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Review Article

Bioactive and pharmacological characterization of *Chenopodium quinoa*, *Sorghum bicolor* and *Linum usitassimum*: A review

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Abstract
Quinoa (*Chenopodium quinoa*), sorghum (*Sorghum bicolor*) and flaxseed (*Linum usitassimum* L.) are grains and seeds popularly known for their nutritional values. This review aimed to discuss the nutritional profile of these grains and seeds, their bioactive compounds and how those compounds help to prevent chronic diseases. These crops were selected for this study as they are all free of gluten; they are a rich source of protein, and they all have a low glycemic index (GI) i.e. they do not spike the blood sugar level, which makes them a good choice for people with diabetes and celiac disease. During the study, it was found that some or all of the bioactive compounds like phenolic acids, flavonoids, saponins, phytosterols, tocopherol, tannins, betalains, stillbenoids, polycosanols, alpha-linoleic acid, and lignans have anti- cancerous, anti- diabetic, anti-hypertensive and cardiovasculareffects on the body. Quinoa posses' bioactive compounds like quercetin, kaempferol, Betacyanins, betalains and tocopherol, that have biological functions such as anti-hypertensive, anti-viral, anti-oxidant, anti-cancerous, anti-diabetic, anti-allergic, anti-thrombosis, and anti-atherosclerosis effects on the body. Sorghum contains trans-resveratrol, caffeic acid, gallic acid, campesterol, stigmasterol and gallotannins, which helps prevent lung, breast and prostate cancer, prevents type-2-diabetes, and has neuroprotective effect. Flaxseed bioactives like Alpha-linolenic acid (ALA), lignans and cyanogenic glycosides have Immunomodulatory, anti-fibrosis, anti-mutagenic and anti-obesity effects. Since the world is moving towards a healthy lifestyle, grains and seeds are a good source of nutritious foods.

Keywords: Bioactive compounds, Biological functions, Chronic diseases, Glycemic index, Good health and well-being, Sustainable Development Goals

INTRODUCTION

Quinoa (*Chenopodium quinoa*) is a pseudo cereal and a dicotyledonous plant belonging to the family Chenopodiaceae. It is widely grown in Latin America, especially in South America, where it originated 5000 years ago near the current Peruvian-Bolivian border near Lake Titicaca (Estrella *et al*., 2018). Quinoa has a protein content of 9.1 to 15.7 %, carbohydrate content of 48.5 to 69.8%, fat content of 4.0 to7.6% and mineral content of 2.0 to 7.7% (Pathan *et al*., 2022).Quinoa has a rich bioactive profile, and it includes bioactive compounds like flavonoids (quercetin and kaempferol), phenolic acids (Ferulic, caffeic and p- coumaric), saponins, phytosterol (β-sitosterol, brassicasterol, campesterol, and stigmasterol), betalains (Betacyanins and Betaxanthins), stilbenoids and tannins (Gallotannins, Ellagitannins, proanthocyanidins) (Hernández-Ledesma, 2019). These bioactive compounds have shown to exert biological activities such as anti-oxidant effect, Immunomodulatory effect, cardiovascular effect, anti-diabetic effect, antiobesity effect, neuroprotective effect and anti -hypertensive effect (Ng and Wang, 2021).

Sorghum (*Sorghum bicolor*) is millet or cereal which belongs to the family Poaceae. It is among the fifth most important cereal in the world after wheat, rice, barley and corn. Domestication of this crop took place in Africa 3000 to 5000 years ago and it is also native to the country (Cardoso *et al*., 2017). Sorghum has a rich nutrient profile, and has a protein content of (4.4.-21.10%), carbohydrate (70-80%), fat (2.10-7.60%), mineral (calcium (11.0-586.0 mg/g), phosphorus (167.0

-751.0 mg/g) and iron (0.90- 20.00 mg/g) and vitamin (Thiamine (0.24-0.54 mg/g), niacin (2.90-6.40 mg/g) and riboflavin (0.10-0.20 mg/g)) (Duodu, 2019). Bioactive compounds found in sorghum are phenolic acid (Caffeic acid, p-coumaric acid, ferulic acid and Gallic acid), flavonoids (luteolin and apigenin, naringenin, kaempferol and quercetin), stillbenoids (trans- resveratrol), tannins (hydrolysable tannins and condensed tannins (proanthocyanidins)), phytosterol (β-sitosterol, brassicasterol, campesterol, and stigmasterol) and polycosanols. Sorghum bioactives exert biological activities like anticancer property, antioxidant property, anti-inflammatory property and anti-obesity property (Li *et al*., 2021).

Flaxseed (*Linum usitassimum*L.), also known as linseed or Alsi, is an ancient crop cultivated for food. It is an annual herb which has flowers of blue colour and yields flaxseeds ranging in colour from reddish brown to golden yellow. Flaxseed has been consumed by humans from ancient times for its medicinal and nutritional qualities as well as fiber content. Nutritional composition of flaxseed has 19.50 g protein, 34.30 g carbohydrate (Morya *et al*., 2022), 42.16 g fat, 27.3 g fiber, 255 mg calcium, 392 mg magnesium, 642 mg phosphorus, 434 mg zinc, 1.64 mg thiamine, 0.16 mg riboflavin, and 3.08 mg niacin (Bekhit *et al*., 2018). Some of the important biologically active compounds accumulated by flaxseed are linoleic acid, linolenic acid, Lignans, cyanogenic glycosides, cyclic peptides and mucilage. Flaxseed has pharmaceutical applications such as anti-diabetic activity, anti-inflammatory function, antioxidant activity, anti-cancerous activity, osteoporotic effect and cardiovascular effect (Shim *et al*., 2019).

This review aimed to evaluate the potential for Quinoa (*C. quinoa*), Sorghum (*S. bicolor*), and Flaxseed(*L. usitassimum*) to be noble food products. Firstly, the nutritional profile of these grains and seeds isintroduced followed by the discussion of bioactive compounds present in them andtheir pharmacological application.

NUTRITIONAL COMPOSITION

Quinoa, sorghum and flaxseed are good sources of some important nutrients like proteins, carbohydrates, fats, vitamins and minerals. Quinoa is one of the only plant sources which contains all essential amino acids while Sorghum is a good source of carbohydrates, whereas flaxseed is a rich source of omega-3-fatty acids.

Protein

Protein is an essentialnutrient required by the body to play functions like enzyme production, production of antibodies and hormones, regulation of metabolic processes and supply of energy. They also function in supplying the body with sulphur compounds, transfer of cholesterol, fat-soluble vitamins, triglycerides and phospholipids in the form of lipoprotein (Mota *et al*., 2016).Quinoa being a pseudo cereal has protein content of 9.1 to 16.7%, which is more than the amount found in cereals (Motta *et al*., 2019) .Globulins and albumins are the two most important protein components. Globulins are insoluble in water but readily soluble in crystalline dilute saline solutions. Chenopodin, a globulin 11S-type protein, is an oligomeric protein having a quaternary structure. The other quinoa protein is a 2S-type albumin with a high concentration of cysteine, arginine, and histidine (Pirozi *et al*., 2017). The second structure of globulin is composed of 20% -helices, 35% -sheets, and 45 percent aperiodic structure. Albumin is easily soluble in water and may be extracted from a water suspension. Furthermore, the secondary structure of quinoa albumin is composed of 4 percent -helices, 50% -sheets, and 46% aperiodic structure (Dakhili *et al*., 2019).

The availability of essential amino acids (nutrients which the body cannot synthesize) determines the nutritional content of proteins. The most critical feature of protein from a dietary standpoint is its basic amino acids (EAA), which cannot be synthesized by humans due to the presence of a carbon skeleton and must instead be obtained by diet and so it is important to consume these amino acids for meeting metabolic needs and for the growth (Joye, 2019). When determining the quality of plant-based protein, protein amino acids' bio availability and structure is considered (Bhuva *et al*., 2021). Quinoa has an excellent balance of amino acid and is one of the only plant sources which contain all essential amino acids (Refer to Table 1) (Mir *et al*., 2018).

Most humans rely on cereal grains like sorghum as a staple food for their daily intake of numerous nutrients, including protein; therefore, sorghum protein quality is an essential criterion. Sorghum proteins are divided into two types: prolamins and non-prolamins. Prolamins account for around 79 percent of the overall proteins, with the remaining made up of albumins, glutamines, and globulins. The kafirins are the main prolamins of sorghum and are divided into three classes: alpha-kafirins (66-84 percent), beta-kafirins (8-13 %), and gamma-kafirins (9-21%) (Cardoso *et al*., 2017). Sorghum includes various essential and non-essential amino acids, such as alanine (7.34–9.62g), glutamic acid (17.5–28.12 g), aspartic acid (4.83–7.06 g), phenylalanine (4.03–5.62 g), valine (4.22–6.86 g), leucine (12.02 –14.48 g), and proline (6.66–12.34 g). However, lysine and tryptophan are deficient (Table 1) (Batey, 2017).

Flaxseed has a protein composition ranging from 20 to 30%, with globulins (linin and conlinin) accounting for roughly 80% and glutelin accounting for 20%. Flaxseed has an amino acid profile similar to soybean and is gluten-free. It also contains peptides with bioactivities associated to the reduction of (Cardiovascular disease) CVD risk factors (Serna and Espinosa *et al*., 2019). Flaxseed also includes a substantial quantity of non-protein nitrogen (NPN), such as vitamins, choline, cyanogenic glycosides and sinapine. Flaxseed protein is rich in asparagine, leucine, glutamic acid, and arginine. The percentage ratio of essential to total amino acid in flaxseed protein is significantly above the 36 percent ratio for proteins, indicating that flaxseed has a high potential for use as a protein source (Kajla *et al*., 2015). High cysteine and methionine content boosts antioxidant levels, lowering cancer risk (Bekhit *et al*., 2018).

Carbohydrate

Carbohydrates are one of the most plentiful and economic human energy sources, constituting one of the main classes of organic compounds present in nature. Together with protein, they form the primary component of a living organism, which constitutes to the most abundant and economical source of energy for human. Quinoa starch has a higher overall viscosity, water absorption potential and swelling strength than wheat and barley starch. Because of its excellent freeze-thaw consistency, it is a perfect thickener for food products that require resistance to retro-degradation (Mota *et al*., 2016). Quinoa contains carbohydrates in the range of 67 to 74 percent of dry matter, with an amylose level of about 11 percent. Other carbohydrates found in trace amounts contain monosaccharides (2%) and disaccharides (2.3%) as previously mentioned (Maki *et al*., 2015).

Sorghum has been found to be a good source of carbohydrates (54.6%–85.2%), of which starch is the dominant one (Adebo, 2020). The starch content varies greatly across cultivars, ranging from 32.1 to 72.5 g per 100 g grain. Sorghum starch is mostly composed of amylose and amylopectin; however certain waxy sorghums may lack or have low amounts of amylose. Sorghum has the lowest starch digestibility among cereal crops due to large amounts of resistant and poorly digested starch and strong interactions between starch granules, endosperm proteins, and condensed tannins. Itis a good source of fibers because the non-starch carbohydrate in sorghum is largely made up of insoluble fibers (75 to 90%) and soluble fibers (10 to 25%) (USDA, 2019).

Flaxseed has fiber content ranging from 22% to 26%, double the high fibre beans rate. A half ounce of dried whole flax seed offers between 20% and 25% of your daily fiber requirements. Flaxseed includes soluble and insoluble dietary fibers in varying proportions ranging from 20:80 to 40:60. The soluble fiber fractions are mucilage gums, while the primary insoluble fiber fractions are cellulose and lignin (Goyal *et al.,* 2018). Flaxseed mucilage is a popular name for flaxseed soluble fiber, which is also known as viscous fiber and flaxseed gum. Recent research discovered that mucilage provided 60 –64 percent of the carbs component. In addition to accounting for flax meal's laxative action, soluble fiber is known to have significant cholesterol-reduction properties, decreasing a key risk factor for cardiovascular disease. Insoluble dietary fiber lowers insulin resistance, aids in constipation treatment, and promotes overall bowel health (Soni *et al*., 2016).

Fat

Pseudo cereals have higher fat content than the majority of cereal species. The fat contained in pseudo cereals has a high concentration of unsaturated fatty acids. Polyunsaturated fatty acids have a number of beneficial effects on cardiovascular disease and insulin sensitivity (Bastidas *et al*., 2016). Fats are dispersed stores of energy that often serve as structural elements of cell membranes, which the body uses to perform a number of regular functions. The consistency of fats is critical. Omega-6, for example, is believed to promote inflammatory activity in the body, while omega-3 has anti-inflammatory properties. A lower omega-6: omega-3 fatty acid ratio is preferable to lower cardiovascular disease risk, cancer, and inflammatory and autoimmune disorders (Sharma and Lakhawat, 2017). Quinoa is recognized as an alternative oily seed due to the high quality and quantity of its lipid fraction. It has an oil content ranging from 2.0 to 9.5% and is high in essential fatty acids such as linoleic and alpha-linolenic acids. It contains elevated levels of antioxidants such as alpha and gamma tocopherol. Palmitic fatty acid, which occurs as a simple saturated fatty acid in quinoa, accounts for 10% of the total fatty acids. Oleic (19.7%-29.5%), alpha-linolenic (8.7%- 11.7%) and linoleic (49.0% -56.4%), and fatty acids account for 87.2%-87.8% of total fatty acids (Duodu, 2019).

Flaxseed is the greatest plant source of linolenic acid, a kind of omega-3 fatty acid (ALA) (Morya *et al*., 2019). Flaxseed oil has high polyunsaturated fatty acid content (73%), low saturated fatty acid content (9%) and moderate monosaturated fatty acid content (18%). The main fatty acid in flaxseed oil is alpha- linolenic acid (ALA), which ranges from 39.00 to 60.42%, followed by oleic, linoleic, Palmitic, and stearic acids, which give a good omega-6: omega-3-fatty acid ratio of around 0.3:1 (Martinez *et al*., 2020). Fatty acids are classified as essential because the body requires them but cannot synthesise, thus, they must be obtained from food. The enzymes necessary for the production of these important fatty acids are lacking in the human body. Omega fats are classified into two types: omega-3 and omega-6 fatty acids. Eicosapentaenoic acid (EPA), Linolenic acid, and docosahexanoic acid (DHA) are three nutritionally essential omega-3 fatty acids. All three fatty acids have been demonstrated to lower the risk of heart disease (Balic *et al.,* 2020, Soni *et al.,* 2016). Although relatively little ALA converts to the long -chain polyunsaturated omega-3 found in marine oils, it does have certain benefits on its own. The advantages of ALA can be evident at intakes as little as 1g/day, with 2g/day suggested for cardio protection (Soni *et al*., 2016).

Vitamins and minerals

Quinoa contains a lot of micronutrients, including vitamins and minerals. Vitamins are substances that are necessary for human and animal health. It is reported to have significant amounts of pyridoxine (B6) and folic acid. The amounts of pyridoxine and folic acid in 100 g of quinoa have been found to fulfill adults' daily requirements. Riboflavin in 100 g of quinoa is said to satisfy 80 percent of children's and 40 percent of adults' requirements. Its niacin level does not satisfy the daily need, yet it is an essential source for diet. Quinoa has less thiamin than barley and oat, but it is more in the case of riboflavin, pyridoxine, and folic acid than most other grains. It is also a good source of vitamin E, with a greater concentration than wheat (Duodu, 2019). Unlike carbohydrates, lipids, and proteins, minerals are inorganic and cannot be synthesized by living organisms. They provide vital roles in the organism. Low intake or reduced bioavailability may result in physiological imbalances and impairment of essential processes. Calcium, iron, magnesium, phosphorus, potassium, sodium, zinc and copper, are among the most well-known. These micronutrients must be consumed as part of a well-balanced diet to meet daily requirements, and special consideration should be paid to the cooking processes and nutrients to maximize bioavailability (Mota *et al*., 2016). Ash level in quinoa seed ranges from 2.4 to 4.8 percent. The ash has a diverse mineral composition, with significant magnesium, calcium, iron, copper and zinc levels. The mineral content of quinoa seeds has been shown to be higher than that of other grain crops (Cruz *et al*., 2015).

Sorghum includes vitamins and minerals, which are important components for humans to execute the activities required to sustain life. Sorghum has relatively high quantities of potassium and phosphorus, minerals known to aid in muscular mobility, nervous system function, and the development of strong bones and teeth. B-vitamins and vitamin E are among the essential vitamins found in sorghum. It contains good amounts of pantothenic acid, nicotinic acid, biotin, riboflavin and pyridoxine (Morya *et al*., 2017). Trace quantities of β-carotene (vitamin A precursor) have also been detected (Refer to Table 2) (Goyal *et al*., 2014). The primary vitamins in sorghum include the vitamin B complex (riboflavin, pyridoxine, and thiamin) and certain fat-soluble vitamins (Vitamins A, D, E, and K). In contrast, the key minerals are phosphorus, potassium, zinc, and magnesium (Martinez *et al*., 2020).

Flaxseed has trace quantities of both water-soluble and fat-soluble vitamins. Vitamin E is found in the form of γ-tocopherol, with a concentration of 39.5 mg/100g. Gamma-tocopherol is an antioxidant that protects cell proteins and fat from oxidation; it increases sodium excretion in the urine, which may aid in the reduction of Alzheimer disease, heart disease risk, and blood pressure. It has the most outstanding potassium content of any meal, and high potassium consumption is inversely associated with stroke risk, free radicals and blood platelet aggregation (Kajla *et al*., 2015).

PROFILE OF PRINCIPLE BIOACTIVE COMPOUNDS

Phenolic acid

The most common plant chemicals obtained from food are phenolic compounds. Phenolic chemicals are non-essential human nutrition components derived from secondary metabolism in plants (Nooshkam *et al*., 2020). Phenolic acids can be soluble free acids, soluble esterified conjugated acids, or insoluble bound, with one functional carboxylic acid covalently linked to cell wall structural components. When phenolic acids are bound, they produce ester bonds with structural carbohydrates and ether bonds with lignin. Natural phenolic acids contain two different carbon frameworks that exist only as hydroxybenzoic and hydroxycinnamic acids, which can be conjugated or free (Schmidt *et al*., 2019).In plants, phenolic chemicals are mostly found in soluble or bound forms. The majority of the soluble forms are produced in the plant's intracellular endoplasmic reticulum and accumulate in the leaves, fruits, stems, and roots, whereas the bound forms are formed when the soluble phenolic compounds are transported to the cell wall and conjugated with cell wall macromolecules such as cellulose and protein via ester and glycosidic bonds (Natalello *et al*., 2020). Phenolic acids make up the bulk of plant secondary metabolites that contribute to a variety of physiological effects. Characterization of phenolics has been mostly focused on extractable(Shetty and Sarkar, 2019). Quinoa phenolic acid mainly consists of ferulic, vanillic, 4-hydroxybenzoic, protocatechuic, P- coumaric, and 8,5′-diferulic acids and their derivatives, as shown in Fig. 1 (Ledesma *et al*., 2019).

Numerous phenolic acids were discovered in both native and processed sorghum grains. Gallic acid, sinapicacid, Caffeic acid, p-hydroxybenzoic acid, p-coumaric acid, protocatechuic acid, and ferulic acid have been investigated more in the phenolic acids listed above, with ferulic acid being the most prevalent. Caffeic, p-coumaric, Ferulic, and 3,4-dihydroxybenzoic acids, for example, were found in red sorghum; ferulic acid was the most abundant phenolic acid (Vanamala *et al*., 2018).There are two types of phenolic acids: hydroxycinnamic acid derivatives and hydroxybenzoic acid derivatives. These acids have significant antioxidant activity *in vitro* and may consequently help human health. Some sorghum varieties have phenolic acid content ranging from 135.5 to 479.40 g/g, with major amounts of ferulic (120.5 to 173.5 g/g) acids and protocatechuic (150.3 to 178.2 g/g) and minor amounts of caffeic (13.6 to 20.8 g/g), vanillic (15.4 to 23.4 g/g), p-coumaric (41.9 to 71.9 g/g), Gallic (14.8 to 21.5 g/g), cinnamic (9.8 to 15.0 g/g), and p hydroxybenzoic (6.1 to 16.4 g/g) (Cardoso *et al*., 2017).

Flavonoids

They are the most common and abundant plant polyphenolic class obtained from a plant-based diet. They attract plant pollinators by imparting flavour, colour, and smell to the flowers, fruits, and seeds (Abderrahim *et al*., 2017). A C6–C3–C6 carbon skeleton dominates the structure, which can be found as aglycones and glycosides. Food flavonoids are classified into six primary sub-classes based on the properties of the aglycones, which include anthocyanidins; flavanones, flavones, flavan-3-ols, and flavonols (Ahumada *et al*., 2016). Anthocyanins are the most common kind of anthocyanidin found in nature (glycosides). Cyanidin is the most common anthocyanidin found in food plants. The most prevalent Anthocyanins kind in sorghum are 3-deoxyanthocyanidins, and their derivatives, luteolinidin and apigeninidin, are seldom seen in higher plants (Mroczek, 2015). Quercetin and kampeferol are the dominant favanols-type flavonoid found in quinoa (Balakrishan and Schneider, 2020).

Sorghum has previously been shown to contain anthocyanidins, flavanones, flavones, and flavonols. These are the second most abundant and biggest class of phenolics in sorghum and the plant world. Flavones found in sorghum grain and stem include luteolin, apigenin, and tricin. While several flavonoids appear to be present throughout the sorghum plant, the flavanones eriodictyol and naringenin have only been found in the grain (Luo *et al*., 2018). The only dietary source of 3-DXAs (Deoxyanthocyanins) is sorghum. The four primary forms of 3-DXAs are luteolinidin (LUT), 5-methoxyluteolinidin, apigeninidin (AP), and 7-methoxyapigeninidin. 3-DXAs are found mostly in plant tissue as aglycones. The genotype of sorghum substantially impacts the amount and composition of 3-DXAs in sorghum grain (Oliveira *et al*., 2017). The most well-known flavones in sorghum grains are luteolin and apigenin, while the most well-known flavanone is naringenin. Furthermore, among the flavonols, quercetin and kaempferol have received the most attention, while catechin has received the greatest attention in the flavonols of sorghum grains (Queiroz *et al*., 2018).

Table 1. Essential amino acid (gram/100 gram) in quinoa, sorghum and flaxseed

Grain	Essential amino acids (in gram/100 gram)									References
	Histidine	**Leucine**	**Lysine**	**Isoleucine**	**Phenylalanine**	**Methionine**	**Tryptophan**	**Threonine**	**valine**	
Quinoa	1.4 –5.4	2.3- 9.4	2.4–7.5	0.8-7.4	0.1-2.7	0.3-9.1	0.6-1.9	2.1-8.9	0.8-6.1	Pathan and siddiqui, 2022; Villacres *et al*., 2022
Sorghum	1.4- 1.8	14.1-14.6	1.0- 2.2	3.2-4.1	5.0-6.8	1.4-4.2	1.1-1.8	2.2-3.3	4.2-5.4	Mofokeng *et al*., 2018; Serna and Espinosa, 2019
Flaxseed	0.9-2.2	1.1-5.9	0.7- 4.1	0.8-4.1	0.9- 4.7	0.3- 1.7	0.5-1.8	0.7- 3.7	1.0-5.1	Kotecka *et al*., 2020; Chishty and Bissu, 2016

Phytosterols

They are triterpenoid compounds with a structure comparable to cholesterol found in animals and humans. A 27-30-carbon ring containing hydroxyl groups makes up the chemical structure (Tang and Tsao, 2017). Despite the fact that the Phytosterol content of quinoa has received little attention, 100 g of quinoa seeds may contain up to 118 mg phytosterol. Quinoa contains phytosterols such as b-sitosterol, campesterol, brassicasterol, and stigmasterol. Epidemiological data, intervention trials, and meta-analyses have all shown that Phytosterols are essential for reducing human cholesterol (Esatbeyoglu *et al*., 2015). Phytosterols reduce blood cholesterol levels by competing for cholesterol absorption in the intestines and perhaps decreasing anthropogenic lipoprotein synthesis in the liver and intestines. Furthermore, Phytosterols were found to have anti-inflammatory, antioxidative, and anti-carcinogenic properties (Duodu, 2019).

Plant-derived steroids are known as phytosterols. Campesterol, β-Sitosterol, and stigmasterol have been separated, and β-sitosterol was shown to be the predominant phytosterol in sorghum grains (Phytosterols found in sorghum are mentioned in Fig. 2 (Deluca *et al*., 2018). When compared to fruits, vegetables, and other cereal grains usually available in the food supply, sorghum grains constitute a comparatively rich source of phytosterol. Sorghum contains three of the more than 200 sterols found in plants (campesterol: 26.1 to 38.0%, sitosterol: 44.8 to 48.2% and stigmasterol: 17.3-25.6%) (Cardoso *et al*., 2017).

Saponins

These are classified as minor components and secondary metabolites and are widely researched due to their biological characteristics. They are regarded as the greatest anti-nutritional component in quinoa seeds, functioning as a natural defense against diseases and herbivorous organisms. Quinoa plant parts contain around 30 different kinds of Saponins (Rao and Sahid, 2016). Saponins, which have a detrimental impact on the flavour and digestion of quinoa, should be eliminated before eating. Saponins have a range of biological actions, including antifungal, antiviral, anticancer, hypocholesterolemic, hypoglycemic, antithrombotic, diuretic, and anti-inflammatory properties (Moreau *et al*., 2018).

Tannins

They are divided into two types depending on their chemical and biological properties: condensed tannin (also known as proanthocyanidin) and hydrolysable tannin. Hydrolysable tannin is complex polymeric molecule divided into two subclasses: Gallotannins generated from gallic acid and Ellagitannins derived from ellagic acid, which is a dimer of Gallic acid. Condensed tannin (Procyanidins) in sorghum grains are effective radical scavengers because they dramatically increase antioxidant capacity. The most fundamental unit of condensed tannin composition is (epi) catechin; other essential units include Epigallocatechin gallate,

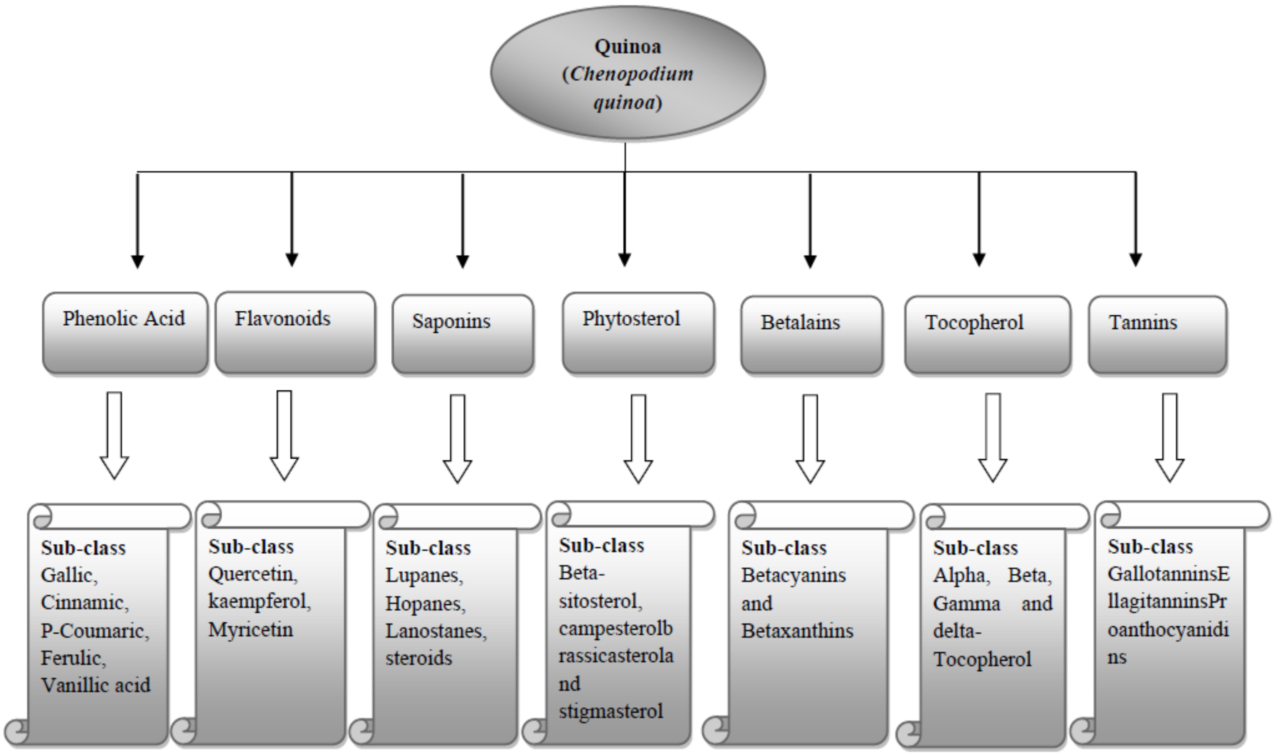
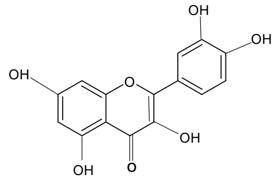
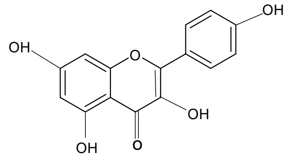
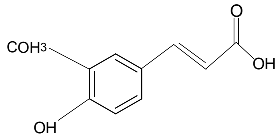
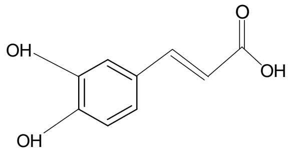
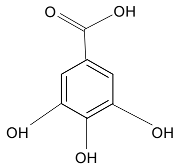
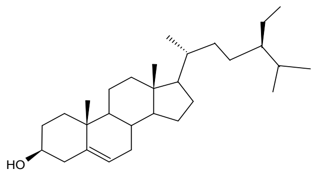
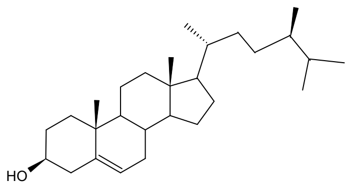
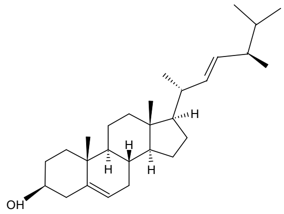
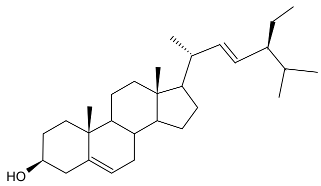


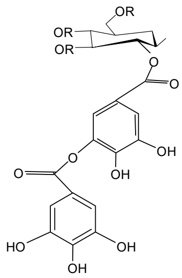
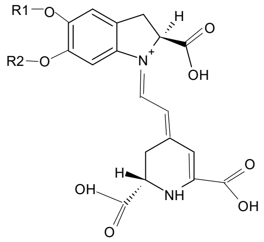
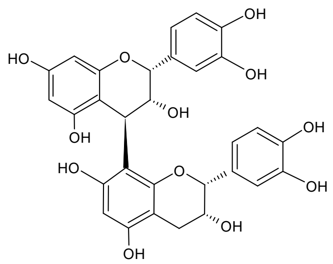
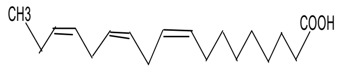
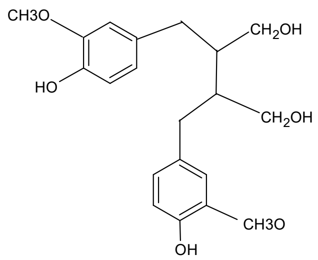
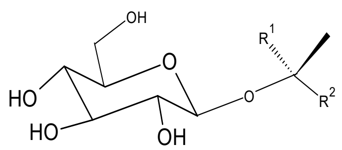
Fig. 1. *Bioactive compounds and their sub-classes in quinoa*

Table 2. Principle bioactive compounds and their health benefits

Bioactive Compound	Food source	Health benefits	Structure	Reference
Quercetin	Quinoa and Sorghum	It has antioxidant activity, antiviral activity, anti-inflammatory effect, anti-cancerous activity, antihypertensive and cardiovascular effect		Batiha *et al*., 2020; Deng *et al*., 2020
Kaempferol	Quinoa and sorghum	It has anticancerous activity, cardiovascular effect, anti-oxidant, antidiabetic, anti-inflammatory, Antiallergic, antiobesity effects		Silva *et al*., 2021; Imran *et al*., 2019
Ferulic acid	Quinoa and Sorghum	It has anti-inflammatory, antidiabetic, antihypertensive and cardiovascular effects		Ng and wang, 2021; Alam, 2019
Caffeic acid	Quinoa and sorghum	It has cardiovascular, anti-hypertensiv, antioxidant, antiinflammatory, anti-obesity and antidiabetic effect		Birkova *et al*., 2020; Muhammad *et al*., 2021
Gallic acid	Quinoa and sorghum	It has anticancer, anti-inflammatory, antidiabetic, antiobesity activity, prevents cardiovascular, gastrointestinal and metabolic diseases		Kahkeshani *et al*., 2019; Dludla *et al*., 2018
β-sitosterol,	Quinoa and sorghum	It has antidiabetic, antioxidant, antimicrobial, neuroprotective, anticarcinogenic and cardio protective effects		Gupta, 2020; Babu and jayaraman, 2020
campesterol	Quinoa and sorghum	Antioxidant, anti-inflammatory and anti-cancerous activity and helps to lower cholesterol level		Singh *et al*., 2017; Gupta, 2020
brassicasterol	Quinoa and sorghum	It has anti-cancerous activity, hence shows preventive action against prostate cancer. It has antiviral properties and protects cardiovascular health		Hassan, 2020; Xu *et al*., 2020
stigmasterol	Quinoa and sorghum	It has preventive action against type 2- diabetes, has cholesterol lowering property and neuroprotective action		Pratiwi *et al*., 2021; Ward *et al*., 2017

Contd……..

Table 2. Contd…...

Trans-resveratrol	sorghum	It has cardio protective and neuroprotective effect, anti-tumor, anticancerous and antiobesity activity	sss	Salehi *et al*., 2018a; Galinaik *et al*., 2019; Kuršvietienė *et al*., 2016
Gallotannins	Quinoa and sorghum	It prevents cancers such as lung cancer, breast cancer, prostate cancer, and has neuroprotective effect		Kurniawan and Zahra, 2021; Youness *et al*., 2021
Betacyanins	Quinoa	It has antidiabetic, anti-cancer, antimicrobial and antiviral activities, and it helps prevent cardiovascular disease, hepatitis and cognitive impairment		Madadi *et al*., 2020; Sadowska and bartosz, 2021
Proanthocyanidins	Quinoa and Sorghum	It has neuroprotective, cardio protective, Immunomodulatory, anticancerous, anti-diabetic, lipid lowering and anti-obesity effects on the body		Rauf *et al*., 2019; Unusan, 2020
Alpha-Linolenic acid (ALA)	Flaxseed	It has cardio protective, anti-carcinogenic, anti-inflammatory, anti-allergic and neuroprotective effects		Yuhan and Jiasong, 2018; Naghshi *et al*., 2021
Lignans	Flaxseed	It has anti-hypolipidemic, anti-mutagenic, antiobesity, antioxidative, anticarcinogenic and neuroprotective effects		De silva and Alcorn, 2019; Mrduljas, 2017
Cyanogenic Glycosides	Flaxseed	It has anticarcinogenic, anti-fibrosis, anti-inflammatory, Immunomodulatory effects		Anjum *et al*., 2022; Appenteng *et al*., 2021

epiafzelechin and Epigallocatechin (Jiang *et al*., 2020). Tannin is a heterogeneous collection of polyphenolic polymers with varying molecular weights and complexities. Tannin has been linked to a variety of health benefits due to itsImmunomodulatory and anticancer activity, anti-oxidant qualities and radical scavenging function; anti-inflammatory, vasodilating, cardio protective and antithrombotic actions (Yu *et al*., 2018). Procyanidins are distinguished by a wide range of bioactivities, including antioxidative, anticancer, and lipid-lowering properties, as well as the prevention of cardiovascular disease. The level of Procyanidin in sorghum has been found to be between 10.6 and 40.0 mg g , however this varies according to the variety (Ribas *et al*., 2018).

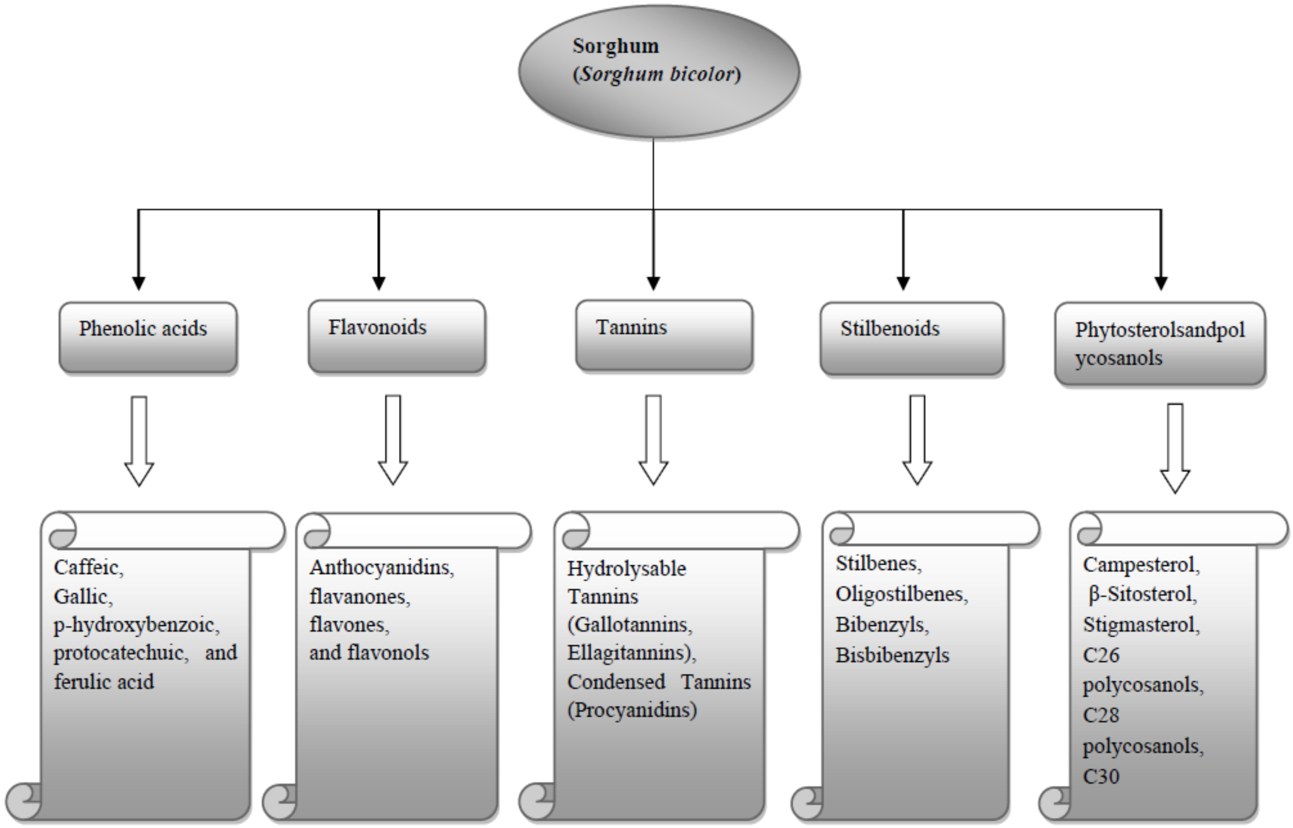


Fig. 2. *Bioactive compounds and their sub-classes in sorghum*

Betalains

Betalains are nitrogen-containing pigments produced from tyrosine and subsequently L-3,4-dihydroxyphenylalanine. They are classified into two subgroups: red-violet Betacyanins and yellow-orange Betaxanthins. Betanin is utilized as a natural food colorant, but it is also an effective scavenger of reactive oxygen species (ROS), an inhibitor of LDL oxidation and DNA damage, and an inducer of phase II enzymes and antioxidant defense mechanisms (Ramakrishna *et al*., 2019). Based on UV/VIS spectrum and LC-MS fragments compared with beet betanin extracts, Betacyanins, primarily betanin and isobetanin, were proven to be the pigments of the red and black quinoa seeds (Delgado *et al*., 2019).

Tocopherol

Vitamin E homologs are tocopherol and tocotrienols. All four tocopherol isoforms were found in quinoa, with alpha-tocopherol (47–53 mg/Kg DW) being the most common, followed by beta-tocopherol (17–26 mg/Kg DW) and gamma-tocopherol in negligible amounts (5 mg/Kg DW) Quinoa seeds also contained trace amounts of the other vitamin E isomers, alpha and beta -tocotrienols (Abderrahim *et al*., 2017). Vitamin E analogues are powerful antioxidants with several physiological roles in humans, including anticoagulant, metabolic, inflammatory, and anticancer control. Tocotrienols functions in human health have gained increased attention in recent years, notably for their hypocholesterolemic, anticancer, and neuroprotective characteristics (Tang and Tsao, 2017).

Stilbenoid

They are a type of chemical that consists of a stilbene parent core and a polymer. Sorghum has the ability to produce Stilbenoids and Stilbenoids metabolites. According to research, red sorghum grains contain 0.4–1 mg/Kg of trans-pieced and up to 0.2 mg/Kg of trans-resveratrol (Wongwaiwech *et al*., 2020). Stilbenes are a small class of phenolic compounds generated from the phenylpropanoid pathway that have a wide range of applications in plant disease resistance and human health. Stilbenes are 1, 2-diarylethenes made from cinnamic acid derivatives. Fungal infection can potentially improve stilbene yields in sorghum (Luo *et al*., 2018).

Polycosanol

Polycosanols are a kind of aliphatic alcohol with a high molecular weight that has a variety of bioactivities. C26 polycosanols, C28 polycosanols, C30 polycosanols, and C32 polycosanols were extracted and identified, with C28 polycosanols being the major polycosanols in sorghum (Marmol *et al*., 2017). Polycosanols (33.4–44%) are a major component of the long-chained lipids isolated from sorghum grain kernels. Polycosanols, which have physiological advantages, may be found in large quantities in sorghum. The total polycosanols content of unpolished sorghum grain was 74.5 mg/100g in the dry kernel, while polished grain had 9.8 mg/100g in the dry kernel (Cardoso *et al*., 2017).

Alpha linolenic acid (ALA)

It is an n3 polyunsaturated fatty acid (PUFA), one of two necessary fatty acids in the human diet (Morya *et al*., 2022). Although ALA may be converted to longer chain Poly Unsaturated Fatty Acids (PUFAs) such as docosahexanoic acid (DHA) and eicosapentaenoic acid (EPA), conversion rates in human tissues are modest (Marmol *et al*., 2017).Omega fats are classified into two types: omega-3 and omega-6 fatty acids. Linolenic acid, docosahexanoic acid (DHA) and eicosapentaenoic acid (EPA) are three nutritionally significant omega-3 fatty acids. All three fatty acids have been found to lower the risk of heart disease. These two polyunsaturated fatty acids are necessary for humans, which means that the body needs them (Morya *et al*., 2022; Soni *et al*., 2016).Increased consumption of unsaturated fatty acids, particularly n3 PUFAs such as ALA, is commonly regarded to benefit cardiovascular health, although nothing is known regarding ALA's impact on colon cancer risk (Morya *et al*., 2022). PUFAs dominate the fatty acid composition of Flaxseed, followed by monounsaturated fatty acids (MUFAs) and only a few saturated fatty acids. Flaxseed has high quantities of both essential fatty acids, ALA and LA (Refer to figure 3 for subclasses of ALA)(Kajla *et al*., 2015).

Lignan

They are polyphenolic chemicals found in fiber-rich plant products; Flaxseeds have 75–100 times more Lignans than other plant sources. Each seed's lignan concentration might range from 1 to 26 mg/g (Akinwumi *et al*., 2018). Flaxseed is the most abundant source of plant lignan. Lignan are phytoestrogens in high concentrations of fiber-rich plants, vegetables, grains, fruits, legumes, tea, berries, and alcoholic drinks. Lignans are diphenolic chemicals formed by the reaction of two coniferyl alcohol residues found in the cell walls of higher plants. The main lignan in flaxseed is secoisolariciresinoldiglucoside (SDG), with low amounts of matairesinol, lariciresinol, pinoresinol, and isolariciresinol. SDG levels in defatted flour vary from 11.7 to 24.1 mg/g, whereas whole flaxseed flour has 6.1 to 13.3 mg/g. Lignans

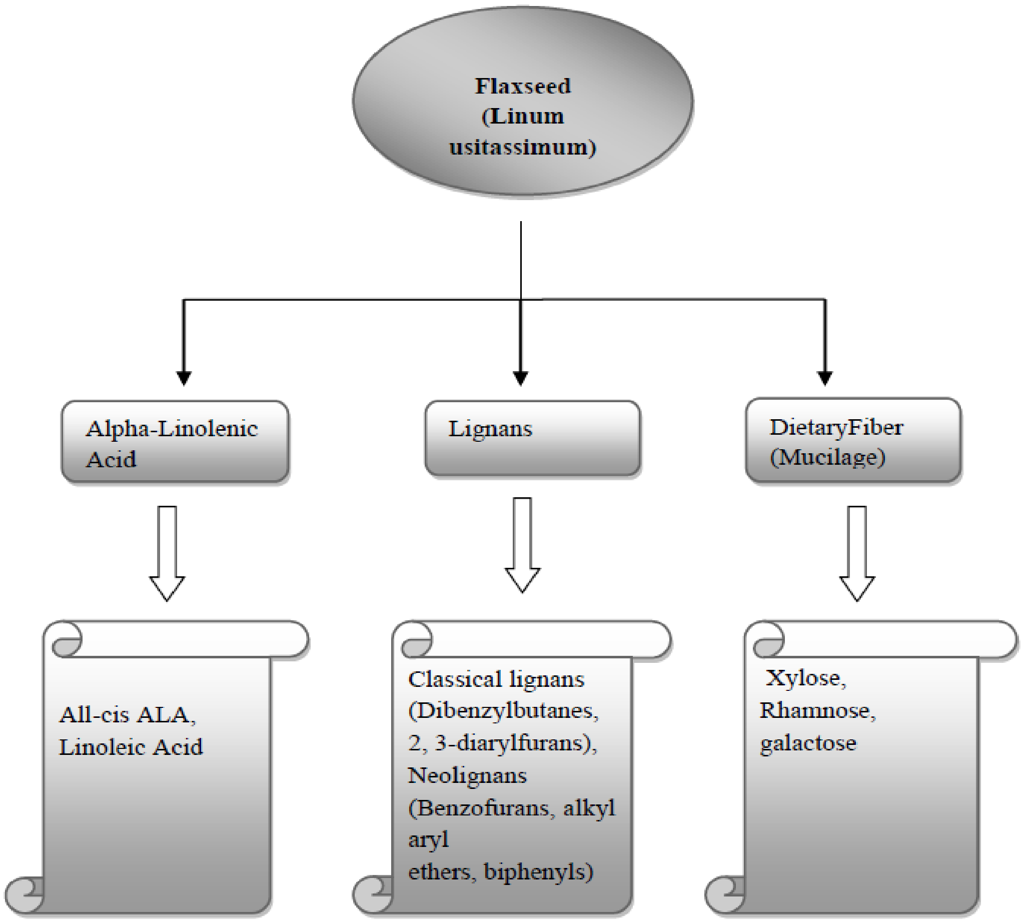


Fig. 3. *Bioactive compounds and their subclasses in flaxseed*

have antioxidant action and may hence contribute to flaxseed's anticancer potential (Kajla *et al*., 2015).

Dietary fiber (Mucilage)

It is a complex carbohydrate resistant to digestion in the small intestine but fermented by bacteria in the colon. Dietary fiber may lower colorectal cancer (CRC) incidence by a variety of methods, including, but not limited to, reducing transit time, bulking stool, and fermenting into short chain fatty acids(SCFAs) (Yagasaki, 2019).Flaxseed mucilage, also known as flaxseed husk mucilage, is a gum-like substance made up of acidic and neutral polysaccharides. The neutral fraction of flaxseed includes 62.8 percent Xylose, whereas the acidic fraction contains mostly rhamnose (54.5 percent), followed by galactose. The total fiber content of whole flaxseed is around 28%. Flaxseed contains insoluble fibressuch as cellulose, lignans and hemicelluloses, whereas around one-third of the fiber in Flaxseed is soluble and present in the form of mucilage gums. Since mucilage is found mostly in the epidermis of the seed coat, removing the seed coat removes a large portion of the soluble fiber in flaxseed. Fiber supplements manufactured from flaxseed are currently accessible on the market, and they include both soluble and insoluble fibers (Cruz *et al*., 2015).

PHARMACOLOGICAL APPLICATIONS

Anti-cancerous activity

Cancer is the leading cause of mortality worldwide. Lung, colorectal, stomach, liver, and breast cancer are the leading causes of mortality in that order (Esposito *et al*., 2017). *In vitro*, the 3-deoxyantocyanins in black sorghum exhibit anticancer and antioxidant effects. Furthermore, sorghum contains flavones with estrogenic characteristics, which have an anticancer impact *in vitro* (Ananthraju *et al*., 2016). Epidemiological data have shown that phenolics have extraordinary health-promoting effects on chronic diseases, including anti-carcinogenic, anti-inflammatory, and antioxidant activity. The anti-carcinogenic potential of phenolics is a key disease-prevention action; they slow the onset and progression of malignancies by limiting the transformation of normal cells, tumor growth, angiogenesis, and metastasis. Furthermore, phenolics increase the production of tumor-suppressing proteins such as p53, phosphates and tensin homolog (PTEN), p21, and p27 (Li *et al*., 2018). Flavonoids' chemo preventive and antiproliferative activities appear to be connected to their inhibitory activity against enzymes involved in carcinogen activation, hence avoiding tumor development (Darband *et al*., 2018). For example, the anthocyanidins delphinidin and Cyanidin have been proven *in vitro* to exert direct cytotoxicity against metastatic colon cancer cell lines, causing apoptosis. This was not necessarily due to their antioxidant activities, since both operated as pro-oxidants, causing ROS buildup in tumor cells, which may enhance oxidative stress and cause an apoptotic response. Delphinidin, in particular, increased the expression of p53, which has the ability to cause cell cycle arrest and death.The flavonol quercetin, like other flavonoids, has been shown to have anti-tumor effect against colon cancer cells both *in vitro* and in vivo. Its cytotoxic action against colon cancer cells is mediated by promotion of apoptosis by p53 activation and inhibition of NFB, cell cycle arrest due to downregulation of cell cycle genes, and reduction of inflammation via downregulation of Cox2, which is typically increased in colon cancer (Refolo *et al*., 2015). Another way quercetin may impact colon cancer cell proliferation is by increasing the expression of the G-protein coupled cannabinoid receptor, CB1-R, which may bind to quercetin, inhibiting cell growth and migration via the Wnt, PI3K, Akt, and STAT3 pathways (Martinez *et al*., 2020). Preclinical cancer models have clearly established the therapeutic advantages of lignan-rich diets, with evidence of decreases in early carcinogenesis as well as prevention of tumor development, angiogenesis, and disease progression. Such evidence supports the hypothesis that lignans have a role in carcinogenesis (Links *et al*., 2015).

Anti-diabetic activity

Diabetes-related hyperglycemia produces chronic consequences such as retinopathy and nephropathy. Some hypoglycemic therapies suppress the digestive enzymes alpha-amylase and alpha-glycosidase, preventing glucose absorption. Dietary flavonoids had a strong hypoglycemic impact by regulating glucose absorption, inhibiting digestive enzymes, regulating intestinal microbiota, inhibiting the production of advanced glycation end products, and other mechanisms (Shi *et al*., 2017). Tannin-rich polyphenolic extracts of sorghum grain have been demonstrated to inhibit alpha-amylase and alpha-glycosidase enzymes *in vitro* and *in vivo* (Gowd *et al*., 2019). Following kaempferol, luteolin, and myricetin, and naringenin, quercetin was the most thoroughly studied flavonoid in the literature for in vivo and cellular antidiabetic properties in animal and cell models (Al- Ishaq *et al* ., 2019).

Through the modulation of glucose metabolism, hepatic enzyme activities, and a lipid profile, flavonoids enhance the pathogenesis of diabetes and its consequences (Sun *et al*., 2020). Anthocyanidins exhibited anti-diabetic efficacy primarily through oxidative stress inhibition, insulin resistance improvement, and insulin secretion stimulation. Anthocyanidins may reduce insulin resistance by controlling blood lipid levels, lowering cholesterol, triglycerides, and low-density cholesterol while raising apolipoprotein and high-density cholesterol (Zhao *et al*., 2019). Resveratrol anti-diabetic activity includes multiple tissue targets, including the liver, skeletal muscle, and pancreas. Resveratrol alters the activity of enzymes that regulate glucose homeostasis in the liver. Indeed, it restores the normal function of enzymes that have been changed in diabetics. As a result, it inhibits phosphoenolpyruvate carboxykinase, lactate dehydrogenase, and glucose-6-phosphatase while increasing hexokinase and pyruvate kinase activity. Furthermore, through activating glycogen synthase and blocking glycogen phosphorylase, resveratrol raises hepatic glycogen content. These modifications result in a decrease in hepatic glucose production. Tannins can postpone the onset of insulin-dependent diabetes mellitus by providing an insulin-like impact on insulin-sensitive tissues, lowering glucose levels through modulating the oxidative environment of pancreatic -cells (Xie *et al*., 2018). Numerous *in vitro* and in vivo investigations have been conducted to understand the antidiabetic mechanisms of proanthocyanidins, including carbohydrate digestion decrease, hepatic glucose metabolism regulation, pancreatic-cell function protection, and the influence of skeletal muscle on glucose absorption. Proanthocyanidins have been shown to block alpha-glycosidase, an enzyme that converts starch and disaccharides to glucose, lowering carbohydrate digestion and, as a result, glucose availability for absorption in the gut (Goszcz *et al*., 2017).

Cardio-vascular activity

The intake of dietary flavonoids is associated with a lower risk of cardiovascular disease. Several studies have shown that those who ingest a high amount of flavonoids had an 18% decreased chance of dying from cardiovascular disease. Several studies have revealed that flavonoids have cardio protective, neuroprotective, and chemoprotective properties (Sharifi *et al*., 2020; Kikuchi *et al*., 2019; Khan *et al*., 2021; Devi *et al*., 2021). Polyphenol-rich meals (mostly anthocyanins) have been demonstrated to enhance endothelial function and plasma lipid profiles while suppressing aberrant platelet aggregation and lowering inflammation. Anthocyanins' primary activity in preventing CVDs is to protect against oxidative stress. The endothelium is a barrier that exists between the blood and the artery wall and regulates vascular function by reacting to hormones, neurotransmitters, and vasoactive substances. Endothelial dysfunction occurs when the atheroprotective balanced production of vasoactive factors is interrupted (Goszcz *et al*., 2017). Resveratrol protects against CVDs by decreasing lipid peroxidation, lowering blood pressure, improving serum cholesterol profile, protecting endothelial cells from death, and lowering platelet aggregation (Salehi *et al*., 2018b).

Anti-hypertension activity

Pulmonary hypertension is a serious disease characterized by an increase in pulmonary arterial pressure (greater than 25 mm Hg at rest or 30 mmHg during physical activity) and vascular remodeling, which eventually leads to right ventricular hypertrophy and right ventricular failure, both of which have a high mortality rate. Several plant-food bioactives have been found as possibly beneficial for both prevention and mitigation of several common hypertension risks (Hao *et al*., 2017). Because of its antioxidant characteristics, resveratrol reduces blood pressure. It aids in the generation of nitric oxide in the body, which induces arterial vasodilatation and hence blood pressure reduction. The angiotensin-converting enzyme (ACE) is recognized to play an important role in the control of arterial blood pressure and cardiovascular function. As a result, inhibiting this enzyme by plant-food bioactives is an important field of research in the treatment of hypertension (Rodríguez-García*et al*., 2019).

Anti-arthritis properties

Resveratrol is a polyphenolic substance found in plants such as grapes, berries, and peanuts. It has been discovered that resveratrol interacts with a variety of molecular targets related to inflammation and immunity. Resveratrol suppressed the inflammatory response by reducing the production and release of pro-inflammatory mediators, altering eicosanoid synthesis, suppressing activated immune cells, or inhibiting iNOS and COX-2 via NF-B or AP-1. Resveratrol decreased MMP1 and MMP13 expression in RA-FLS and limited its invasive potential *in vitro*. In CIA rats, resveratrol similarly lowered MMP1 and MMP13 levels and relieved joint edoema and injury in vivo (Liu *et al*., 2019).

Anti-obese properties

Polyphenols confer anti-obesity properties through a variety of pathways, including enzyme inhibition, stimulation of energy expenditure, appetite suppression, inhibition of adipocyte development, control of lipid metabolism, and manipulation of gut microbiota (Singh *et al*., 2020). The peroxisome proliferator, a key regulator of adipogenesis, can activate the peroxisome proliferator activated receptor- (PPAR-), which regulates the expression of adipogenic genes such as fatty acid synthase (FAS) and lipoprotein lipase (LPL). Plant-based phenolic compounds reduce hunger by delaying the release of appetite-stimulating hormones, altering MCH receptors, or inactivating appetite sensors. Flavonoid-rich extracts from plants have been demonstrated to inhibit hunger (Adiamo *et al*., 2018).

Recent trends, status and future prospects

Recent developments in the usage of quinoa, sorghum, and flaxseed include their use for a variety of applications. Quinoa and sorghum are being used to make gluten-free items such as breads, pasta, and drinks. One of the alcoholic beverages made from quinoa is beer. Quinoa micro-malting tests are carried out in order to better understand its brewing behavior. To improve the total soluble nitrogen and free amino nitrogen contents of quinoa, an alternate alkaline steeping approach is applied. These preliminary experiments suggested that these grains are appropriate for manufacturing Gluten Free beers and that alkaline steeping is an effective procedure for enhancing malt quality (Chandra *et al*., 2021). The current state of sorghum production in India is that, as compared to the green revolution era (1960s), the crop area has decreased from 19, 22,501 to 9094mha, while productivity and overall production have improved dramatically. The crop's worldwide picture in terms of the total area under cultivation and production has not altered much. According to USDA projections for 2016–17, the United States and Nigeria are the biggest sorghum producers, with total output of 12,199,000t and 6,500,000t, respectively. India is the world's fifth largest sorghum producer, with a total production of 4,800,000t, ranking fifth among the top ten producers. Bolivia and Peru are the world's largest quinoa producers. In 2017, Bolivia had 110,000ha of quinoa agriculture, whereas Peru had 61,000ha. These two nations produce more than 80% of the world's quinoa, followed by Ecuador, the United States, China, Chile, Argentina, France, and Canada, which produce 15–20% of the world's quinoa. The global yield was 8470hg/ha. The growth rate of regional exports has not been consistent, as in 2017, 173,242ha of quinoa were planted worldwide, yielding 146,735t (Fernández-López *et al*., 2020). Because quinoa, sorghum, and flaxseed are popular crops these days, many experiments are being conducted to discover new uses for them. These are some of their potential prospects: Quinoa is used as an antioxidant in the meat industry for a variety of meat products. Quinoa has high antioxidant content, therefore, it can help prevent oxidation and extend the shelf life of meat and meat products. Flaxseed oil microencapsulation is also done because flaxseed oil offers significant advantages, mostly linked to omega-3 fatty acids, which are increasingly employed in the food business. However, several conditions, such as pH, temperature, oxygen, and light, restrict the ability of these various components (omega-3 fatty acids) to be used in the formulation of many meals. In this view, the creation of functional meals necessitates the preservation of active components' stability, bioactivity, and bioavailability; hence, microencapsulation techniques have been developed and employed to build flaxseed oil-enriched food items to solve these challenges. Sorghum is being used to make fuel ethanol. It is difficult to develop new ethanol-producing cultivars since the important features, such as plant height, total soluble solids, juice output, and lignin: cellulose: hemicelluloses ratio, are "non-additive." Scientists are striving to make it possible (Kouamé *et al*., 2021).

Conclusion

Quinoa (*C. quinoa*), Sorghum (*S. bicolor*) and Flaxseed (*L. usitassimum*) are some of the popularly consumed crops these days due to their nutritional profile and therapeutic activities. The present review includes the studies discussing these food ingredients' nutritional and bioactive profile. Quinoa, sorghum and sorghum are rich sources of bioactive compounds like phenolic acids, flavonoids, tannins, stillbenoids, lignans, alpha-linolenic acid and phytosterols. The therapeutic activities such antioxidant, anti-inflammatory, anticancer, antidiabetic, antihypertensive, and anti-obesity effects make them beneficial for curing certain chronic diseases. Since these grains and seeds provide enough nutrients to meet daily nutrient requirements and help prevent diseases, they directly or indirectly help achieve sustainable development goal 3 (SDG3), i.e. “Good health and well-being”.

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Conflict of interest

The authors declare that they have no conflict of interest.

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