Food applications of sorghum derived kafirins potentially valuable in celiac disease

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ABSTRACT
The current review has measured the effect of kafirins in the development of functional foods and its valuable function against different diseases. Kafirins are usually a protein that is mostly present in sorghum. Chemically, kafirin is divided into different categories including α-kafirin, β-kafirin, and γ-kafirin. Kafirins that are formed in sorghum endosperm and then transferred into the lumen of the rough endoplasmic reticulum. The different functional food products are being developed by using kafirins in the form of sorghum flour. These products play a valuable role in human beings. Previous studies suggested that kafirins have pharmacological properties that are an aid in reducing CVD, hyperglycemia and inflammation. The kafirins are present in sorghum flour that protects humans from Celiac Syndrome. The aim of study was to extract kafirin from sorghum and add into different products for the purpose of reduce the risk of diseases especially celiac disease. Conclusively, food products prepared by using sorghum-kafirin is played a valuable role in human health.

Introduction

Prolamin proteins (kafirins) and non-prolamin proteins (globulins, glutelins, and albumins) are the two types of protein found in sorghum. Kafirins are the most common kind of storage protein in sorghum grain, accounting for 70% of the total protein content. The hydrophobic proteins are α-, β-, γ-, and δ-kafirin that formed in securely coiled protein bodies in the endosperm and are divided into four categories based on molecular weight. β- and γ-kafirins resulted in a significant disulfide bond cross-linking due to the presence of significant amount of cysteine and in turn possess certain hydrophilic properties. Kafirin’s strong hydrophobicity and ability to produce substantial disulfide cross-links are expected to have an adverse impact on isolated kafirins functional properties, particularly its protein digestibility. Kafirin is indigestible due to the presence of cysteine-cysteine disulfide bonds in peripheral protein bodies. P721Q is a floury sorghum mutant with a single amino acid change in the conserved 21st amino acid signal peptide cleavage site of a gene that produces 22-kDa proteins. Alpha kafirin, which was created via ethyl methanesulfonate mutagenesis. This mutation prevents protein digestion, resulting in kafirin in the presence of a minor abundance but dominant-acting 81 kafirins. The overall quality of the protein is improved by this mutation by decreasing lysine-deficient kafirins and boosting lysine-rich non alpha kafirins. Furthermore, P721Q mutant altered...
kafirin accumulation causes the protein body to shift from a spherical to a reticulated shape, which is thought to aid protein digestion by enhancing accessibility to stomach proteases.\textsuperscript{[3,6]} Grain characters like increased digestibility and high lysine are generated as a result of the P721Q mutation. Researchers utilized an RNA interference technique to create the inhibiting the alpha kafirins in sorghum with kafirin alternative having an increased amount of lysine and digestibility.\textsuperscript{[7]} Prolamins also referred to as kafirins, contain a number of distinguishing characteristics that could make them beneficial in both culinary and nonfood applications. Sorghum proteins are made up of 30% albumins, globulins, and glutelins, with the remaining 70% being alcohol soluble prolamins known as kafirins.\textsuperscript{[2]} Antioxidant peptides are made from natural sources and are usually regarded as safe at large doses. They are also a good supply of vital amino acids. Peptide antioxidants may also assist as functional additives with unique characteristics (Gelation, emulsification, foaming, and water and/or oil binding ability are examples owing to their surface amphipilicity).\textsuperscript{[8,9]} The result suggests that they are used as a food additive, and also seem to be viable alternatives to synthetic antioxidants for preventing lipids from oxidation. Enzymatic hydrolysis exposes antioxidative activity-related structures (e.g., functional side groups and structural territory) and releases specific peptide sequences from intact proteins’ globular matrix.\textsuperscript{[10]} Although the solubility of hydrolyzed proteins is enhanced, the amino acid composition in antioxidants may stay largely the same or improve.\textsuperscript{[11]} The peptide fractions obtained from the resultant hydrolyzates may be purified and separated using a variety of methods to produce peptide fractions with improved activity. In defining the end-use characteristics of hydrolyzates, enzyme selection is critical. Sorghum and its byproducts (such as distillers’ grains) contain a large number of proteins, particularly kafirin; nevertheless, only a few studies have been carried out to assess its potential for use as peptide antioxidants.\textsuperscript{[12–14]} The present review was conducted to identify the different types of kafirins in sorghum. Chemically, kafirin is divided into different categories including α-Kafirin, β-kafirin, and γ-kafirin. Kafirins are formed in sorghum endosperm and then transferred into the lumen of the rough endoplasmic reticulum. These proteins are played valuable role in the development of functional foods. The functional foods are considered a healthy diet against various diseases.

**Methodology**

The literature about the kafirins we used Google Scholar, PubMed, Web of Science and Science Direct. For the paid articles we taken help from Library of Government College University, Faisalabad, Pakistan. We made a contents first to make the proper structure of the review and then made the conceptualization. We formed the different partitions of the review and discussed the chemistry of kafirins, role in functional foods and the potential to combat chronic diseases especially celiac disease.

**Overview of kafirin**

Protein, after starch, is the second most prevalent component in sorghum grain, accounting for about 6–18% of the total.\textsuperscript{[15]} Endosperm proteins of sorghum may be set up in the form of a matrix or they are found as protein entities encased in the matrix. Globulins, kafirins, cross-linked kafirins, albumins, and glutelins are several types of proteins found in sorghum. The average protein content is 11% in sorghum grains.\textsuperscript{[16,17]} They are divided into two categories: prolamin (storage protein) and non-prolamin (non-storage protein). Kafirin is said to be a vital prolamin, as contains a lot of glutamine and proline. They are divided between the base of their molecular load, solubility, configuration, and assembly of amino acids. Kafirin is alcohol soluble as well.\textsuperscript{[18]} Sorghum is substituted with whole-grain sorghum in an 80% sorghum diet, nitrogen digestibility dropped from 65.4% to 60.5%, indicating that high fibers of sorghum cultivars may have lesser digestibility of protein. As Prolamin and non-prolamin proteins are two types of proteins found in sorghum. Kafirins, the primary storage proteins, are prolamins, which means they have a lot of proline and glutamine and can be dissolved in nonpolar solvents like aqueous alcohols. Overall, sorghum prolamins are high in glutamic acid and nonpolar
amino acids (proline, leucine, and alanine), whereas lysine is nearly non-existent.\textsuperscript{19} Kafirin is the utmost hydrophobic prolamin, and it digests slowly. It prevents celiac disease when consumed because its amino acid sequences differ from those of wheat, barley, and rye.\textsuperscript{2,20} It is more hydrophobic and minor digestible than zein.\textsuperscript{3,17}

Non-kafirin proteins like albumins, globulins, as well as glutelins make up approximately 30% of total protein and are wide-ranging.\textsuperscript{21} It also comprises approximately 77–82% of the protein molecule in the endosperm.\textsuperscript{22} From an evolutionary standpoint, the kafirins are the oldest prolamins, and their early deposition is critical for the configuration and practicable characteristics of the body.\textsuperscript{23}

The incapacity of sorghum kafirins to create an elastic type of dough and the struggle of producing bread that is acceptable to consumers are the problems that have prompted study for the production of high character sorghum-based products which are said to be gluten-free foods.\textsuperscript{24,25} Because of the advancement of cross-linking particularly when wet cooked, sorghum kafirins are poorly digested, resulting in protease resistance.\textsuperscript{3} When heated, the protein digestibility of sorghum flour was reduced from 42.1 to 16.1%, which was the same as the result obtained by Nunes et al.\textsuperscript{26} with the PAN 8564 sorghum variety. The decrease in sorghum protein digestibility improved by heating has been attributed to the formation of disulfide cross connections between β-kafirins and g-kafirins, which are located on the surface of sorghum protein bodies.\textsuperscript{6,27} The digestibility of extracted kafirins improved slightly (approximately 1.1-fold) when sorghum was pressure cooked.\textsuperscript{27} Sorghum flour protein digestibility can be improved through changes in non-covalent connections within protein molecules, as well as a breakdown of SS bonds and a rise in free SH groups, resulting in increased pepsin accessibility.\textsuperscript{28} Increased protein digestibility is critical in sorghum-used populations where protein deficiency is a problem, and fermentation like lactic acid, removal of the outer covering, and dislodgement has been demonstrated to enhance the digestibility of protein and therefore amino acid accessibility.\textsuperscript{29}

The significance of kafirins as a potential source of protein for gluten-free goods has been highlighted in recent years.\textsuperscript{19} Due to the development of disulfide connections between its monomers, kafirins have a high degree of polymerization. After heating, these crosslinks are strengthened, resulting in more polymerized proteins.\textsuperscript{3,30} Due to its potential application in the development of gluten-free products, kafirin has been isolated from a variety of sorghums taking several approaches to create efficient food-grade extraction procedures to isolate functional kafirins. Aqueous ethanol is one of the most commonly utilized extractants in this research, and sodium metabisulfite is the chosen reducing agent for extracting cross-linked kafirins or finely powdered whole or decorticated kernels are the most commonly utilized raw materials to evaluate various extraction methods.\textsuperscript{31–34}

The bioactivity of peptides comprises antioxidants that act as antianxiety, anticancer, antibacterial, immunomodulatory and effects of cholesterol reduction, as well as narcotic characteristics.\textsuperscript{35–38} Unusual properties of kafirin, such as lacking affinity for water tending and indigestibility, have prompted study into a wide range of uses, including biofilm formation and encapsulation.\textsuperscript{39,40}

**Chemistry and structure of kafirin**

The structure of kafirins differs from that of wheat glutenin and gliadin and storage proteins.\textsuperscript{41} Kafirins are kept in protein bodies that are separated from one another. Kafirin protein structure is located around the starch granules which interact with other constituents during processing to produce desired food texture.\textsuperscript{6,42} B-kafirin and γ-kafirin present at the periphery contains high levels of cysteine that form disulfide bonds. While covalently bonded, these proteins form the dense web of protein material that makes up the majority of the outermost layer of the protein body. They have a diameter of 0.4–2 μm. However, some sorghum lines lack the protein body component Beta-Kafirin.\textsuperscript{3} Albumins, globulins, and glutelins form a matrix surrounding the kafirin bodies of protein, causing the protein bodies to attach to the granules of starch. The matrix of protein acts as a hurdle because of crosslinking between gamma and beta kafirins and matrix proteins in starch gelatinization as well as
digestion.\textsuperscript{[21,43]} Alpha kafirins account for almost 81–83% of the total number of proteins in vitreous endosperms and nearly 65–72% in opaque endosperms, while γ-kafirin accounts for 8–13% of the total kafirin fraction in vitreous endosperms and 18–22% in opaque endosperms. Figure 1 shows the structure of kafirins

**Sources of kafirin**

Kafirin was extracted from the whole sorghum grain which is largely cultivated in the terrains of subtropical and tropical. In countries of Africa and Asia (Nigeria and India), it is amongst the chief crops and is used in manufacturing foods like porridge and bread. Particularly, it is used in some semi-arid and under-developed areas. It serves as a major means of nutrition and energy for humans.\textsuperscript{[44]} It is essentially raised for animal feeding in Western countries like Australia, Mexico, and the United States. Though, because of its natural constituents which are good for the growth of functional and healthy foods the interest is being shifted toward raising sorghum for human intake and bio-fuel production.\textsuperscript{[45,46]}

It is famous because of its brilliant agricultural enforcement, which is flexible to burst in various environmental conditions. Such flexibility is exhibited through drought tolerance, heat tolerance also has the strength to thrive in huge peaks as well as salty conditions and depleted soil. It contributes to the root process of sorghum that is well-developed and has a lofty root to leaf correlation, and the leaves of sorghum are also guarded with wax and can likewise curl in light of extrinsic stimulus/hazard.\textsuperscript{[44]} Other than its agricultural benefits, it is free from the grains of gluten, is a wellspring of nutrients and contains a high amount of resistant starch, and above all, houses a wide domain of bioactive phenolic substances.\textsuperscript{[47,48]} In contrast to further prime quality of cereal crops, it carries richer and varied phenolic substances; it holds almost all categories of phenolic substances, as well as flavonoids, complex phenolic acids, and tannins as a presiding class.\textsuperscript{[48,49]}

**Classification of kafirin (α-, β-, γ-kafirin)**

Kafirin is similar to zein concerning its solubility, molecular weight, amino acid composition, and structure.\textsuperscript{[50]} It is drawn out with the help of a reducing agent in an aqueous solution of 70% ethanol.\textsuperscript{[21]} Kafirins are classified as α, β, γ, or δ on the basis of their molecular weight and solubility. Depending on whether it is floury or vitreous, sorghum endosperm contains roughly 66% to 84% α-kafirin, 8% to 13% β-kafirin, and 9% to 21 percent γ-kafirin, as well as small amounts of a poorly characterized γ-kafirin.\textsuperscript{[2]} Alpha-kafirin makes up 80% of the total kafirin and is also regarded as a superior sorghum protein for storage, Beta-kafirin makes up 5% of the total kafirin, while Gamma-kafirin comprises only about 15%. Kafirins make up about 77 to 82% of endosperm protein.\textsuperscript{[2,51]}

Immunological analysis revealed the distribution of the kafirin subclasses inside the spherical protein body of the wild sorghum line: Beta- and Gamma-kafirins are present in black spots inside the body and on the border, forming a shell, protein bodies are deeply folded, difficult-to-digest. Alpha-kafirin protein is found in the central light-staining area.\textsuperscript{[5]} Nonpolar amino acids are found abundantly in α-kafirins and are present essentially as simple and complex compounds. Such proteins

![Figure 1. Structure of kafirins.](image-url)
do not cross-connection substantially and result in the formation of intramolecular disulfide bonds. The beta-kafrin has an excessive amount of sulfur having building blocks of protein like methionine as well as cysteine. They are present in the form of simple and complex compounds. These proteins do not bond chemically extensively and have a major role to play in the making of intramolecular disulfide bonds chiefly. Gamma-kafrin is abundant in cysteine, proline, and histidine amino acids. These are located as polymers and oligomers.\textsuperscript{[19]}

In sorghum, the amount of kafrin has an effect on protein and starch digestion. In comparison to commercial zein (primarily α-zein), total zein and total kafrin contain the cysteine-rich subclasses β- and γ-zein/kafrin.\textsuperscript{[52]} Cysteine has the ability to generate a disulfide bond, which aids in the stability of forms.\textsuperscript{[53]} The high cysteine content of γ-kafrins makes it resistant to pepsin action, reducing digestibility and energy, and has a high affinity for tannin binding. Sorghum grain proteins are also surrounded by γ and β. As a result, if these kafirins have a low digestibility, they can reduce the digestion of proteins, especially those that contain α-kafrins.\textsuperscript{[54]} Furthermore, α-prolamins are low in cysteine, whereas β- and γ-prolamins are high in cysteine. Strong disulfide bonds may be formed by cysteine, making the lamellae that surround the air bubbles stiffer and more elastic.

**Food application of kafrin**

Sorghum had remained a chief source of food production in the early days when fermented porridges were produced in Nigeria followed by Sudan. They were making Nasha, a weaning food. Earlier, chapati (a staple diet of Pakistani and Indian), tortillas, porridges, cookies, and ready-to-eat breakfast cereals were produced as gluten free and cheapest food from sorghum.\textsuperscript{[55]} The demand of gluten free food product has increased with the rising issue of Celiac disease. In 2006, gluten free market was at $700 million and growing rapidly with high rate as reported by Mintel.\textsuperscript{[56]} It is plant source protein cheap than animal sources having functional as well as sensorial attributes therefore supplemented in different food commodities to get desired characteristics.\textsuperscript{[57]} Meanwhile, its characteristics vary based on processing treatments during extractions and product development.\textsuperscript{[58]} However, bulk density is a key parameter to be monitored for packaging, storage and transportation steps.\textsuperscript{[59]} Also, some properties like water absorption and oil absorption vary with the structural and ionic nature of the protein.\textsuperscript{[60]} Whereas, quality of the food products with low or free gluten has not attained as per consumer demand while it generated obstacle on its replacement because it is structure forming protein in bakery goods, therefore, its replacement or cut off will results in poor baked products as well as their fresh life.\textsuperscript{[61]} Pre-cooked pasta with the incorporation of sorghum flour has been developed using extrusion technology, cooking method and forming,\textsuperscript{[62]} but the cooking quality was similar to the wheat incorporated pasta. Whereas, sorghum flour based noodles were reported to depend on starch for their excellent properties,\textsuperscript{[63]} further, the quality of pre-cooked sorghum based pasta developed by Cheng and others\textsuperscript{[62]} can be recognized to change of proteins in the extrusion method. (Figure 2) The food application of kafirins is shown in Table 1.

**Heath properties of kafrin**

The possible functional dominance for human health is linked with the utilization of such substances obtained from sorghum, and its complete grain is unrevealed. Sorghum is considered to be a superb origin of bioactive substances which is beneficial for the health of human beings. Different studies have demonstrated that substances obtained from sorghum chiefly phenolic are vital for human health as it helps in eradicating various long-lasting non-communicable conditions like excessive fat accumulation, hyperglycemia, dyslipidemia, heart-related disorders, cancerous diseases, rapid loss in weight, controlling the cholesterol level, triacylglycerol, increased level of lipoprotein-cholesterol, low-reduced level of lipoprotein-cholesterol, fasting glucose, control of glycemic index, fasting insulin, insulin feedback, oxidative limits, exaggeration, interleukins, gut microbiota and increased level of anxiety and tension.\textsuperscript{[14,71–78]}
The beneficial character of sorghum makes this cereal crop much more interesting as a grain for eating. It is considered a food product utilized by weak people so various plans have been put up which increases the nutritional characteristics of this cereal crop especially its protein as well as micronutrient status to satisfy the dietary demands of such weak populations which are considered to be vital. Functional dominance of sorghum is chiefly signed to oligomers, as they are the topic of higher demand. The complex compounds of tannins present in food items make about up 19% of the antioxidant content of the human diet. It is very beneficial for human beings because of its cancer-
related, immunity-boosting, antioxidant, anti-radical, anti-drug, blood vessels widening, protective covering of the heart, blood clotting reduction, and anti-ultraviolet activity.\textsuperscript{[44,80,81]} Figure 3 show the health properties of kafirins

**Sorghum and its protein role in CVD (Cardio Vascular Disease)**

The grains of Sorghum consist of several bioactive hydroxylated aromatic ring-containing compounds, and these compounds have a major role to play as a protective cover against the damage of several heart-related diseases and dyslipidemia. Lipid Sorghum having polycosanols and phytosterols is improved the health of the heart by coordinating the assimilation, elimination, and integration of cholesterol. For instance, intake of a diet containing sorghum lipids is enhanced the secretion of cholesterol and its end products, and thus resulted in lessening the amount of liver cholesterol and the plasma.\textsuperscript{[82–84]} Lipids of Sorghum have a great impact on the gut microbiota, like lowering the family of *Coriobacteriaceae*, which results in lowering the assimilation of cholesterol.\textsuperscript{[85]}

Phytosterols are considered as one of the important bioactive substances obtained from sorghum lipid molecules which enables them to eradicate the assimilation of cholesterol. Various studies have elaborated that phytosterols separated from other food items obstructed the assimilation of

| Kafirins sources | Kafirins types | Vitro/vivo Model | Reduce risk | Authors |
|------------------|----------------|------------------|-------------|---------|
| Sorghum flour    | α-kafirins     | Vitro/vivo       | hyperlipidemic rats | Reduce the risk of CVD [127] |
| Bicolor flour    | –              | Cell culture     | THP-1 human mononcytic leukemia cells | anti-inflammatory [128] |
| Sorghum flour    | –              | Vitro            | THP-1 human macrophages | Reduce inflammatory response in THP-1 human macrophages [129] |
| Sorghum hybrid   | α, β, and γ-kafirins | – | Human | nontoxic for celiac patients [41] |
| White sorghum grain | – | Vitro/vivo Organotypic cultures | Human skin | Anti-inflammatory and anti-aging [130] |
| White sorghum flour | – | Vitro | HepG2 cell | Antioxidant and anticancer [131] |

Figure 3. Functions of kafirins in human body against different diseases.
cholesterol in human beings, which leads to the maximization of fecal elimination and lessened the level of plasma LDL.\cite{86,87} Phenolic substances of Sorghum also have a vital part to play in the metabolism of cholesterol. Recent work has proved that the execution of phenolic compounds of sorghum concentration greatly reduces the plasma cholesterol and triacylglycerol value in highly obese people.\cite{78,88}

Results show that the whole grain of sorghum and its constituents (phenolic contents) have positive impacts on the health of human beings. This assistance is chiefly acquired from the antioxidant aftermath of phenolic substances, which helps in inhibiting the chain of bad oxidative chain feedback and also lessens the absorption of food by its gradual digestible protein as well as starch and their coordinate complex with the phenolic substances. These substances help in lessening the level of cholesterol grabbed in the narrow channel of enterocytes by holding back its penetration into micelles and results in lessening the assimilation of cholesterol.\cite{89}

Furthermore, the molecules of lipid Sorghum also result in disturbing the assimilation, structure, and elimination of endogenous cholesterol. The bioactive substances of Sorghum which includes polycosanols as well as phytosterols disturb the metabolism of cholesterol through the same procedure which is used for substances abstracted from other plants. The feasible metabolic route damaged by the sorghum lipid molecules, which includes the expression of protein as well as genetics is still not fully explained and understandable. Sorghum lipid molecules and Sorghum phenolic substances also alter the cholesterol metabolism while the procedure involved in the functional assistance has not been cleared.

**Sorghum kafirin valuable role in Hyperglycemia**

Sorghum consists of beneficial carbohydrates which contain an excessive amount of resistant starch (RS) as well as SDS parts, which are linked with beneficial characteristics in human work.\cite{90–93} The excessive amount of RS and SDS in sorghum can assist the observation of the consumers for an extended period, possibly removing the abundance of snacking as well as intake of calories, that results in lessening the glycemic mark,\cite{92} and also lowers the exposure of getting long-term diseases including diabetes and obesity. The capability of having a diet of sorghum helps in reducing the hyperglycemia which brings about sorghum as an old grain cereal crop.\cite{93}

Oxidative limits and higher weight of body are the important agents that advance toward the evolution of insulin counteraction, accumulation of fats in the arteries, deep-rooted minor-level of inflammation, glucose disposition, and kind II diabetes mellitus as well nonalcoholic fatty liver conditions. Bran of sorghum consists of a large number of phenolic compounds, dietary fiber, antioxidant content as well as a reduced glycemic mark.\cite{94} Foods with a large glycemic mark account for an active and increased glucose elimination and are directly linked with higher exposure to diabetes, while the reduced glycemic mark foods consist of moderate-digesting carbohydrates and it results in slowing down and decreasing the amount of blood glucose. It has been declared that the grains of sorghum have reduced digestibility of starch as a match-up to maize and different types of cereal crops. The genotypes of sorghum with increased tannin as well as phenolic amount are linked with the hindrance of enzymes as well as starch molecule contact. It results in destroying the digestibility of starch, enhancing the counteraction of starch, and lessening the glycemic mark in food items.\cite{13}

Hyperglycemia which is linked with diabetes results in serious disorders such as nephropathy and retinopathy. Remedy to lower the hyperglycemia hinders α-amylase as well α-glucosidase digestive enzymes which holdbacks the assimilation of glucose. Tannin-productive polyphenolic sorghum extracts have an inhibitory action inside and outside against the enzymes of α-amylase and α-glucosidase.\cite{95} Contemporary work shows that the molecules of sorghum regulate the metabolism of glucose in animals because of the activity of the phenolic substances. It is still not accepted that the abstract part obtained from the complete grain and sorghum itself is useful for human beings. The consumption of extracts of sorghum phenolic substances results in lowering the area which comes in the curve of glycemia as well as glucose.\cite{78,88,96}
The process through which the sorghum-related phenolic substances occupy the metabolic route formerly and thereafter the assimilation of simple sugar results in the obstruction and cure of various glycemic conditions in human beings. Recent studies have proved that the extracts result in hindering the outside activities of the enzymes \textit{B. steaothermophilus} \(a\)-glucosidase and the human pancreatic as well as salivary \(a\)-amylase.\textsuperscript{97} A decline in the value for the absorption of glucose with the help of enzymes blockage is the starting step for the process of sorghum on the metabolism of humans. Recent work tells us that phenolic substances also result in disturbing the insulin-dependent route, which includes the absorption as well as the susceptibility of this hormone in human beings.

\textit{Inhibition of inflammation}

Excessive fat accumulation is very dangerous as it has a direct linkage with many non-communicable disorders. Various studies have shown that sorghum having a large amount of tannins results in the reduction of weight in living organisms.\textsuperscript{71,98,99} Adipocytes and increased fat buildup play a crucial role as an inflammatory negotiator in the entire process.

Obesity is characterized by an inflammatory process in the muscular tissues, which has prompted much research into the inflammatory process in obesity.\textsuperscript{100} Rapid weight reduction can be beneficial against excessive fat accumulation in human beings. The rapid reduction of weight in animals that are given sorghum-rich tannins helps in forming a coordination complex of this compound to sorghum-rich starch that plays a major part in reducing the intake of calories.\textsuperscript{101}

Moreover, sorghum-rich tannins can put down the digestion of starch by hindering the enzymes of saccharase as well as amylase.\textsuperscript{102–104} One more vital aspect that leads to reducing the weight is the coordination complex of tannins with proteins and digestive inhibiting enzymes like lipases, trypsin, and chymotrypsin.\textsuperscript{54,103–107}

\textit{Sorghum kafirin promote GIT (Gastro-Intestinal Tract) function}

The stomach and the intestine of all the living organisms are filled with multiple numbers of microorganisms particularly bacteria which perform vital functions in the body of human beings related to immunity, normal functioning of the human body, and different biochemical processes which take place in the body of human beings. These micro-organisms have a prominent role to play regarding the healthfulness and the food of the host, as it helps in protecting the host from germs and diseases which affects the whole body of living organisms.\textsuperscript{41,108,109}

Bioactive components of sorghum having biological activity and promoting health condition of human beings have an apparent cause on the gut of micro-organisms living in a wide environment but it is still not prominent as it deserves a lot of attention in the human work. Various documentations tell us about the beneficial causes of non-absorbative compounds having hydroxylated aromatic rings and their intermediate end products as it helps in maintaining the healthfulness of the gut by adjusting the proportion of micro-organisms present in the gut with the help of speeding up the expansion of good bacteria and blocking of bad bacteria using such fibers which humans cannot digest but our gut can digest.\textsuperscript{109–112}

The tannins are the most important substance from all the categories. They are present in an excessive amount and they are processed by the micro-organisms of the colon.\textsuperscript{111} The health beneficial characteristics of various dietary substances having hydroxylated aromatic rings have been the topic of vital importance whereas the causes of these substances on microbiota dysbiosis require more exploration.\textsuperscript{111–113} (Table 2).

\textit{Sorghum protein helpful in celiac disease patient}

Celiac disease (CD) is considered as a long-lived explosive syndrome present in the small intestine of living organisms as it happens due to the taking of great worth of wheat gluten substances like glutamine and
proline which have subparts of glutenin and gliadin as well as similar proteins obtained from the flours of barley and rye. By avoiding gluten protein for a lifetime is the only way of treating Celiac Syndrome. Sorghum is a cereal grain that is considered rain deficient as well as heat-resistant and it cultivates only in semiarid situations. However, it is also used as a feed for the animals found in various Western countries, about 40% of sorghum produced in the world is used as food especially in India and Africa.\[44\]

It is acknowledged as a sound food for the patient with celiac syndrome because it is very familiar with maize as compared to rye, barley, and wheat.\[114,115\] In the modern era, harvesters in the United States have started to produce the hybrids of sorghum from white grain which is obtained from the tan-color plant often known as the “Sorghum Food-grade” as it is used to produce wheat free foods for such human beings suffering from Celiac Syndrome.\[116\] Sorghum is considered as a foundation of gluten-free foods for such people having Celiac Syndrome.

The alone way to treat the Celiac Syndrome is to take such diet having no protein of gliadin, glutenin as well as hordein present in cereals of the group Triticum and similar grains like rye, barley, and triticale.\[41\] The fruit or seed of a bean, its grain, and starchy grains are known as gluten-free and considered as sound for celiac patients which accommodates arrowroot, amaranth, various kinds of pulses, buckwheat, rice, soy, corn, sorghum, mesquite, millet, quinoa, as well as teff.\[41,117–120\] As the treatment of Celiac Syndrome proceeds, the patient is first affected by the shortage of calcium, folate, and iron due to the difficulty in digesting the nutrients present in the small intestine.

Lactose secondary disposition is very frequent in patients suffering from Celiac Syndrome due to lessening assembly of lactase enzyme from inflicted villi present in the small bowel of human beings. The absence of vitamins like A, D, E, K is very frequent. The infection happened in the small bowel recovers and the amount related to the serum and other body fluids comes to its average position after having a gluten-free diet.\[121\]

There are various other gluten-accommodating cereal crops like barley and wheat but only sorghum is acknowledged as free from gluten and it is an encouraging and sound backup source of food for such human beings suffering from Celiac Syndrome. After taking Sorghum food, no manifestation of gastro-intestinal pain has been found in such patients suffering from Celiac Syndrome.\[41,122\] Because of the growing interest in gluten-free meals in Europe and developing countries, it serves as an excellent junction that should be highlighted as a gluten-free food item. It’s also included in gluten-free health foods like cookies and biscuits. The potential of kafirin in celiac disease is presented in Table 3.

### Conclusion

In recent studies, sorghum kafirin has attracted a great deal of interest from researchers and scientists because of its antioxidant potential in both in-vitro and in-vivo research works. The chronic disease places a heavy burden on individual health and healthcare organizations. Kafirins have pharmacological properties that aid in reducing CVD, hyperglycemia and inflammation. The kafirins are present in sorghum flour that protects humans from Celiac Syndrome. Sorghum kafirins shows that it has the

| Table 3. Potential of kafirin in celiac disease. |
|-----------------------------------------------|
| Kafirin source      | In vivo/ In vitro | Health benefit                                                                 | Authors                     |
| Sorghum (Sorghum bicolor (L.) Moench)         | In vivo and In vitro | Biochemical and genetic evidence that sorghum is safe for celiac patients Sorghum-derived products did not show toxicity for celiac patients | \[20\] \[41\] |
| Sorghum             | In vivo and In vitro | The consumption of only gluten free product is the only remedy for celiac disease | \[123\] |
| Rice, corn and sorghum | –              | Gluten free product that may aid in celiac disease                             | \[124\] |
| Sorghum flour       | –              | Gluten-free products                                                            | \[125\] |
| Oat                | –              | Improve the nutritional status of a celiac patient                             | \[126\] |
potential to reduce the risk of CVD. However, future studies are needed for the sorghum kafirin to be used as a biomaterial.

**Disclosure statement**

The authors declare no conflict of interest.

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