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Millets for Health: Nutrigenomic Revelations and Innovative Processing Solutions

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Abstract

Millets are a collection of minuscule grain cereal crops that are cultivated in areas with limited fertility and rely on rainfall for irrigation. Millets are the most practical crops, making them an ideal match for the present circumstances of food insecurity, destitution, nutritional difficulties, and marginal agriculture. These crops are known for their high nutritional value and various test techniques revealed that the millet types had the highest antioxidant potential. Millets' antioxidant, anti-atherosclerogenic, anti-hypertensive, anti-inflammatory, hypoglycaemic, anti-tumorigenic, and antimicrobial characteristics have been a boon to human health, and they play an important part in nutrigenomics. Using current research as a foundation, this study delves deeply into millets' nutraceutical characteristics, possible health advantages, and processing.
Millets including Pearl, Finger, Foxtail, Proso, Kodo, Little, and Barnyard Millet are nutritious powerhouses with different protein profiles. These antioxidant-rich grains are hypoglycemic, anti-atherosclerogenic, and anti-inflammatory. Malting, extrusion cooking, and fermentation improve millets' nutritional profiles, making them flexible for cooking. Albumins, globulins, prolamins, and glutelins make about 7-14% of the protein. Millets provide sustainable solutions for global food security and nutritional issues, albeit values vary by variety and processing.

Keywords: Millets, Agriculture, Proteins, Nutrition, Fiber.

I. INTRODUCTION

According to the Food and Agriculture Organization (FAO) in 2018, millets contribute to a mere 2% of global grain output. Furthermore, Asia and Africa collectively account for 95% of the world's millet production. Millets are classified within the Poaceae family-Gramineae. Millet is a widely used name that refers to a collection of small-seeded cereal crops that are grown annually. These crops possess remarkable qualities in terms of their agricultural productivity, ability to withstand different climatic conditions, and nutritional value [4, 5]. There is a significant concentration of protein, fiber and fat in these seeds, which are extremely nutritious.

Pearl, Kodo, foxtail, finger, barnyard, proso, and other millets are the most widely grown. Food, fodder, biofuel biomass, and pharmaceutical additives are their main uses. The cultivation of each of these millets is not only pest-free but also requires low expenditures, and it has greater water- and nitrogen-use efficiency (WUE and NUE). Each of these millets is nutritionally superior. It is possible that the optimal functioning of the immune system may be achieved by consuming millet grains since they include the appropriate blend of vitamins, antioxidants and minerals. Millets include a high level of resistant starch, which ensures that glucose is released into the bloodstream in a steady and continuous manner. Additionally, millets provide a daily supply of upto 2 to 3 Kilo calories for each individual.

Millets have had a significant influence on the cultural practices of indigenous people in India, such as the Soligas tribe, who lives in the BR Hills, which is situated in the Chamarajanagar district of Karnataka. The "Ragi Habba festival" is a celebration that takes place in these communities to honor the harvest of millets [2]. "Bajre ki roti" is the name given to the chapatis that are made using the majority of the pearl millet flour that is produced in India. A meal known as "Madira ki Kheer" is particularly well-liked in the Indian state of Uttarakhand. This dish is made using porridge made from barnyard millet [6, 7].

Agronomically, millets are advantageous because they can withstand rainfed environments in marginal soils while tolerating biotic stressors, salt, heat, and drought. Approximately 97% of millets worldwide are cultivated and eaten in developing countries, while the remaining portion originates from other regions [10]. The projected global millet production for the years 2019, 2020, and 2021 are estimated to be 28,273,641.59 metric tons, 30,825,151.54 metric tons, and 30,08,9625 metric tons, respectively. Millets serve as a viable alternative to primary cereals, effectively addressing health issues such as obesity and diabetes. Additionally, those with celiac disease can safely incorporate millets into their diet. In 2023, the world will observe the "International Year of Millets" with the objective of promoting knowledge about the advantages of consuming millets, with the ultimate goal of boosting their production and use.

II. GLOBAL CULTIVATION OF MILLETS:

Millets serve as a crucial food supply for millions of individuals and are cultivated in many regions worldwide, such as Asia, South America and Africa. FAO data indicates that millets are cultivated in more than 100 countries worldwide, with India, Nigeria, and Niger ranking as the leading producers. Millets, the second most extensively produced cereal in Africa, are vital in semi-arid rainfed areas.

In Figure 1 we can see the top ten nations that produce millet globally [9].

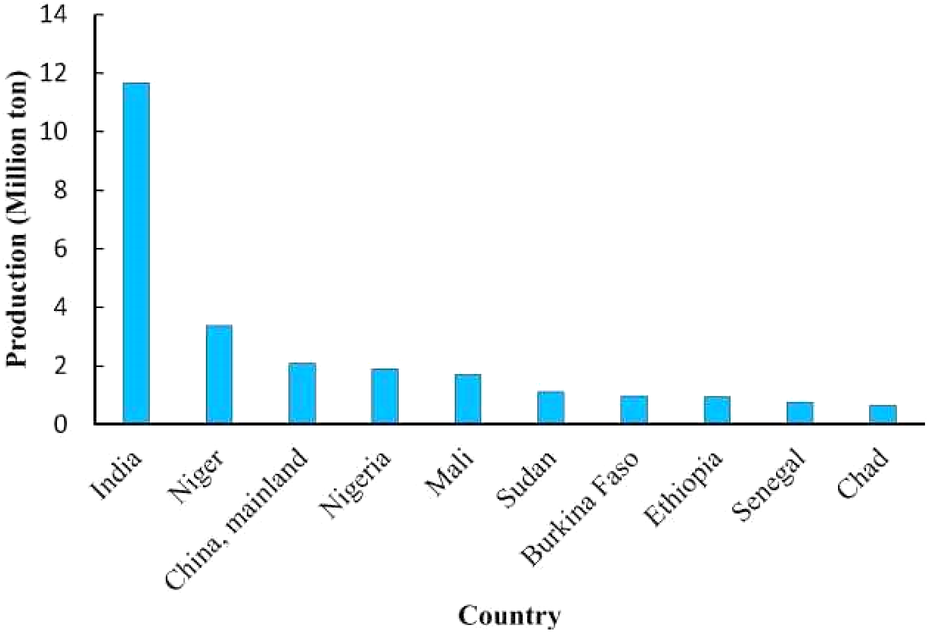

Figure 1: ***Top Millet producing nations.***

2.1. Pearl Millet

Figure 2: ***Pearl Millet plant and processed seeds***

It is well-suited for harsh agricultural circumstances. It was tamed around 4000 years ago and is presently the most extensively cultivated millet. Pearl millet is phosphorus-rich and promotes bone development. Ingesting this substance can alleviate constipation, prevent gastric ulcers, mitigate cardiac ailments, alleviate respiratory issues due to its elevated magnesium content, and facilitate weight reduction. Pearl millet has a significant quantity of insoluble fiber, which helps reduce the body's excessive production of bile and so prevents the formation of gallstones. The pearl millet had greater concentrations of iron and zinc compared to pigeon pea and chicken pea [1]. Additionally, pearl millet also shown increased protein digestibility.

2.2. Finger millet

Figure 3: ***Finger millet*** plant and its processed seeds

There is no gluten in finger millet grains, and they do not produce acid. Additionally, they have a low glycemic index. A large reservoir of calcium and polyphenols. Commonly used as a dietary option for young children and included into recipes using the process of fermentation. This drug has a range of notable advantages, including its anti-diabetic, anti-diarrheal, anti-tumerogenic, anti-ulcer, anti-inflammatory, anti-atherosclerogenic, antioxidant, and antibacterial properties. Considered a "wonder grain" and an essential minor millet commodity, it is extensively cultivated throughout Africa and South Asia. Domestication occurred around 5000 BC. India refers to it as "Ragi" as well.

2.3. Foxtail millet

Figure 4: ***Foxtail millet plant and its processed seeds***

The practice of cultivating foxtail millet in China dates back to 8000 years ago. The name "Foxtail" is derived from its bushy panicle, which has a resemblance to the tail of a fox. This plant is considered the first cultivated species. Additionally referred to as Italian millet, this plant is the focus of scientific investigation due to its compact genome, varied germplasm, and C4 photosynthetic pathway. An abundance of vital amino acids and a high protein content without gluten. Healthy foods for diabetics that are high in polyunsaturated fats (PUFA) and have anti-cancer and anti-lipidemic properties. Semolina, bran oil, bread, snacks, chocolates, baby items, and dietary supplements all make use of it.

2.4. Proso Millet

Figure 5: ***Proso millet plant and its processed seeds***

In addition to being free of gluten, this item is also low in glycemic index, rich in protein, fiber, lecithin, and thiamine, and high in energy (in the form of kilocalories). A possible rise in the concentration of HDL might be brought about by the consumption of HDL. Individuals who suffer from diabetes and heart conditions might benefit from it. shown anti-proliferative activities in cancer cells by demonstration. Millet, also known as broom corn millet, is a crop that is grown on a vast scale in India, China, Africa, Nepal, and Russia. Other names for this crop are black corn millet. Those regions that get a little amount of rainfall and have a limited amount of time for growth are ideal for cultivating this crop. Additionally, it should be able to thrive on arid and less productive terrain. Companies that manufacture birdseed are the primary farmers of this land.

2.5. Kodo millet

Figure 6: ***Kodo millet plant and its processed seeds***

The Deccan plateau of India relies heavily on it as a significant food supply. Paspalum ergot is a poisonous fungal infection that affects both cattle and people, arising from the association between grain and fungus. Because of its resistance to gelatinization, Paspalum ergot is suitable for a wide variety of culinary applications. These applications include the baking of bread and cakes, the preparation of sauces and soups, the extrusion of cereal-based goods, fast set gel, porridge, and instant powders. Because glutelin, a kind of protein, makes up the majority of kodo millet, this grain is an excellent source of dietary fiber from a nutritional standpoint. Presumably, it has a high concentration of antioxidants and phenolics, which are known to inhibit the onset of cancer and reduce the likelihood of cardiovascular disorders.

2.6. Little millet

Figure 7: ***Little millet plant and its processed seeds***

This particular kind of millet is mostly cultivated in arid and semi-dry regions of India, which are prone to experiencing drought. To a considerable extent, it is used for the purpose of cooking, particularly among those who are struggling financially. This particular plant is cultivated not only in India, but also in Nepal, Western Burma, and a few countries in Africa. Phosphorus, iron, phenolics, GABA, sterols, phytates, lignans, and resistant starch are all present in significant quantities in this substance by the way. As a result of enhancing the immune system, increasing healthy cholesterol levels, and slowing digestion, consumption is advantageous for diabetic patients.

2.7. Barnyard Millet

Figure 8: ***Barnyard millet plant and its processed seeds***

Countries like India, China, Japan, Africa, and Malaysia cultivate it. Continuous crops are cultivated on hillside slopes and other marginal land for agricultural improvement. It is now widely recognized as a crucial crop for livestock feed and fodder. Abiotic stresses and marginal terrain are no match for its remarkable adaptability.

One way to look about barnyard millet is as a functional grain. Millets include tannins, steroids, glycosides, and alkaloids, which have anticarcinogenic, anti-inflammatory, antibacterial, and wound healing properties. Reducing cholesterol and blood sugar levels is one of its primary benefits. A great substitute for rice, it's high in fiber.

Millets include a significant amount of unsaturated fatty acids, minerals, iron, energy, phytochemicals, and phosphorus, among which components phenol are particularly abundant. According to a study that was conducted in the tribal areas of the Adilabad district in India [2], it was found that a supplemental weaning malted meal sample that was high in energy and contained wheat, sorghum, soybeans, and ragi had the potential to increase the growth of children, newborns, and nursing mothers, as well as prevent malnutrition. Millet-based items may be found in the Indian market, and some of the products that are accessible include millet muesli, dosa mix, flour, multigrain chocolate malt, rava, porridge, chikkis, cookies, flakes, pops, organic baby food, and roti. In the Indian state of Karnataka, millet-based meals like chakli, papads, and fermented "Paddu" are not only exceptionally nutrient-dense but also have the potential to create a considerable job opportunity [9]. These meals are just a few examples.

III. VARIOUS NUTRIENT COMPOSITION OF DIFFERENT MILLETS

A tabulated overview of the nutrient composition for Pearl Millet, Finger Millet, Foxtail Millet, Proso Millet, Kodo Millet, Little Millet, and Barnyard Millet. The values are given per 100 grams of raw millet:

Table 1: ***List of nutrient composition of per 100 grams of raw millets***

Nutrient	Pearl Millet	Finger Millet (Ragi)	Foxtail Millet	Proso Millet	Kodo Millet	Little Millet	Barnyard Millet
Calories (kcal)	378	336	349	354	329	360	342
Carbohydrates (g)	72	72	73	71	65	68	72
Protein (g)	11	7	11	12	8	7	11
Fat (g)	4	1	4	4	1	1	3
Fiber (g)	8	3	6	2	9	7	6
Calcium (mg)	8	344	31	20	35	17	11
Iron (mg)	4.7	3.9	2.8	2.6	1.2	1.5	11

Magnesium (mg)	0	0	0	0	0	0	0
Phosphorus (mg)	285	290	296	0	172	0	0
Potassium (mg)	0	0	0	0	0	0	0
Sodium (mg)	17	34	5	4	12	1	18
Zinc (mg)	3.1	2.7	2.8	0	1.2	0.9	0.5
Copper (mg)	0.1	0.1	0.1	0.3	0.2	0.1	0.2
Manganese (mg)	1.6	1.6	2.6	0	0.3	0.5	0.0
Selenium (mcg)	8.2	8.3	4.2	0	0.7	0.8	0.0
Vitamin C (mg)	0	1.6	0	1.7	0	0.0	0
Thiamine (B1) (mg)	0.4	0.1	0.4	0.2	0.1	0.1	0.1
Riboflavin (B2) (mg)	0.3	0.2	0.1	0.1	0.1	0.0	0.1
Niacin (B3) (mg)	4.7	1.2	2.8	1.3	2.6	1.3	6.6
Pantothenic Acid (B5) (mg)	0.9	0.6	0.6	1.3	0.8	0.5	1.0
Vitamin B6 (mg)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Folate (B9) (mcg)	34	16	24	18	15	15	36
Vitamin E (mg)	0.5	1.0	0.1	0.7	0.5	0.0	0.0
Vitamin K (mcg)	0.7	0.9	9.7	0.0	0.6	0.9	0.0

It is important to keep in mind that the figures shown here are approximations and may change depending on a variety of variables, including the processing techniques, growing circumstances, and the exact variety of millet.

3.1. Features of the proteins in millet seeds

In millet, protein makes up around 10% of the total weight and is the second most prevalent ingredient after starch. The total protein content of many species of millet seeds ranges from 7.52 percent to 12.1 percent, which is comparable to the protein content of rice and wheat. There are a number of factors that influence the concentration, content, and quality of millet protein. These factors include species, cultivar, anatomical distribution, growing circumstances, and agricultural techniques such as the quality of the soil, the availability of water, chemical inputs, and growth temperatures.

3.2. Composition and distribution of Proteins in Millets

The endosperm portion of the millet seed is the most abundant source of protein due to its size relative to the other seed components. The granular structures known as amyloplast contain starch, whereas the cytoplasmic proteinaceous matrix coexists with endospermic proteins in protein bodies. A portion of the seed's total protein composition is accounted for by enzymes found in the bran and embryo portions, which assist metabolism. So, storage proteins and enzymatic proteins are the two main categories of grain proteins according to distribution and function.

Glutamin, albumin, prolamin, and globulin are millet seed proteins. The cultivar, species, and analytical extraction procedure may affect these proteins' relative levels. The detergent-reducing agent approach that Landry and Moureaux developed for the purpose of extracting polymeric cross-linked proteins contributed to the development of yet another well-established category. Solubility is a factor that determines the protein content of miso. By weight, foxtail millet, sorghum, pearl millet, barnyard millet, proso millet, and small millet all have 12 percent of protein. Kodo millet comes in second with 11 percent, while finger millet has 9 percent.

Table 2: ***Protein Content and Distribution in Millets (per 100 grams)***

Millet Type	Total Protein (per 100g)	Albumins	Globulins	Prolamins	Glutelins
Pearl Millet	10-12	2.6-3.6	1.4-1.9	4.8-5.4	1.5-1.8
Finger Millet (Ragi)	7-10	2.0-2.5	0.5-0.8	1.0-1.2	2.5-3.0
Foxtail Millet	11-12	5.3-6.5	1.3-1.7	2.3-2.7	0.8-1.1
Proso Millet	12-14	2.2-2.9	0.5-0.7	3.8-4.5	2.5-3.3
Kodo Millet	8-11	1.9-2.5	0.6-0.9	1.9-2.5	2.5-3.2
Little Millet	7-12	2.2-3.1	0.6-0.9	1.8-2.3	2.6-3.2
Barnyard Millet	11-12	2.2-2.8	0.5-0.8	2.8-3.4	3.0-3.5

This above table provides a clearer presentation of the protein content and distribution in different millet types.

It has been shown that the water-soluble protein content of pearl millet seed is the highest, followed by that of sorghum, foxtail, and proso millet. Alcohol causes the prolamins to disintegrate. Prolamin was first found in foxtail millet and then in pearl millet. Pearl millet has little crosslinked prolamin percentage, whereas finger millet has a lot [8]. Few millet proteins were extracted using SDS. The millet proteins that were polymeric and crosslinked were isolated by reducing agents. According to the findings of the experiment, the proportion of cross-linked protein in barnyard millet was the greatest, while the percentage in foxtail millet was the lowest.

Chemical solubility demonstrates that prolamin, which is soluble in alcohol and fraction II, and glutelin, which is soluble in alkali, are significant soluble protein fractions in a number of millet species. Different amounts of detergent and a reducing agent, 2-mercaptoethanol (2-ME), are used to form fractions III and IV, which then undergo varying degrees of crosslinking. They provide nitrogen during seed germination and make up 50% of the seed protein reserve. Seed outer layers include low-molecular-weight complex proteins called albumin and globulin. These compounds dissolve easily in water and salt and provide essential amino acids. Recent research shows that seed maturation affects protein content. Young millet seeds have more plant-based proteins than mature ones. The growth stage of millet seeds studied in protein content data is unknown. More study is needed to determine how seed maturity affects protein content.

IV. MILLET PROTEINS APPLICATION

Millet protein has several applications that might be advantageous to various industries, including culinary, pharmaceutical, and industrial sectors. With its notable attributes like as excellent digestion, hypoallergenic properties, and efficient foaming and emulsifying powers, this resource is valuable for a wide range of applications [3].

Millet protein may be used as a functional ingredient to enhance the nutritional content and sensory attributes of many food items. One of the specific applications is in breads and bakery products. Incorporating millet protein into bread dough may enhance its stability, increase the volume of the loaf, and enhance the quality of the crumb. Additionally, it might be used in cakes, muffins, and biscuits to augment the protein and fiber content.

The addition of millet protein to the formulation of pasta and noodles enhances their nutritional profile and texture. Furthermore, it may be used in the manufacturing of gluten-free pasta and noodles.

Millet protein is used in a wide range of plant-based meat products, such as meatballs, sausages, and veggie burgers, as meat replacements and extenders. It provides a strong and consistent texture and improves the protein composition of the stated goods.

Smoothies, protein shakes, and other drinks can benefit from the addition of millet protein, which increases their protein content and gives them a further supply of necessary amino acids.

The prospective uses of millet protein in the pharmaceutical sector have also drawn attention. Because of its hypoallergenic qualities, it can be used by people who are allergic to common proteins like wheat and soy. Furthermore, studies have demonstrated the anti-inflammatory, anti-diabetic, and antioxidant characteristics of millet protein, indicating its possible application in the creation of nutraceuticals and functional meals.

Researchers are looking at the possibility of using millet protein in a number of commercial applications, such as bioplastics. Biopolymers made of millet protein can be utilized to make environmentally friendly and biodegradable plastics.

As a natural adhesive, millet protein finds utility in a variety of contexts, including packaging and construction.

Due to its moisturizing and skin-conditioning attributes, millet protein can be integrated into cosmetic formulations, including creams and lubricants.

In general, millet protein shows promise as a component with several possible uses in many industries. We may anticipate a rise in the use of millet protein across a range of products and sectors as more is learned about its special qualities and advantages.

V. INNOVATIVE PROCESSING SOLUTIONS OF MILLETS

The objective of developing innovative processing techniques for millets is to improve their taste, nutritional value, and adaptability in different food items. These processing techniques may effectively tackle issues such as the presence of anti-nutrients, texture, and sensory characteristics. Although milling and dehulling are widely used, current research is investigating innovative strategies to enhance the efficiency of millet consumption. Below are few cutting-edge processing options for millets:

5.1. Malting

Malting is the process of inducing germination in millet grains, which triggers the activation of enzymes responsible for breaking down complex chemicals into simpler ones. This technique enhances the bioavailability of nutrients, particularly minerals and B-vitamins.

5.2. Extrusion Cooking

Extrusion cooking is a thermal processing technique that involves subjecting millet-based goods to high temperatures for a brief duration. This strategy has the capacity to improve the sensory attributes of the items. It enhances the capacity to metabolize food, reduces impediments to nutrient assimilation, and enables the production of various items like snacks and breakfast cereals.

5.3. Fermentation

Fermentation utilizes microorganisms to break down complex carbohydrates and enhance the nutritional profile of millets. Fermented millet products, such as dosa and idli, are not only nutritious but also known for their unique flavors.

5.4. Sprouting

The sprouting of millet seeds involves the germination process, which leads to an increase in certain nutrients, such as vitamins and minerals. Furthermore, this approach might potentially reduce the levels of anti-nutrients, hence improving the nutritional composition and digestibility of millets.

5.5. Popping

When millet seeds are popped, they acquire a delicate and crisp feel. Puffed millets may serve as garnishes in salads or yogurt, imparting a distinctive texture and elevating the overall sensory perception.

Micronization refers to the process of reducing the size of particles or substances to a very small scale, typically in the range of micrometers or nan

5.6. Micronization

Micronization is the process of subjecting millet grains to heat and pressure, which leads to a final product that has enhanced nutritional properties, shorter cooking time, and greater digestibility.

5.7. Instantization

Instant millet products are specifically formulated for rapid and convenient preparation. These goods often use pre-cooking and dehydration techniques, which decrease the amount of time customers need to spend on meal preparation.

5.8. Composite Flour Formation

Combining millet flours with other flours that do not contain gluten, such as chickpea or rice flour, may improve the functional characteristics of the resultant mixture, making it appropriate for a broader array of uses, including baking.

5.9. Encapsulation

In the context of object-oriented programming, the term "encapsulation" refers to the act of enclosing data and methods inside a single unit that is specifically referred to as a class. Encapsulation methods may be used to safeguard delicate nutrients throughout the process of handling and preservation. This guarantees the preservation of the nutritional advantages of millets over an extended period.

5.10. Extraction of Bioactive Compounds

Current research is investigating novel techniques to extract bioactive chemicals, including phenolic compounds and antioxidants, from millets. These chemicals enhance the health benefits of millets.

5.11. Nanotechnology Applications:

Research is now exploring the potential of nanotechnology to improve the absorption of nutrients and enhance the sensory qualities of millet-based goods.

Ongoing research is focused on developing scalable and economically feasible processing techniques for millets, with the goal of making them more accessible and attractive to a wider range of consumers.

VI. CHALLENGES IN CULTIVATION OF MILLETS

Smallholder farmers in marginal regions mostly cultivate millets because of their strong nutritional value, high feed value, and economic potential. The potential of millet to increase food security and decrease poverty is, unfortunately, hindered by a variety of issues with its cultivation. The main problem with millet farming is that there aren't any better varieties or production methods available apart from this there are few more- awareness, Low production, Diseases and pest, decrease of cultivating land, climate change and uncertainty, market opening is very limited, very few investments in research and development and labor problem etc [6].

VII. CONCLUSION

Researchers found that little millets had an energy value between 330 and 362 kcal, which is on par with or slightly higher than rice and sorghum. Due to their nutritional properties, millets have the ability to be transformed into nutraceutical meals that promote long-term health. The government, corporations, and NGOs will need to collaborate to promote millet growing and keep production methods sustainable. Marketing millets as a substitute for other cereal crops is important, as is creating new value chains to link farmers with buyers and sellers. The underutilization of millet, a coarse grain seed crop, persists among farmers. Researchers have been focusing on its optimal human dietary use for decades, but their findings have not permeated communities or businesses. The protein and other seed components that may have medicinal uses have hitherto been underutilized since millets are mostly used as animal feed or as a substitute for wheat and rice when these grains are unavailable. Additionally, additional research is needed to determine if the various millet types' extraction processes result in protein compounds with different functions. Despite their little size, millets have the potential to provide a high protein output due to their low production costs and simplicity of growth. This is particularly true in warm and dry places, which is why they are being used for biodegradable goods and food all over the world.

Millets provide a range of nutrients and may be processed in creative ways, making them a potential answer for improving human health and correcting nutritional inadequacies. Millets' distinct protein compositions and distribution, together with their abundance of antioxidants, make them important additions to a sustainable and healthy diet. Additional investigation and widespread acceptance of these grains may have a crucial impact on enhancing worldwide food security and promoting a more healthful society.

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Conflicts of Interest

The authors declare no conflict of interest.

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