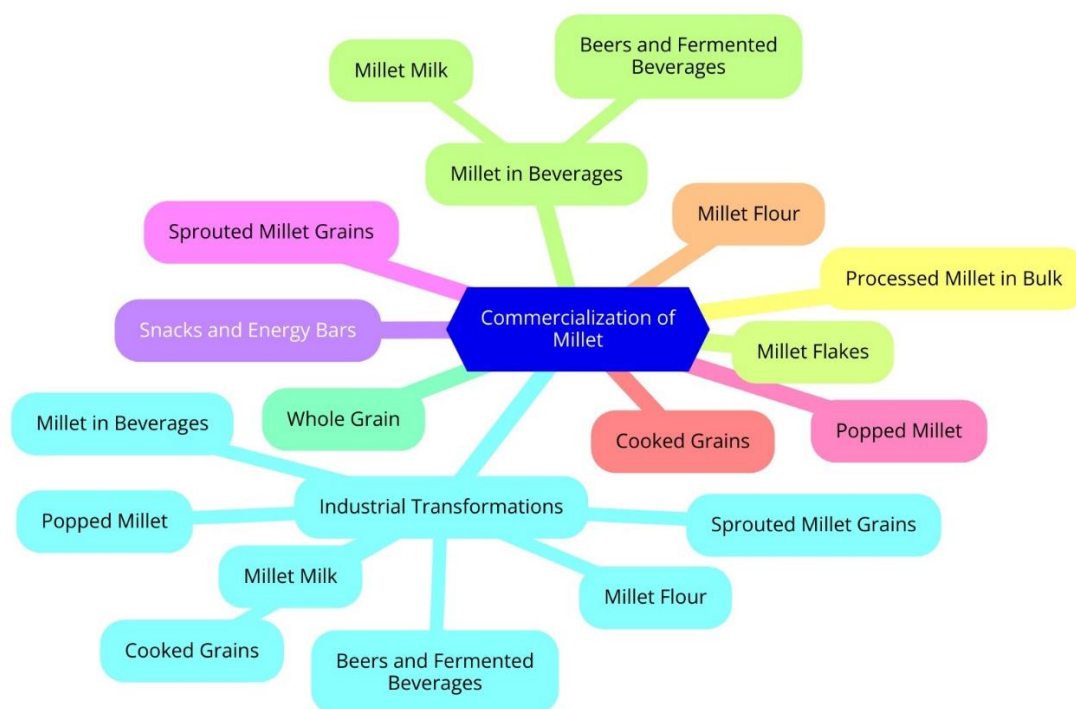


Figure 5: Mind map diagram to illustrate the different ways of marketing millet

Millet flour is used to make breads, cakes, cookies, and other baked goods. It is a gluten-free option, suitable for people with gluten intolerance or celiac disease. Similar to oat flakes, millet flakes are used in breakfast cereals, granola, and cereal bars. They can be eaten raw or cooked. Similar to popcorn, millet can be popped to make a crunchy and healthy snack. Whole grain millet can be cooked and used as a substitute for rice or couscous in salads, main dishes, and side dishes. Millet can be sprouted, and used in salads, sandwiches, and smoothies. Sprouting increases the nutritional value of the grains. Millet milk is an alternative to cow's milk, especially for those who are lactose intolerant or vegan. Additionally, millet can be used to make beer and other fermented beverages. Millet is often used in healthy snacks and energy bars due to its balanced nutritional profile. Some pasta products, such as noodles and noodles, are made from millet flour.

CONCLUSION

Millet, quinoa, and amaranth present viable alternatives for future agricultural development due to their adaptability to challenging soil and climatic conditions and their impressive nutritional profiles. As climate change continues to impact global agriculture, these crops offer sustainable and resilient options to ensure food security and nutritional diversity. Promoting their cultivation can help mitigate the adverse effects of climate change while providing nutritious food sources for growing populations. From nutritional aspect, millet is rich in essential nutrients such as magnesium, phosphorus, and iron. It also contains high levels of

antioxidants, provides a good source of plant-based protein, making it a valuable food source in vegetarian and vegan diets, high in dietary fibre, millet aids in digestion and promotes a healthy gut. In addition, the pseudocereals quinoa and amaranth are both highly nutritious foods with nutrient profiles that make them valuable additions to a variety of diets. Although there are slight differences in their proximate compositions, both offer significant nutritional benefits. Quinoa generally has slightly more protein and fibre, while amaranth has a slightly higher fat content. These differences may influence the choice between one or the other depending on specific dietary needs and culinary applications.

References

Abugoch James, L. E. (2009). "Quinoa (*Chenopodium quinoa* Willd.): Composition, chemistry, nutritional, and functional properties." *Advances in Food and Nutrition Research*, 58, 1-31. Doi: 10.1016/S1043-4526(09)58001-1

Aguiar, Etienne V.; Santos, Fernanda G.; Centeno, Ana Carolina L.S.; Capriles, Vanessa D. (2021). Influence of pseudocereals on gluten-free bread quality: A study integrating dough rheology, bread physical properties and acceptability. *Food Research International*, 150, 110762. Doi: 10.1016/j.foodres.2021.110762.

Ascheri, J. L. R.; Nascimento, R. E.; Spehar, C. R. Composição química comparativa de farinha instantânea de quinoa, arroz e milho. Rio de Janeiro: Embrapa, Out. 2002. 4 p. (Comunicado Técnico, 52).

Balakrishnan, G.; Schneider, R.G. (2022). The Role of Amaranth, Quinoa, and Millets for the Development of Healthy, Sustainable Food Products—A Concise Review. *Foods*, v.11, 2442. Doi: 10.3390/foods11162442.

Boelsma, E., Hendriks, H.F., & Roza, L. (2001). Nutritional skin care: health effects of micronutrients and fatty acids. *American Journal of Clinical Nutrition*, 73(5), 853-864.

Bressani, R., & García-Vela, L. A. (1990). "Protein fractions in amaranth grain and their chemical characterization." *Journal of Agricultural and Food Chemistry*, 38(5), 1205-1210. Doi: 10.1021/jf00095a013)

Calder, P.C. (2009). Polyunsaturated fatty acids and inflammatory processes: New twists in an old tale. *Biochimie*, 91(6), 791-795.

Calder, P.C. (2010). Omega-3 fatty acids and cardiovascular disease: evidence explained and mechanisms explored. *Clinical Science*, 107(1), 1-11.

Fanzo, J.C., Downs, S.M. (2021). Climate change and nutrition-associated diseases. *Nat Rev Dis Primers* 7, 90. <https://doi.org/10.1038/s41572-021-00329-3>.

Feitosa, Bruno Fonsêca; Barros, Jefferson Henrique Tiago; Feitoza, João Vitor Fonseca. (2024) Pseudocereals – A bibliometric analysis and literature review on the potential for manufacturing flours, bakery products and milk analogues. *NFS Journal*, v. 34, n. 100163. Doi: 10.1016/j.nfs.2024.100163.

Gehring, M., et al. (2021). "Using plant biology to address climate change." *MIT News*.

Gupta, S., Cox, S., & Abu-Ghannam, N. (2010). "Effect of different pre-treatments on the antioxidant and saponin content of quinoa." *Food Research International*, 43(5), 1464-1470. DOI: 10.1016/j.foodres.2010.04.028.

Hanson, J., et al. (2022). "Feeding the world in 2050 and beyond – Part 1: Productivity challenges." *Michigan State University Extension*. DOI: 10.1016/j.envres.2021.111256.

Innis, S.M. (2007). Dietary (n-3) fatty acids and brain development. *Journal of Nutrition*, 137(4), 855-859.

IPCC. (2021). *Intergovernmental Panel on Climate Change: Reports Climate Change the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. Link to report: <https://www.ipcc.ch/report/ar6/wg1/>

Jägermeyr J, Müller C, Ruane AC, Elliott J, Balkovic J, Castillo O, Faye B, Foster I, Folberth C, Franke JA, Fuchs K, Guarin JR, Heinke J, Hoogenboom G, Iizumi T, Jain AK, Kelly D, Khabarov N, Lange S, Lin TS, Liu W, Mialyk O, Minoli S, Moyer EJ, Okada M, Phillips M, Porter C, Rabin SS, Scheer C, Schneider JM, Schyns JF, Skalsky R, Smerald A, Stella T, Stephens H, Webber H, Zabel F, Rosenzweig C. Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. *Nat Food*. 2021 Nov;2 (11):873-885. doi: 10.1038/s43016-021-00400-y.

Jarvis, D. E., Ho, Y. S., Lightfoot, D. J., Schmöckel, S. M., Li, B., Borm, T. J. A., & Tester, M. (2017). "The genome of *Chenopodium quinoa*." *Nature*, 542(7641), 307-312. DOI: 10.1038/nature21370.

Kuljanabhagavad, T., Thongphasuk, P., Chamulitrat, W., & Wink, M. (2008). "Triterpene saponins from *Chenopodium quinoa* Willd." *Phytochemistry*, 69(9), 1919-1926. DOI: 10.1016/j.phytochem.2008.03.014.

Lauritzen, L., Hansen, H.S., Jørgensen, M.H., & Michaelsen, K.F. (2001). The essentiality of long chain n-3 fatty acids in relation to development and function of the brain and retina. *Progress in Lipid Research*, 40(1-2), 1-94.

Medina-Meza, I. G., Aluwi, N. A., Saunders, S. R., & Ganjyal, G. M. (2016). "GC-MS Profiling of Triterpenoid Saponins from 28 Quinoa Varieties (*Chenopodium quinoa* Willd.) Grown in Washington State." *Journal of Agricultural and Food Chemistry*, 64(45), 8583-8591. DOI: 10.1021/acs.jafc.6b03712.

Miller, S., Chua, K., Coggins, J., & Mohtadi, H. (2021, October 1). Heat waves, climate change, and economic output. *Journal of the European Economic Association*. Oxford University Press. <https://doi.org/10.1093/jeea/jvab009>.

Mozaffarian, D., & Wu, J.H. (2011). Omega-3 fatty acids and cardiovascular disease: effects on risk factors, molecular pathways, and clinical events. *Journal of the American College of Cardiology*, 58(20), 2047-2067.

Myers, S., et al. (2021). "Climate Change & Nutrition." Harvard T.H. Chan School of Public Health. DOI: 10.1038/s41598-021-87667-7.

NASA. (2020). *Global Climate Change: Vital Signs of the Planet*. NASA's Jet Propulsion Laboratory. Link to resource: <https://climate.nasa.gov/>.

National Research Council. (2010). *Advancing the Science of Climate Change*. The National Academies Press. Link to book: <https://www.nap.edu/catalog/12782/advancing-the-science-of-climate-change>.

Palombini, Sylvio Vicentin; Claus, Thiago; Maruyama, Swami Arêa; Gohara, Aline Kirie; Souza, Aloisio Henrique Pereira; De Souza, Nilson Evelázio; Visentainer, Jesuí Vergílio; Gomes, Sandra Terezinha Marques; Matsushita, Makoto. Evaluation of nutritional compounds in new amaranth and quinoa cultivars. *Food Sci. Technol, Campinas*, 33(2): 339-344, Apr.-June 2013. DOI: 10.1590/S0101-20612013005000051.

Pastrana-Pastrana, Álvaro Javier; Flores-Gallegos, Adriana Carolina; Roa-Acosta, Diego Fernando; Rodríguez-Herrera, Raúl; Solanilla-Duque, José Fernando. (2025). Rheological behavior of quinoa, lentil, and rice flour mixtures under different pH conditions, *Food Hydrocolloids*, v. 158, 110457. doi.org/10.1016/j.foodhyd.2024.110457.

Pennington, D., Nagelkirk, M., & Singh, M. (2023). "Planting the 2023 Wheat Crop." Michigan State University Extension. https://www.canr.msu.edu/news/planting_winter_wheat_crop.

Ranhotra, G. S., Gelroth, J. A., & Glaser, B. K. (1993). "Nutritional profile of three millet varieties grown in the U.S." *Cereal Chemistry*, 70(3), 215-218. DOI: 10.1094/CCHEM.1993.70.3.215.

Renato Rodrigues. - <https://planetacampo.canalrural.com.br/colunistas/como-a-tragedia-no-rio-grande-do-sul-esta-ligada-a-mudanca-do-clima/>.

Repo-Carrasco-Valencia, R. A., & Serna, L. A. (2011). "Quinoa (*Chenopodium quinoa*, Willd.) as a source of dietary fiber and other functional components." *Food Science and Technology*, 46(2), 357-363. Doi: 10.1016/j.lwt.2010.08.008)

Ryan, M. R., et al. (2022). "Carbon footprint and sustainability in cereal crop production." Cornell University. DOI: 10.1016/j.jclepro.2021.127239.

Schmidt, Davi; Verruma-Bernardi, Marta Regina; Forti, Victor Augusto & Borges, Maria Teresa Mendes Ribeiro (2023) Quinoa and Amaranth as Functional Foods: A Review, *Food Reviews International*, V.39, n4, 2277-2296, DOI: 10.1080/87559129.2021.1950175.

Schnitkey, G., Coppess, J., Paulson, N., & Zulauf, C. (2019). "Intense rainfall is as damaging to crops as heatwaves and drought, and climate change is making it worse." *Global Change Biology*, 25(6), 1881-1891. DOI: 10.1111/gcb.14526.

Schnitkey, G., et al. (2021). "Impact of intense rainfall on crop production." *Yale Environment* 360. <https://e360.yale.edu/>

Shukla, S., & Srivastava, A. K. (2011). "Evaluation of nutritional quality of barnyard millet (*Echinochloa frumentacea*) grain for food production." *Journal of Food Science and Technology*, 48(4), 504-508. Doi: 10.1007/s13197-011-0215-5

Simopoulos, A.P. (2002). The importance of the ratio of omega-6/omega-3 essential fatty acids. *Biomedicine & Pharmacotherapy*, 56(8), 365-379.

Spehar, C. R. (Ed. Técnico). Quinoa: alternativa para a diversificação agrícola e alimentar. Planaltina, DF: Embrapa Cerrados, 2007. 103 p.

Spehar, C. R. Adaptação da quinoa (*Chenopodium quinoa* Willd.) para incrementar a diversidade agrícola e alimentar no Brasil. *Cadernos de Ciência & Tecnologia*, Brasília, v. 23, n. 1, p. 41-62, Jan./Abr. 2006.

Spehar, C. R.; Santos, R. L. B. Quinoa BRS Piabiru: alternativa para diversificar os sistemas de produção de grãos. *Pesquisa Agropecuária Brasileira*, Brasília, v. 37, n. 6, p. 889-893, Jun. 2002.

Stikic, R., Glamoclija, D., Demin, M., Vucelic-Radovic, B., Jovanovic, Z., Milojkovic-Opsenica, D., & Milovanovic, M. (2012). "Agronomical and nutritional evaluation of quinoa seeds (*Chenopodium quinoa* Willd.) as an ingredient in bread formulations." *Journal of Cereal Science*, 55(2), 132-138. DOI: 10.1016/j.jcs.2011.10.007.

Su, K.P., Matsuoka, Y., & Pae, C.U. (2015). Omega-3 polyunsaturated fatty acids in prevention of mood and anxiety disorders. *Clinical Psychopharmacology and Neuroscience*, 13(2), 129-137.

Sustainable Agriculture Research & Education Program (2022). "Conservation tillage." University of California, Davis. https://www.sustainableharvest.org/?msclkid=aeaf8e4a4ea71f863f78e8fc74026136&utm_source=bing&utm_medium=cpc&utm_campaign=SHI%20-%20Branded&utm_term=sustainable%20methods%20for%20agriculture&utm_content=Sustainable%20Agriculture%20Methods

Tang Yao & Tsao Rong. (2017). Phytochemicals in quinoa and amaranth grains and their antioxidant, anti-inflammatory and potential health beneficial effects: a review. *Molecular Nutrition & Food Research*. V. 61, pp. 1613-4125. Doi: 10.1002/mnfr.201600767.

Tobias-Espinoza, Jazmin Leticia; Amaya-Guerra, Carlos Abel; Ruíz-Gutiérrez, Martha Graciela; Sánchez-Madrigal, Miguel Angel; Neder-Suárez David and Quintero-Ramos Armando. Sensory qualities and hydration kinetics of instant-extruded cereals with flaxseed and amaranth. *British Food Journal* Vol. 126 No. 7, 2024. pp. 2940-2955. DOI 10.1108/BFJ-07-2023-0641.

UNFCCC- United Nations Framework Convention on Climate Change. (2015). Paris Agreement. United Nations. Link to document: https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

Weng, J., et al. (2021). "Controlled Environment Agriculture (CEA) and its impact on food security." Cornell University. <https://cea.cals.cornell.edu/>.

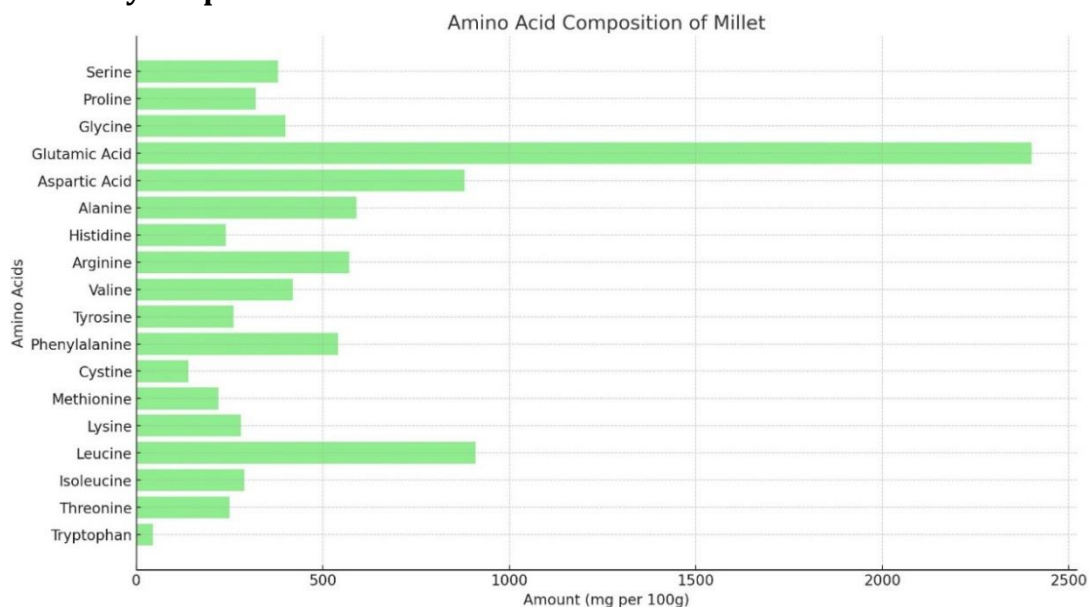
World Bank. (2014). Turn Down the Heat: Confronting the New Climate Normal. World Bank Publications. Link to report: <https://openknowledge.worldbank.org/handle/10986/20595>.

Abstract Graphic

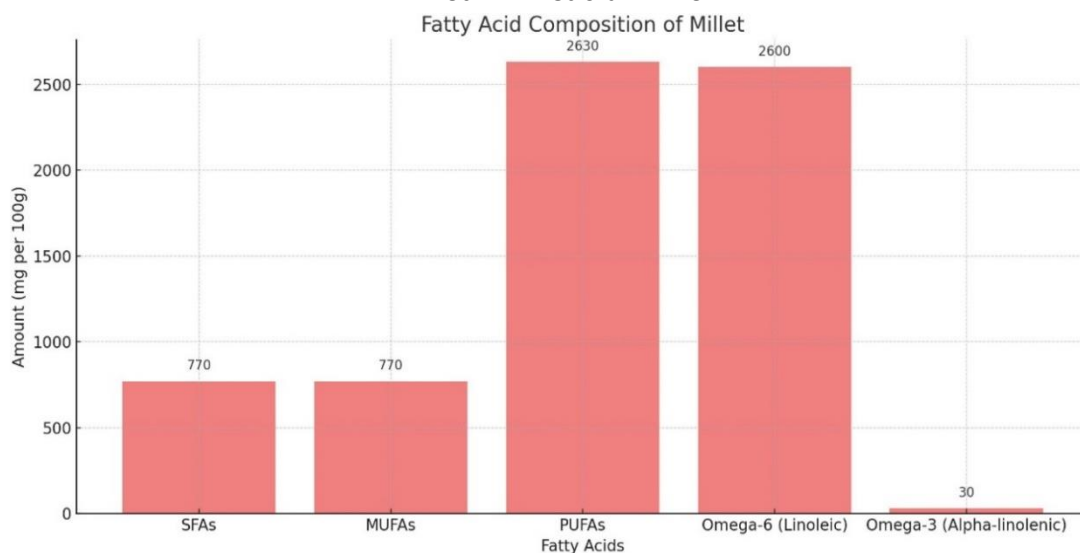


Abstract Graphic. Mind map diagram to illustrate the different ways of marketing millet.

Complementary Graphics



Millet Aminoacid Profile.



Bar chart showing the fatty acid composition of millet, detailing the amounts of saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), linoleic acid (omega-6), and alpha-linolenic acid (omega-3) per 100 grams.

Source: <https://www.suite42.in/contract-manufacturing-your-partner-in-millet-based-new-product-development/>



Source: <http://www.teorema.com.mx/tendencias/amaranto-y-quinua-la-nueva-mina-de-oro-alimenticio/>