COMPARATIVE EVALUATION OF NUTRITIONAL QUALITY ATTRIBUTES OF MILLETS IN COMPARISON WITH WHEAT AND RICE

ANURATHA, A.[1] – KRISHNAN, V.[2*] – CHITRA, M.[3*] – SHIBI, S.[1] – TAMILZHARASI, M.[2] – KAMALASUNDARI, S.[4] – SANGEETHA, M.[5] – ARULSELVI, S.[6] – AHILADEVI, P.[1] – RAVI, G.[1]

[1]Agricultural College and Research Institute, TNAU, Keezhvelur, Nagapattinam, Tamil Nadu, India

[2]Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

[3]Dr. M. S. Swaminathan Agricultural College and Research Institute, Tamil Nadu Agricultural University, Eachangkottai, Thanjavur District, Tamil Nadu, India

[4]Dryland Agricultural Research Station, Tamil Nadu Agricultural University, Chettinadu, Sivagangai, Tamil Nadu, India

[5]Regional Research Station, Tamil Nadu Agricultural University, Paiyur, Krishnagiri District, Tamil Nadu, India

[6]ICAR – Krishi Vigyan Kendra, Tamil Nadu Agricultural University, Thiruvarur District, Tamil Nadu, India

**Corresponding authors*
e-mail: anurathakrishnan66@gmail.com; mchitrabiochem@gmail.com, chitram@tnau.ac.in

(Received 6th Feb 2024; accepted 16th Jul 2024)

Abstract. Globally, millets are small-seeded grasses cultivated for human consumption and livestock feed. They thrive in low rainfall regions, poor soil quality, and challenging terrains. Millets are a healthy food choice due to their high nutrient content, including proteins, soluble fiber, vitamins, and minerals such as copper, magnesium, phosphorus, and manganese. Compared to major cereals, millets are packed with antioxidants and essential amino acids. They have a low glycemic index (GI) due to their high complex carbohydrate content, which provides a healthier option than conventional wheat flour. Millets support a healthy gut microbiome, reduce constipation, and decrease excessive gas. Their soluble fiber helps lower "bad" cholesterol levels, reducing the risk of atherosclerosis, and produces a gel in the stomach that alleviates ulcer conditions. Millets serve as nutrient-dense foods and are nutritionally assessed across six attributes: carbohydrates, protein, fat, fiber, vitamins, and minerals. In this review and comparative statistical evaluation of eight millets with Rice and Wheat, the overall ranking for all six nutritional attributes was derived using the Smith Selection Index. The top five ranked grains were Finger millet (first rank), Pearl millet (second rank), Wheat (third rank), Foxtail millet (fourth rank), and Kodo millet (fifth rank). First ranked Finger millet: Finger millet is superior to Rice and Wheat for protein quality, fiber quality, and mineral profile; superior to Rice for vitamin profile; and superior to Wheat for carbohydrate quality parameters. Additionally, Finger millet surpasses Foxtail millet, Sorghum, Little millet, Kodo millet, and Pearl millet in carbohydrate quality; Sorghum in protein quality; Kodo millet, Proso millet, Pearl millet, and Sorghum in fiber quality; and Sorghum in mineral profile. Second ranked Pearl millet: Pearl millet is superior to Rice and Wheat for protein and fiber quality, as well as for vitamin and mineral profiles. It also surpasses Wheat in carbohydrate quality parameters. Pearl millet is superior to all millets except Proso millet in protein quality; Sorghum in fiber quality; Kodo millet and Finger millet in fat quality; all millets in vitamin profile; and all except Finger millet in mineral profile. Third ranked Wheat: Wheat is superior to Finger millet, Sorghum, and Rice in protein quality; Sorghum and Rice in fiber quality; Rice, Pearl millet, Kodo millet, and Finger millet in fat quality; all millets except Pearl millet and Rice in vitamin profile; and all except Finger millet and Pearl millet in mineral profile. Fourth ranked Foxtail millet: Foxtail millet is superior to Sorghum, Proso millet, Kodo millet, Pearl millet, and Rice in carbohydrate quality parameters; Finger millet, Sorghum, Wheat, and Rice in protein quality; all

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

millets, Rice, and Wheat in fiber quality; all except Barnyard millet in fat quality; Sorghum, Kodo millet, Little millet, and Rice in vitamin profile; and Little millet, Kodo millet, Sorghum, Proso millet, Barnyard millet, and Rice in mineral profile. Fifth ranked Kodo millet: Kodo millet is superior to Pearl millet and Rice in carbohydrate quality; all millets except Proso millet and Pearl millet, Rice, and Wheat in protein quality; Proso millet, Pearl millet, Sorghum, Rice, and Wheat in fiber quality; Finger millet in fat quality; Little millet, Proso millet, Barnyard millet, and Rice in vitamin profile; and Sorghum, Proso millet, Barnyard millet, and Rice in mineral profile. Tenth ranked Rice: Rice holds the lowest rank, indicating its inferiority to all millets and Wheat in overall nutritional attributes. However, Rice is superior to all millets and Wheat in carbohydrate quality parameters but inferior to all millets except Sorghum in protein quality; inferior to all millets and Wheat in fiber quality; inferior to all except Pearl millet, Kodo millet, and Finger millet in fat quality; all except Proso millet and Barnyard millet in vitamin profile; and inferior to all millets and Wheat in mineral profile.
Keywords: *attributes, nutritional quality, selection index, nutrients comparison, millets, rice, wheat*

Introduction

In India, millets have been mentioned in some of the oldest Yajurveda texts, indicating that millet consumption was very common, pre-dating to the Indian Bronze Age (4500 BC). Millets are classified into two categories: major millets and minor millets. Major millets, including Jowar (*Sorghum bicolor*) and Pearl millet or Bajra (Pennisetum glaucum), are found in abundance and grown in large quantities by farmers (USDA, 2019). These are relatively easy to grow, though proper irrigation is essential for cultivating these varieties.

Minor millets include Finger millet (*Eleusine coracana*), Foxtail millet (*Setaria italica*), Barnyard millet (*Echinochloa frumentacea*), Kodo millet (*Paspalum scrobiculatum*), Proso millet (*Panicum miliaceum*), and Little millet (*Panicum sumatrense*). Millets are highly resistant to harsh conditions and are sustainable for cultivation. They do not get destroyed easily and remain good for consumption even after 10-12 years, thus providing food security and reducing food wastage. Millets are highly nutritious, non-glutinous, and non-acid forming (Amadou et al., 2013). They act as probiotics, feeding the gut microflora and preventing constipation, excessive gas formation, bloating, and cramping.

They are rich in antioxidants (Chandra et al., 2016) and the essential amino acid profile of millets is better than major cereals. Millets are high in dietary fiber, calcium, iron, potassium and Phosphorus. The nutritional quality of millets under the following headings was discussed.

Carbohydrate quality in millets

The quality of carbohydrates parameters includes starch content per cent (SCP), non-starch content per cent (NCP), Carbohydrate to fiber ratio (CFR), Amylose to Amylopectin ratio (AAR), Glycemic index per cent (GIP) and shape of starch granules. The mean values for these parameters were tabulated from valid sources mentioned below the *Table 1*. The score values of these parameters were decided based on the range of different values and are indicated in *Table 2*. The low starch content is favored against higher non-starch content for better quality carbohydrates. The non-starchy polysaccharides are indication of inert carbohydrates that remain undisturbed during digestion but play active role in preventing constipation during assimilation of digested carbohydrates in our intestine (Krishna Kumari and Thayumanavan, 1998). Similarly, low Carbohydrate to fiber ratio, higher will be the colon health in human (Saldivar, 2003). This condition prevents constipation in small

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

intestines and colon-rectal disorders in human. The lower ratio of amylose to amylopectin indicates the slow release of glucose into the blood stream during digestion. Low amylose/amylopectin ratio indicates the higher amount of amylose with corresponding decrease in amylopectin starch. This results in slow release of glucose in to the blood stream during digestion. Glycemic index (GI) is a measure of how quickly a food can make our blood sugar rise. Only foods having carbohydrates have GI. A low GI indicates the slow release of glucose in to our blood stream. Krishna Kumari and Thayumanavan (1998), Ajibona et al. (2021) and Sukhija et al. (2016) reported similar findings in the minor millets.

Table 1. *Selection index-based ranking of millets for carbohydrate quality parameters in comparison with rice and wheat*

Millet	[1]SCP	[2]NCP	[3]CFR	[4]AAR	[5]GIP	SI	Rank
Sorghum	59.70	12.90	35.35	0.32	61.20	25.77	6
Pearl millet	55.21	12.29	29.13	0.27	56.60	21.52	9
Finger millet	62.13	9.87	20.00	0.19	61.10	27.71	4
Foxtail millet	55.62	5.28	8.99	0.21	54.50	25.96	5
Barnyard millet	58.56	6.94	4.82	0.50	42.30	45.42	2
Kodo millet	60.96	4.94	12.67	0.32	65.40	22.59	8
Proso millet	61.80	8.60	13.54	0.39	55.00	34.78	3
Little millet	56.07	10.93	8.82	0.13	50.20	24.79	7
Rice	70.68	7.52	78.20	0.78	79.60	49.39	1
Wheat	63.61	7.59	35.60	0.56	85.00	5.86	10

SCP: Starch Content per cent; NCP: Non-starch Content per cent; CFR: Carbohydrate/Fiber ratio in per cent; AAR: Amylose/Amylopectin ratio and GIP: Glycemic Index per cent
Sources: 1, 2 & 3- Sorghum and millet in human nutrition, FAO (1991); 4- Gbenga-Fabusiwa et al. (2018); 5- Anitha et al. (2021)
SI: Selection Index-Weightage scores: SCP 2.0; NCP -1.5; CFR 0.5; AAR -0.5 and GIP -1.5

Table 2. *Selection index-based ranking of millets for protein quality parameters in comparison with rice and wheat*

Millets	[1]PCP	[2]PDP	[2]PER	[2]PBV	SI	Rank
Sorghum	10.40	46.00	0.74	37.00	128.28	10
Pearl millet	11.60	94.60	1.60	58.80	227.10	2
Finger millet	7.30	76.00	2.00	52.00	184.60	8
Foxtail millet	12.30	95.00	0.80	48.40	217.10	4
Barnyard millet	6.20	95.30	0.95	54.80	212.05	6
Kodo millet	8.30	96.60	0.90	56.50	219.80	3
Proso millet	12.50	99.30	1.10	52.40	228.55	1
Little millet	7.70	97.70	0.90	53.00	216.75	5
Rice	6.80	66.00	1.67	63.10	179.04	9
Wheat	11.80	81.00	0.79	49.10	195.78	7

PCP-Protein content per cent; PER- Protein Efficiency Ratio; PDP- Protein Digestibility per cent; PBV- Protein Biological Value in per cent
Sources: 1- Sorghum and millet in human nutrition, FAO (1991), Amaduo et al. (2013); 2- Singh et al. (1987), Geervani and Eggum (1989)
SI: Selection Index- Weightage scores: PCP 2.0; PDP 1.5; PER 2.0 and PBV 0.5

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

Ranking of millets for carbohydrate quality attributes

Selection index scores for different carbohydrate quality attributes were derived by assigning weightage as detailed in *Table 1* and *Figure 1*. The highest selection index score was registered by Rice (49.39), taking the first rank, followed by Barnyard millet (45.42) taking the second rank. The next best selection index scores were registered by Proso millet (34.78), followed by Finger millet (27.71), Foxtail millet (25.96), Sorghum (25.77), Little millet (24.79), Kodo millet (22.59) and Pearl millet (21.52), ranking from three to nine respectively. The least selection index score was registered by Wheat (5.68) and hence, it is inferior in carbohydrate quality attributes than Rice and all millets.

The first ranked Rice though had the highest starch content (70.52%) and Glycemic index (79.60%), they comparatively higher non-starch content (7.52%), amylose to amylopectin ratio (0.78) that gave higher selection index score for securing first rank. The second ranked Barnyard millet have lower starch content (58.56%), moderate non-starch content (6.94%), least carbohydrate to fiber ratio (4.82), low Amylose to Amylopectin ratio (0.50) and the least glycemic index (42.30%). The third ranked Proso millet have lower starch content (61.80%), lower Carbohydrate to fiber ratio (8.60), lower carbohydrate to fiber ratio (13.54), moderate amylose to amylopectin ratio (0.39) and moderate glycemic index (55.00%), followed by fourth ranked Finger millet that have moderate starch content (62.13%), moderate non-starch content (9.87%), moderate Carbohydrate to fiber ratio (20.00), low amylose to amylopectin ratio (0.19) and moderate glycemic index (61.10%). The fifth ranked Foxtail millet have lower starch content (55.62%), low non-starch carbohydrates (5.28%), lower Carbohydrate to fiber ratio (8.99), moderate amylose to amylopectin ratio (0.21), and moderate glycemic index (54.50%), followed by sixth ranked Sorghum that have moderate starch content (59.70%), moderate non-starch content (12.90%), moderate amylose to amylopectin ratio (0.32) and moderate glycemic index (61.20%). To conclude, all millets are inferior to Rice, but superior to Wheat in carbohydrate quality attributes. Among different millets, Barnyard millet took top position followed by Pros millet, Finger millet, Foxtail millet and Sorghum for carbohydrate quality attributes. The least performing millet is Pearl millet, followed by Kodo millet, and Little millet (*Figure 1*).

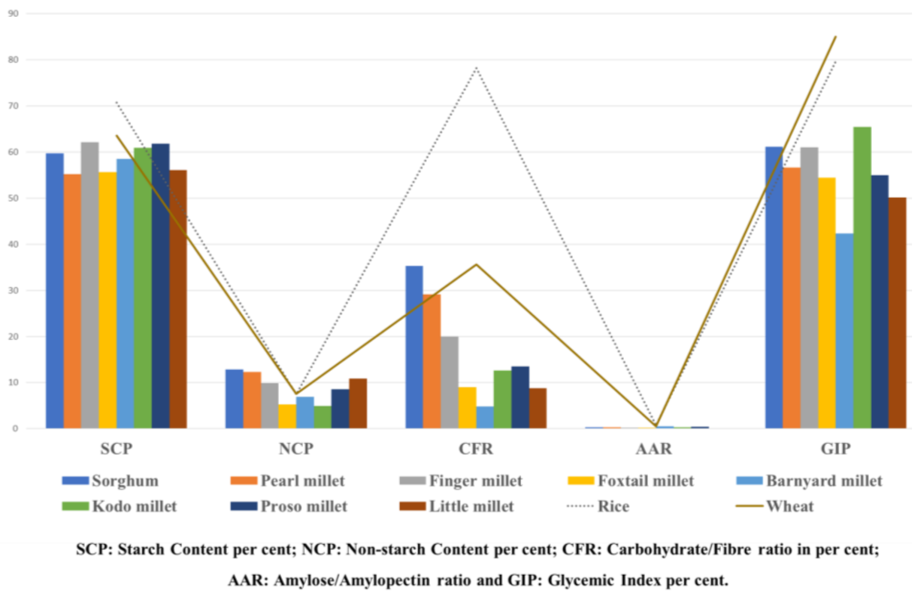


Figure 1. *Carbohydrate quality parameters of millets in comparison with rice and wheat*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

Protein quality of millets

Protein is one of the major nutrients that our body needs to grow and repair cells and to work properly (FAO, 1991). Proteins are the building blocks of body tissue and can also serve as a fuel source (Lopez et al.,2023). Proteins provide 4 kcal (17 kJ) per gram as like Carbohydrates, in contrast to lipids that provide 9 kcal (37 kJ) per gram (Geervani and Eggum,1989). Proteins are composed of amino acids that are classified into essential and non-essential amino acids. Millets are having higher protein content than Rice and Wheat. Protein digestibility per cent is defined as how well a given protein is digested. Along with the amino acid score, protein digestibility determines the values for Protein Digestibility Corrected Amino Acid Score (PDCAAS) value (Devi et al., 2018). Higher per cent of Protein digestibility is an indication of protein quality that a food protein gets easily digested and gets assimilated in the body (Mitchell,1923). Protein efficiency ratio is based on the weight gain of a test subject to the intake of a particular food protein during the test period. Higher the PER value of the protein, the more beneficial it is to the test subject (FAO, 1991). Protein biological value is a measure of the proportion of absorbed protein from a food which becomes incorporated into the proteins of the organism’s body.

Ranking of millets for protein quality attributes

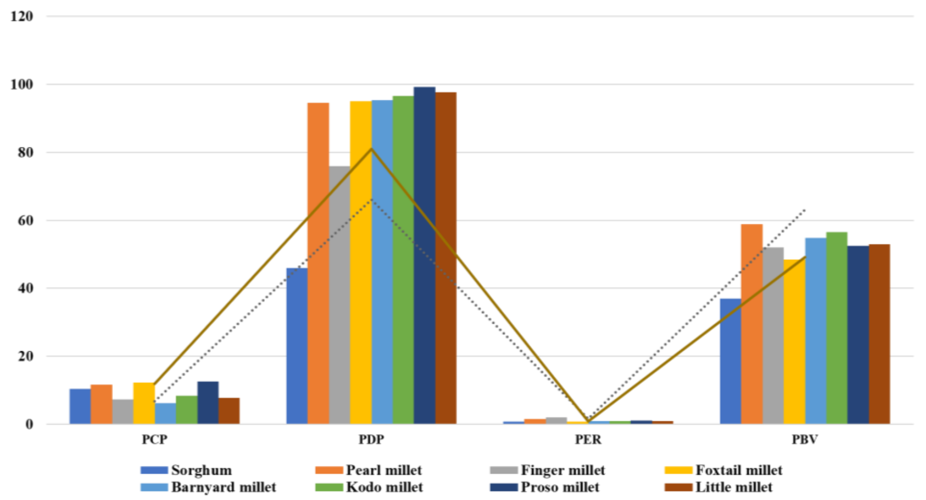
Selection index scores for different protein quality attributes were derived by assigning weightage as detailed in *Table 2*. Based on the selection index scores, the highest performer for protein quality is Proso millet (228.55) securing first rank; followed by Pearl millet (227.10), securing second rank; Kodo millet (219.80), securing third rank (*Figure 2*). The fourth rank is secured by Foxtail millet (217.10), fifth rank by Little millet (216.75) and sixth rank by Barnyard millet (212.05). Wheat occupied seventh place in protein quality attributes, followed by Finger millet (eight rank), Rice (ninth rank) and the least rank by Sorghum. The top performing millet *viz*., Proso millet have the highest protein content (12.50%), the highest protein digestibility (99.30%), moderate protein efficiency ratio (1.10) and high protein biological value (52.40%); followed by Pearl millet that have higher protein content (11.60%) that is equivalent to wheat, higher protein digestibility (94.60%), higher protein efficiency ratio (1.60) and higher protein biological value (58.80%). Similarly, the third ranked millet *viz*., Kodo millet have moderate protein content (8.30%), but higher than rice, higher protein digestibility (96.60%) and high protein biological value (56.50%); followed by the fourth ranked millet *viz*., Foxtail millet that have higher protein content (12.30%), high protein digestibility (95.00%) and moderate protein biological value (48.40%). To conclude, all millets except Sorghum and Finger millet exceeded in protein quality attributes than wheat and rice. Finger millet is superior than rice but inferior to Wheat. Finally, Sorghum is the least protein quality millet inferior to both rice and Wheat

Fiber quality in millets

Dietary fiber is a crucial component of a balanced diet and plays a supportive role in various bodily functions. It originates from plant-based sources and passes through the digestive system without being fully broken down. There are two main types of dietary fiber: water-soluble and water-insoluble. Soluble fiber, such as plant pectin and gums, dissolves in water, while insoluble fiber, like plant cellulose and hemicellulose, does

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

not. Both types are essential for our well-being. These are remnants of plant cell fiber that resist digestion by human digestive enzymes. They encompass cellulose, hemicellulose, lignin, oligosaccharides, pectin, gums, and waxes (Trowell et al., 1985). Dietary fiber enhances the volume of our meals, leading to a quicker feeling of fullness. It also absorbs water and forms a gel-like substance during digestion, which captures carbohydrates and slows down the absorption of glucose into the bloodstream. This promotes the absorption of nutrients, lowers blood cholesterol levels, fosters the growth of beneficial gut microbes, and prevents constipation (Schneemann, 1999). Crude fiber refers to the residual plant material after solvent extraction, followed by digestion with mild acid and alkali. It represents the indigestible components like cellulose, hemicellulose, and lignin in plant-based foods after removing all soluble and easily digestible elements such as sugars, starches, and proteins (Sarmila, 2023). Foods rich in crude fiber offer health advantages to consumers. Crude fiber acts as a natural stool softener, encourages regular bowel movements, prevents constipation, and supports the proliferation of beneficial microorganisms in our intestines. Additionally, crude fiber also reduces cholesterol and blood glucose levels, thereby reducing the risk of chronic diseases (Gbenga-Fabusiwa et al., 2018).



PCP-Protein content per cent; PER- Protein Efficiency Ratio; PDP- Protein Digestibility per cent; PBV-Protein Biological Value in per cent

Figure 2. *Protein quality parameters of millets in comparison with rice and wheat*

Insoluble fiber adds bulk to the stool and appears to help pass more quickly through the stomach and intestine. Insoluble fiber attracts water into our stool, making it softer and easier to pass with less strain on our bowel. Insoluble fiber can promote bowel health and regularity. It also supports insulin sensitivity and like soluble fiber help reduces the risk of diabetes (Norris, 2023). Soluble fiber dissolves in water and gastrointestinal fluids and enters the stomach and intestines. Here it is transformed into a gel –like substance, which is digested by large intestine bacteria, releasing gases and a few calories. Soluble fiber act as fat mimics and spread out as soluble gel and prevent fat absorption, thereby lowering blood cholesterol level. Soluble fiber also limits absorption of glucose into the blood stream, thereby preventing sharp increase in blood glucose level. Soluble fiber rich foods act as feed to beneficial bacteria, as it is fermentable in the colon and helps them to thrive longer (Huizen, 2023). A good diet

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

must contain 3:1 ratio of insoluble fiber: soluble fiber for a healthy life (Gloria Tsang, 2021). This indicates that insoluble fiber must make up 75% and soluble fibers make up 25% of our total diet.

Ranking of millets for fiber quality attributes

Selection index scores for different fiber quality attributes were derived by assigning weightage as detailed in *Table 3*. Based on selection index, Foxtail millet (72.09) ranked first, followed by Barnyard millet (53.58), Little millet (30.48), Finger millet (28.31), Kodo millet (24.11), Proso millet (14.25) and Pearl millet (14.17) (*Figure 3*). These seven millets outperformed both rice and wheat in fiber quality attributes. For Fiber quality attributes, Rice registered a negative selection index value of -65.43 indicating its inferiority over all millets and Wheat, all of them having positive selection index score. The millet Sorghum have the least fiber quality performance that is inferior to both Rice and Wheat. In conclusion, all the millets except Sorghum are superior to wheat as well as Rice for fiber quality.

Table 3. *Selection Index based ranking of millets for fiber quality parameters in comparison with rice and wheat*

Millets	DFC	CFC	IFC	SFC	ISR	CFR*	SI	Rank
Sorghum	10.22	1.60	8.49	1.73	4.91	35.35	5.94	9
Pearl millet	11.49	1.20	9.14	2.34	3.91	29.13	14.17	7
Finger millet	11.18	3.60	9.51	1.67	5.69	20.00	28.31	4
Foxtail millet	19.11	8.00	10.70	0.85	12.59	8.99	72.09	1
Barnyard millet	13.00	9.80	8.40	4.20	2.00	4.82	53.58	2
Kodo millet	6.39	9.00	4.29	2.10	2.04	12.67	24.11	5
Proso millet	6.89	2.20	4.33	2.56	1.69	13.54	14.25	6
Little millet	7.72	7.60	5.45	2.27	2.40	8.82	30.48	3
Rice	2.81	0.20	1.99	0.82	2.42	78.20	-65.43	10
Wheat	11.23	1.20	9.63	1.60	6.02	35.60	9.72	8

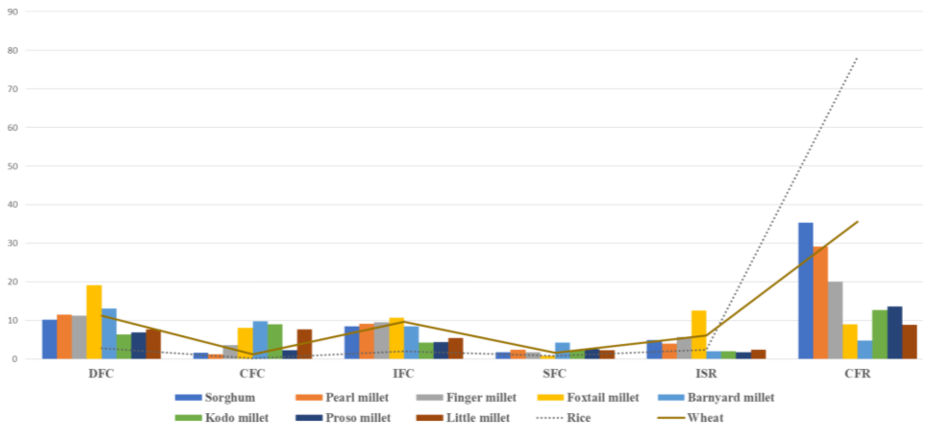
CFC- Crude Fiber Content per cent; DFC -Dietary fiber Content per cent; IFC- Insoluble Fiber content in per cent; SFC- Soluble Fiber content in per cent; ISR- Insoluble to soluble fiber ratio; CFR- Carbohydrate to fiber ratio. *Values taken from *Table 1*
Sources: Sorghum and millet in human nutrition, FAO (1991), Amaduo et al. (2013), Chandra et al. (2016), Saldivar (2003)
SI: Selection Index-Weightage scores: DFC 2.0; CFC 1.5; IFC 1.0; SFC 1.0; ISR 1.5 and CFR 0.5

Fat quality in millets

A fat is a compound consisting of a glycerol backbone and fatty acids. These fatty acids, comprised of chains of carbon atoms, are crucial for the proper functioning of our body’s systems (Kent, 1983). While essential fatty acids must be obtained from food, non-essential ones can be synthesized from them (Thomas, 2000). Essential fatty acids are instrumental in producing hormones that regulate the immune and central nervous systems. They fall into two categories: Omega-3 and Omega-6. Cereals and millets contain Omega-3 fatty acids, like linolenic acid, and Omega-6 fatty acids, such as linoleic acid. Maintaining a ratio of Omega-3 to Omega-6 fatty acids at 1:5 is vital for a healthy lifestyle. Saturated fats are a type of fat with fatty acid chains containing only single bonds, making them saturated with hydrogen molecules. These fats are solid at

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

room temperature. Reducing saturated fat intake and substituting it with nutrient-rich foods can lower the risk of heart disease and promote overall well-being (Thomas, 2000). A higher ratio of unsaturated to saturated fatty acids corresponds to a lower risk of health issues like liver fibrosis (Zhu et al., 2022).



CFC – Crude Fibre Content per cent; DFC- Dietary fibre Content per cent; IFC- Insoluble Fibre content in per cent; SFC- Soluble Fibre content in per cent; ISR- Insoluble to soluble fibre ratio; CFR- Carbohydrate to fibre ratio

Figure 3. *Fiber quality parameters of millets in comparison with rice and wheat*

Omega-3 fatty acids are essential and beneficial for heart health, aiding in reducing triglyceride levels. Since our bodies cannot produce them, we must obtain Omega-3s from our diet. They play a crucial role in normal cellular function, forming a vital part of cell membranes that support interactions between cells (Haris, 2010) Omega-3 fatty acids are particularly important for maintaining a healthy cardiovascular, endocrine, and nervous system, including the brain (Chaddha and Kim, 2015). Omega-6 fatty acids are also essential for human health, but our bodies cannot produce them. Alongside Omega-3 fatty acids, they contribute significantly to brain function, normal growth, and development. They stimulate skin and hair growth, maintain bone health, regulate metabolism, and support the reproductive system (Chandha and Kim, 2015; Ajibona et al., 2021). A narrow ratio of 1:4 or 1:5 of Omega-3 to Omega-6 is crucial for preventing cardiovascular and other chronic diseases. However, achieving such a narrow ratio is challenging in grain crops like millet. Therefore, considering this ratio helps assess the nutritional quality of different millets.

Ranking of millets for fat quality attributes

Selection index scores for different fat quality attributes were derived by assigning weightage as detailed in *Table 4*. Among the eight millets and two cereals assessed, the highest-ranking crop was Barnyard millet (457.60), followed by Foxtail millet (326.91), Little millet (322.97), Proso millet (305.16), and Sorghum (278.47) (*Figure 4*). These millets surpassed both wheat and rice in fat quality attributes. The other three millets, namely Pearl millet, Finger millet, and Kodo millet, were inferior to both wheat and rice. Barnyard millet, which ranked first, has a moderate total fat content (2.20%), equivalent unsaturated (76.60%) and saturated fatty acids (23.40%) comparable to wheat and rice, a low unsaturated to saturated fatty acid ratio (3.27), the least omega-3 fatty acid content (0.35%), high omega-6 fatty acid content (51.20%),

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

and the highest omega-3 to omega-6 fatty acid ratio (146.29). Foxtail millet, ranked second, has a high total fat content (4.30%), high unsaturated fatty acid content (84.50%), low saturated fatty acid content (16.50%), a moderately high unsaturated to saturated fatty acid ratio (5.12), low omega-3 fatty acid content (0.67%), moderate omega-6 fatty acid content (38.20%), and a high omega-3 to omega-6 fatty acid ratio (146.29). Little millet, ranked third, has a high total fat content (4.70%), equivalent unsaturated (77.60%) and saturated fatty acids (22.40%) comparable to wheat and rice, a moderate level of unsaturated to saturated fatty acid ratio (3.46), moderate omega-3 fatty acid content (1.20%), the highest omega-6 fatty acid content (57.60%), and a high omega-3 to omega-6 fatty acid ratio (48.00).

In summary, five millets, in order of superiority—Barnyard millet, Foxtail millet, Little millet, Proso millet, and Sorghum—are superior to both wheat and rice in fat quality attributes. In contrast, three millets—Finger millet, Kodo millet, and Pearl millet—are inferior to both wheat and rice.

Table 4. *Selection index-based ranking of millets for fat quality parameters in comparison with rice and wheat*

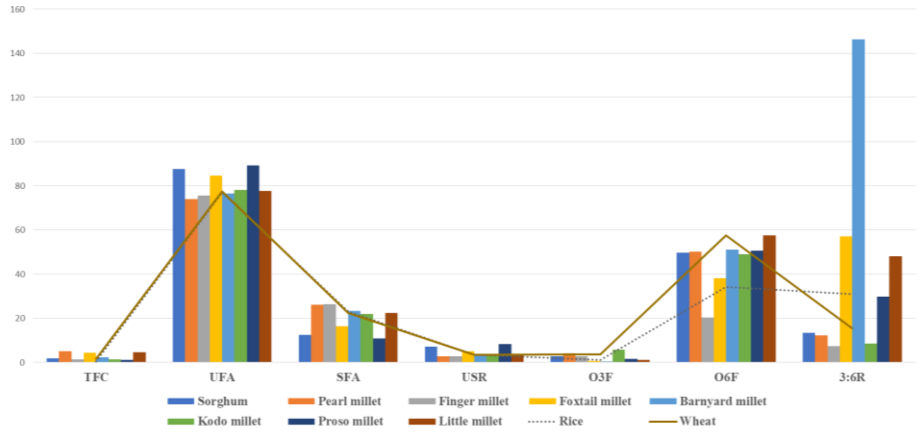
Millets	[1]TFC	[2]UFA	[2]SFA	[3]USR	[4]O3F	[4]O6F	[5]3:6R	SI	Rank
Sorghum	1.90	87.60	12.40	7.06	2.70	49.70	13.43	278.47	5
Pearl millet	5.00	74.00	26.00	2.85	4.10	50.10	12.21	261.78	8
Finger millet	1.30	75.60	26.40	2.86	2.70	20.26	7.50	220.83	10
Foxtail millet	4.30	84.50	16.50	5.12	0.67	38.20	57.01	326.91	2
Barnyard millet	2.20	76.60	23.40	3.27	0.35	51.20	146.29	457.60	1
Kodo millet	1.40	78.10	21.90	3.57	5.76	49.00	8.51	257.75	9
Proso millet	1.10	89.20	10.80	8.26	1.70	50.60	29.76	305.16	4
Little millet	4.70	77.60	22.40	3.46	1.20	57.60	48.00	322.97	3
Rice	0.50	77.00	23.00	3.35	1.10	34.10	31.00	266.70	7
Wheat	1.50	77.50	22.50	3.44	3.70	57.50	15.54	272.99	6

TFC – Total fat Content in per cent; UFA- Unsaturated fatty acid content in per cent; SFA- Saturated fatty acid content in per cent; USR- Unsaturated to Saturated fatty acid ratio; O3F-Omega-3 fatty acid content in per cent; O6F- Omega-6 fatty acid content in per cent; 3:6R- Omega-3: Omega-6 Ratio
Sources: 1- Sorghum and millet in human nutrition, FAO (1995); 2- Ajibona et al. (2021), Zhang et al. (2015); 3- Derived value; 4- Kent (1983); 5-Derived value
SI: Selection Index-Weightage scores: TFC 1.5; UFA 2.0; SFA 1.0; USR 2.0; O3F 1.5; O6F 1.0 and 3:6R 1.5

Vitamin profile in millets

Vitamins are vital organic compounds, or vitamers, closely related molecules that are essential in small quantities for proper metabolic function in organisms. Since these nutrients cannot be produced in sufficient amounts by the body, they must be obtained through the diet (Konings, 2006). Vitamins play a crucial role in supporting growth and enabling the body to function optimally (UNICEF, 2015). There are 13 essential vitamins, including Vitamin A, C, D, E, K, and B vitamins such as Thiamine (B1), Riboflavin (B_2), Niacin (B3), Pantothenic acid (B_5), Pyridoxine (B_6), Biotin (B_7), Folic acid (B_9), and Cobalamine (B_{12}). Cereals and millets contain a maximum of eight of these vitamins, and some millet may lack one to four of them.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561



TFC – Total fat Content in per cent; UFA- Unsaturated fatty acid content in per cent; SFA- Saturated fatty acid content in per cent; USR- Unsaturated to Saturated fatty acid ratio; O3F-Omega-3 fatty acid content in per cent; O6F- Omega-6 fatty acid content in per cent; 3:6R- Omega-3: Omega-6 Ratio.

Figure 4. *Fat quality parameters of millets in comparison with rice and wheat*

Vitamin A, a fat-soluble vitamin, is essential for human health. It encompasses a group of chemically related compounds including Retinol, Retinal, Retinoic acid, and provitamins like carotenoids and beta-carotene. Cereals and millets primarily contain the precursor of Vitamin A, beta-carotene. This vitamin is crucial for embryo development, maintaining the immune system, and ensuring clear vision. Vitamin A deficiency is prevalent in developing countries, particularly among preschool children and pregnant women, affecting about one-third of children under five worldwide (UNICEF, 2015).

Vitamin B_1, also known as Thiamine, is a water-soluble vitamin that plays a pivotal role in cell growth and function. Since only a small amount is stored in the liver, it must be consumed daily for overall health. Vitamin B_1 is involved in fundamental cellular processes and the breakdown of major nutrients for energy. Vitamin B_2, or Riboflavin, is a water-soluble vitamin that acts as an antioxidant, combating free radicals that can harm cells and DNA. This vitamin contributes to the anti-aging process and may help prevent heart diseases and cancer. Riboflavin is also essential for converting Pyridoxine (B_6) and Folate (B_9) into usable forms in the body. It is crucial for the growth and production of red blood cells. Deficiency in Vitamin B_2 can lead to fatigue, digestive issues, mouth sores, eye fatigue, throat swelling and soreness, and sensitivity to light (Fishman, et al., 2000).

Vitamin B_3, also known as Niacin or Nicotinic acid, is an essential water-soluble vitamin for human nutrition. It acts as a coenzyme, supporting over 400 enzyme-dependent reactions. Niacin helps convert nutrients into energy, produce good cholesterol and fats, create and repair DNA, and exert antioxidant effects. Deficiency in this vitamin may lead to pigmented skin rashes when exposed to sunlight, rough skin, a bright red tongue, depression, and memory loss (Stipanuk et al., 2013).

Vitamin B_5, or Pantothenic acid, is a water-soluble vitamin that plays a role in breaking down fats and carbohydrates for energy. It is involved in the production of red blood cells, sex and stress-related hormones, and maintaining a healthy digestive tract. Additionally, it aids in the utilization of Vitamin B_2. Deficiency in this vitamin can lead to irritability, restlessness, disturbed sleep, nausea, vomiting, stomach cramps, and muscle cramps (Konings, 2006).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

Vitamin B_6, or Pyridoxine, is a water-soluble vitamin that acts as a coenzyme in over 100 enzyme reactions, mostly involved in protein metabolism in the body. It plays a role in cognitive development through the biosynthesis of neurotransmitters and helps maintain normal homocysteine levels in the blood (NMCD, 2011). Vitamin B_9, also known as folic acid or folate, is a water-soluble vitamin essential for forming DNA and RNA and involved in protein metabolism. It plays a crucial role in breaking down homocysteine, which in excess can have harmful effects on the body. Folate is necessary for producing healthy red blood cells and is critical during periods of rapid growth, such as pregnancy and fetal development (Alpert et al., 2000).

Vitamin E, or Tocopherol, is a fat-soluble vitamin with various forms, but only alpha-tocopherol is used by the human body. It scavenges reactive oxygen species (ROS), thereby preventing damage to cells and blood vessels that can lead to cardiovascular diseases and cancer. Additionally, Vitamin E inhibits the proliferation of cancerous cells. Deficiency in Vitamin E can result in peripheral neuropathy, ataxia, skeletal myopathy, retinopathy, and impairment of the immune response (Taber, 2006).

Ranking of millets for vitamin profile

Selection index scores for vitamin profile were derived by assigning weightage as detailed in *Table 5*. Based on selection index for vitamin profile, Pearl millet (331.48) ranked first, followed by Wheat (175.38), Finger millet (145.31), Foxtail millet (144.72), Sorghum (140.79), Kodo millet (48.44) and Little millet (21.59). These six millets and wheat were superior to Rice. Two millets *viz*., Barnyard millet (4.63), followed by Proso millet (6.39) are inferior to both Wheat as well as Rice (*Figure 5*). To conclude, only Pearl millet is superior to both Wheat and Rice, while six other millets in the order of superiority *viz*., Finger millet, Foxtail millet, Sorghum, Kodo millet and Little millet are superior to rice, but not Wheat. Two millets *viz*., Barnyard millet followed by Proso millet are inferior to both Wheat and Rice.

Table 5. *Selection index-based ranking of millets for vitamin profile (mg/100 g) in comparison with rice and wheat*

Millets	A	B_1	B_2	B_3	B_5	B_6	B_9	E	SI	Rank
Sorghum	47	0.38	0.15	4.30	1.25	0.21	20.00	12.00	140.79	5
Pearl millet	132	0.38	0.21	2.80	1.09	0	45.50	19.00	331.48	1
Finger millet	42	0.42	0.19	1.10	0	0	18.30	22.00	145.31	3
Foxtail millet	32	0.59	0.11	3.20	0.82	0	15.00	31.00	144.72	4
Barnyard millet	0	0.33	0.10	4.20	0	0	0	0	4.63	10
Kodo millet	0	0.15	0.09	2.00	0	0	23.10	0	48.44	6
Proso millet	0	0.41	0.28	4.50	1.20	0	0	0	6.39	9
Little millet	0	0.30	0.09	3.20	0	0	9.00	0	21.59	7
Rice	0	0.41	0.04	4.30	0	0	8.00	0	20.75	8
Wheat	64	0.41	0.10	5.10	0	0.57	36.60	0	175.38	2

Source: Sorghum and millet in human nutrition, FAO, 1991; Millets in your meals, https://www.shajasamrudha.org/

SI: Selection Index-Weightage scores: Vit A 1.5; Vit B_1 1.0; Vit B_2 1.0: Vit B_3 1.0; Vit B_5 1.0: Vit B_6 1.0; Vit B_9 2.0 and Vit E 2.0

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

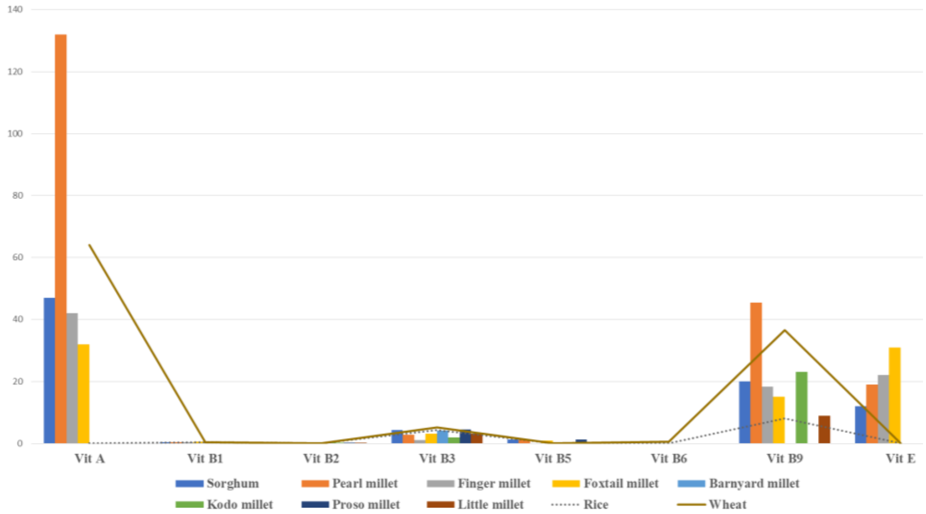


Figure 5. *Vitamin profile of millets in comparison with rice and wheat*

Mineral profile in millets

Minerals are essential chemical elements crucial for various metabolic and structural functions in the body (Thor,2019). They are divided into macro-minerals, which are required in relatively larger quantities (e.g., Calcium, Phosphorus, Magnesium, Sodium, and Potassium), and microminerals or trace elements, needed in smaller amounts (including Iron, Zinc, Copper, Manganese, Selenium, Iodine, Chromium, and Molybdenum) (Shenkin, 2006, Tiwari et al., 2023).

Calcium, the most abundant mineral in the body, forms a significant part of bones and teeth, contributing to their strength and flexibility. Approximately 99% of the body’s calcium is stored in bones, with the remaining 1% distributed in blood, muscle, and other tissues (Thor, 2019). Phosphorus is another crucial mineral found abundantly in the body. It plays essential roles in the structure of bones, teeth, DNA, and RNA, as phospholipids (EFSA, 2019). Additionally, it is a fundamental component of cell membranes and the energy currency of the body, ATP. Phosphorus aids in energy production, pH balance, genetic material synthesis, and the transport of oxygen by red blood cells. It also contributes significantly to the proper functioning of nerve cells and the brain (EFSA, 2013).

Iron is vital for growth and development in the body. It is a key component in the production of hemoglobin, a protein in red blood cells responsible for carrying oxygen from the lungs to all body tissues. Iron also serves as a component of myoglobin, which supplies oxygen to muscles, supporting muscle metabolism and healthy connective tissue. Furthermore, it plays essential roles in physical growth, neurological development, cellular functioning, and the synthesis of certain hormones. Iron deficiency manifests in stages, starting from the depletion of iron stores, progressing to erythropoiesis, and ultimately leading to iron deficiency anemia in humans (Aggett, 2012).

Magnesium is a vital nutrient essential for maintaining various aspects of our health. It plays a crucial role in regulating muscle and nerve function, blood sugar levels, blood pressure, as well as in the production of proteins, bones, and DNA. Prolonged low magnesium intake can lead to symptoms like loss of appetite, nausea, fatigue, and weakness, while severe deficiency can result in more serious issues such

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

as numbness, muscle cramps, seizures, and irregular heart rhythm (Rude, 2012). Manganese, a trace mineral, is necessary for the body in small quantities. It is primarily stored in bones, with smaller reserves in the liver, brain, kidneys, and pancreas. Manganese acts as a coenzyme for numerous enzymes involved in the breakdown of carbohydrates, proteins, and cholesterol. Additionally, it supports enzyme activity related to bone formation, immune function, and reproductive system health. Manganese also collaborates with vitamin K in the blood clotting process, aiding in wound healing (USDA, 2019).

Sodium, an essential mineral required in relatively larger amounts, is crucial for maintaining cellular balance, regulating fluid and electrolyte levels, and managing blood pressure (EFSA, 2019). Potassium, another essential mineral for all tissues in the body, is known as an electrolyte due to its ability to carry a small electrical charge, which activates various cellular and nerve functions. Its main role is in maintaining proper fluid levels within cells, aiding in muscle contractions, and supporting healthy blood pressure (NAM, 2019).

Zinc, a trace mineral needed in small amounts, is essential for nearly 100 enzymes that facilitate critical chemical reactions. It plays a significant role in DNA synthesis, cell growth, the formation of structural proteins, tissue repair, and bolstering the immune system (IM FNB, 2000). Copper, also an essential mineral, acts as a cofactor (or Cuproenzyme) for several enzymes involved in processes like energy production, iron metabolism, neuropeptide activation, connective tissue synthesis, and neurotransmitter synthesis (IM FNB, 2000).

Molybdenum, an essential trace element, is required for the processing of proteins and DNA. It also aids in the breakdown of drugs and toxic substances that enter the body (IM FNB, 2000). Chromium, another essential trace element needed in small quantities, enhances the action of the hormone insulin. It also plays a role in the breakdown and absorption of carbohydrates, proteins, and fats. Vitamins B3 (Niacin) and C assist in the absorption of Chromium in the body (IM FNB, 2000).

Sulphur is an essential mineral element crucial for DNA synthesis, protecting cells against damage, producing sulphur-containing amino acids, regulating gene expression, and supporting normal metabolic processes (FDA, 2010). Chloride, a major mineral nutrient needed in relatively larger quantities, is naturally present in a variety of foods and is commonly consumed in the form of table salt (Sodium chloride). Like Sodium and Potassium, chloride forms specific channels in cell membranes that aid in crucial cellular functions. It plays a pivotal role in maintaining fluid balance in the body, thereby regulating blood pressure and pH levels (EFSA, 2013).

Ranking of millets for mineral profile

Selection index scores for mineral profile were derived by assigning weightage as detailed in *Table 6*. Based on the estimated selection index for mineral profile, Finger millet (2241) ranks first, followed by Pearl millet (1361) securing second rank (*Figure 6*). Rice secured third rank for mineral profile (1316). All other millets in the order of superiority *viz*., foxtail millet (1160), little millet (850), kodo millet (841), sorghum (824), proso millet (809) and barnyard millet (424) are superior to Rice, but inferior to Wheat. To conclude, for mineral profile, Finger millet and Pearl millet are superior to both Wheat and Rice, while Foxtail millet, Little millet, Kodo millet, Sorghum, Proso millet and Barnyard millet are superior to Rice.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

Table 6. *Selection index-based ranking of millets for mineral profile (mg/100 g) in comparison with rice and wheat*

Millets	Ca	P	Fe	Mg	Mn	Na	K	Zn	Cu	Mo	Cr	S	Cl	SI	Rank
Sorghum	25	222	4.10	171	0.78	8.1	131	1.6	0.46	0.039	0.008	54	44	824	7
Pearl millet	42	296	8.00	137	1.15	10.9	307	3.1	1.06	0.069	0.023	147	39	1361	2
Finger millet	344	283	3.90	137	5.49	11.0	408	2.3	0.47	0.102	0.028	160	44	2241	1
Foxtail millet	31	290	2.80	81	0.60	4.6	250	2.4	1.40	0.070	0.030	171	37	1160	4
Barnyard millet	20	280	5.00	82	0.96	0	0	3.0	0.60	0	0.090	0	0	424	9
Kodo millet	27	188	0.50	147	1.10	4.6	144	0.7	1.60	0	0.020	136	11	841	6
Proso millet	14	206	0.80	153	0.60	8.2	113	1.4	1.60	0	0.020	157	19	809	8
Little millet	17	220	9.30	133	0.68	8.1	129	3.7	1.00	0.016	0.180	149	13	850	5
Rice	10	160	0.70	90	0.59	0	0	1.4	0.14	0.058	0.004	0	0	277	10
Wheat	41	306	5.30	138	2.29	17.1	284	2.7	0.68	0.051	0.012	128	47	1316	3

Source: Sorghum and millet in human nutrition, FAO, 1995; Millets in your meals, https://www.shajasamrudha.org/
SI: Selection Index -Weightage scores: Ca 2.25; P 1.0; Fe 2.0; Mg 1.0; Mn 1.0; Na 1.75; K 2.0; Zn 1.85; Cu 1.25; Mo 1.0; Cr 0.5; S 1.0 and Cl 0.75

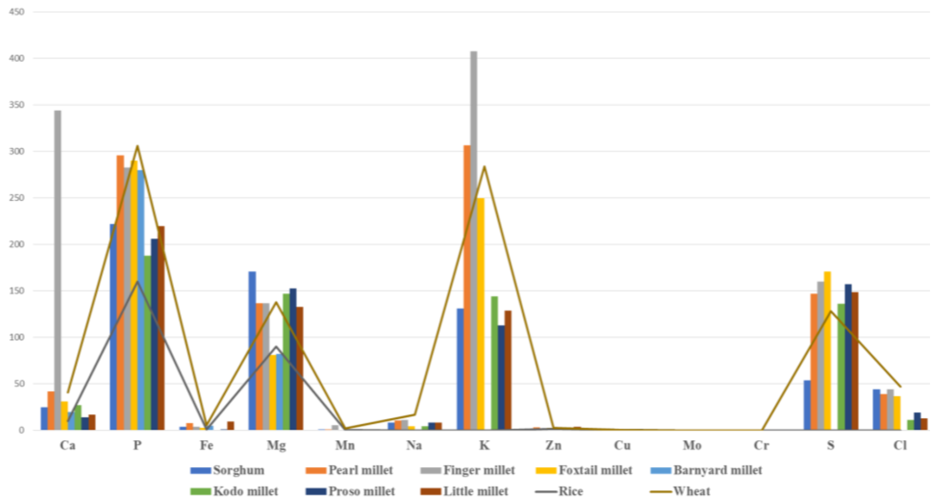


Figure 6. *Mineral profile of millets in comparison with rice and wheat*

Overall ranking for nutritional quality of millets

The Overall ranking for nutritional quality attributes of eight millets and two cereals were derived *via* selection indexing, using the cumulative score value of six different quality attributes *viz.*, carbohydrate, protein, fiber, fat, vitamin profile and mineral profile (*Tables 1–6*) were compared and presented in *Table 7*. Based on the overall ranking, the different millets and two cereals are summarized below (*Figures 7* and *8*).

First ranked finger millet

Based on the overall selection index values, Finger millet secured the first rank with an overall selection index score of 2257. This millet ranked first in Mineral profile, third in Vitamin profile, and fourth in Carbohydrate quality and Fiber quality attributes. However, it placed eighth in Protein quality and last in fat quality attributes. Considering its overall ranking for nutritional quality, Finger millet is superior to all other millets, Wheat, and Rice. The main reason for Finger millet's top ranking is its

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

superior values in vitamins and mineral profiles, and its fiber quality, which is on par with Rice. Finger millet also exceeds Wheat in mineral profile. The superiority of Finger millet over other millets, Rice, and Wheat has been reported by Zhang et al. (2015) and Anitha et al. (2021). Its superiority in fiber quality was highlighted by Hasan et al. (2019).

Table 7. *Combined selection index-based ranking of millets based on cumulative scores of six different nutritional quality attributes in comparison with rice and wheat (based on total index score values of Tables 1–6)*

Millets	CQTS	PQTS	FbQTS	FaQTS	VTS	MTS	OSI	Overall rank
Sorghum	169.47	94.14	62.3	174.79	85.29	662.09	1026	7
Pearl millet	153.5	166.6	57.21	174.26	200.98	992.30	1883	2
Finger millet	153.29	137.3	51.65	136.62	84.01	1399.29	2257	1
Foxtail millet	124.6	156.5	60.24	206.3	82.72	871.90	1492	4
Barnyard millet	113.12	157.25	42.22	303.31	4.63	391.65	521	9
Kodo millet	144.29	162.3	36.49	168.24	25.34	661.52	1050	5
Proso millet	139.33	165.3	31.21	191.42	6.39	674.62	1016	8
Little millet	126.15	159.3	34.26	214.96	12.59	683.98	1031	6
Rice	236.78	137.57	86.44	170.05	12.75	262.89	339	10
Wheat	192.36	142.69	65.28	181.68	106.78	972.13	1591	3

CQTS-Carbohydrate quality Total Score; PQTS-Protein Quality Total Score; FbQTS- Fiber Quality Total Score; FaQTS- Fat Quality Total Score; VTS - Vitamin Profile Total Score; MTS - Mineral Profile Total Score, and OSI - Overall Selection Index Score

Second ranked pearl millet

Pearl millet secured second place with an overall selection index score of 1883, following Finger millet. It ranked first in Vitamin profile, second in Protein quality and Mineral profile. However, Pearl millet ranked ninth in Carbohydrate quality, eighth in fat quality, and seventh in fiber quality. Pearl millet surpassed both Rice and Wheat in protein quality, vitamin, and mineral profiles, but was inferior to both in carbohydrate and fiber quality and on par with them in fat quality. The superiority of Pearl millet over other millets, except Finger millet, as well as over Rice and Wheat, was reported by Anitha et al. (2021). Its superior fat quality compared to other millets, except Finger millet, was noted by Hasan et al. (2019).

Third ranked wheat

Wheat ranks third overall with an overall selection index score of 1591, following Finger millet and Proso millet. Wheat secured second place in Vitamin profile, third in Mineral profile, and sixth in Fat quality. However, it ranked seventh in Protein quality, eighth in Fiber quality, and last in Carbohydrate quality. From these observations, it is evident that Wheat has a better Vitamin and Mineral profile than most millets (except Pearl millet for vitamins and minerals and Finger millet for minerals) and is inferior to all millets for Carbohydrate quality. It ranks below all except Sorghum and Finger millet in Protein quality, and all except Sorghum in Fiber quality. Wheat has a moderate fat quality value, slightly better than Rice. Moreover, Wheat is not suitable for celiac patients, whereas all millets and Rice can be suitable substitutes for Wheat.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

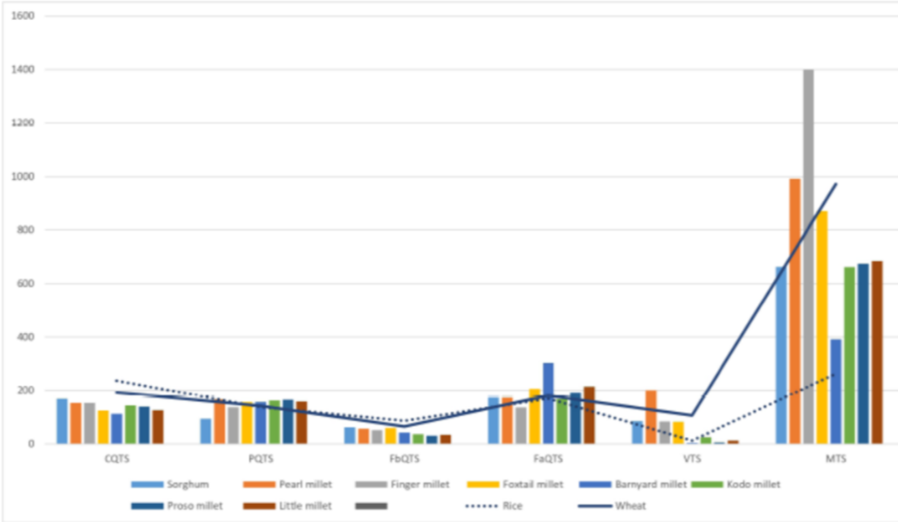


Figure 7. *Cumulative score for six different nutritional attributes of different millets compared with rice and wheat*

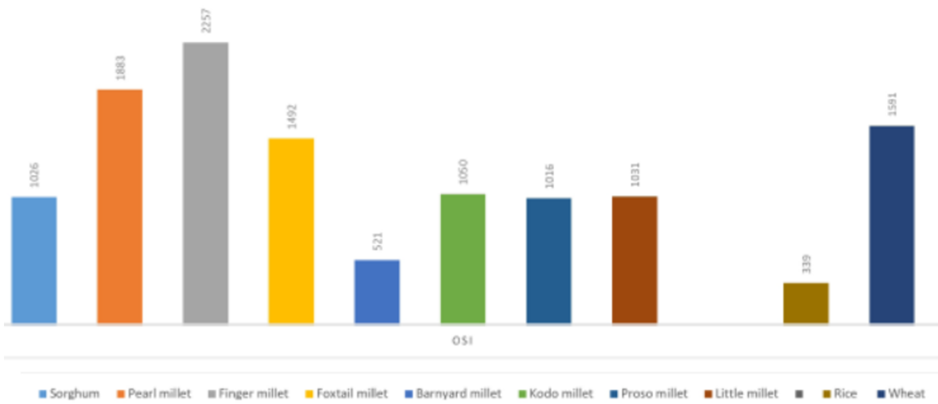


Figure 8. *Overall selection index score of different millets compared with rice and wheat*

Fourth ranked foxtail millet

Foxtail millet secured the fourth rank with an overall selection index score of 1492, surpassing Kodo millet, Little millet, Sorghum, Proso millet, Barnyard millet, and Rice. It ranked first in fiber quality, second in fat quality, fourth in protein quality and vitamin profile, and fifth in carbohydrate quality. Foxtail millet is superior to Rice and Wheat in protein quality and fat quality parameters, but inferior to both in carbohydrate quality, fiber quality, and mineral profile. It is superior in Vitamin profile compared to Rice but not Wheat. The superiority of Foxtail millet over other millets as well as Rice and Wheat were reported by Zhang et al. (2015), and its superiority in fat quality was noted by Hasan et al. (2019).

Fifth ranked kodo millet

Kodo millet secured the fifth rank with an overall selection index score of 1050. It ranked third in protein quality, fifth in fiber quality, and sixth in vitamin and mineral

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

profiles. Kodo millet is superior to both Rice and Wheat in protein quality and superior to Rice in mineral profile, but not Wheat. The superiority of Kodo millet in fiber quality over Rice and Wheat was reported by Hasan et al. (2019).

Sixth ranked little millet

Little millet secured the sixth rank with an overall total score of 1031. It ranked third in fiber and fat quality parameters and fifth in mineral profile. Little millet is superior to Rice and Wheat in protein, fiber, and fat quality parameters, superior to Rice in vitamin and mineral profile, and superior to Wheat in carbohydrate quality parameters. The superiority of Little millet in fiber quality over Rice and Wheat was reported by Hasan et al. (2019).

Seventh ranked sorghum

Sorghum secured the seventh rank with an overall total score of 1026. It ranked fifth in fat quality parameters and vitamin profile. Sorghum is superior to Rice and Wheat in mineral profile, superior to Rice in fiber quality parameters, vitamin and mineral profiles, and superior to Wheat in carbohydrate quality parameters. The superiority of Sorghum in fiber and fat quality over Rice and Wheat was reported by Hasan et al. (2019).

Eighth ranked proso millet

Proso millet secured the eighth rank with an overall total score of 1016. It ranked first in protein quality parameters, third in carbohydrate quality parameters, fourth in fat quality parameters, and sixth in fiber quality parameters. Proso millet is superior to Rice and Wheat in protein, fiber, and fat quality parameters, superior to Rice in vitamin and mineral profiles, and superior to Wheat in carbohydrate quality parameters. The superiority of Proso millet in fat quality over Rice and Wheat was reported by Hasan et al. (2019).

Ninth ranked barnyard millet

Barnyard millet secured the ninth rank with an overall total score of 521. It ranked first in fat quality, second in carbohydrate and fiber quality, and sixth in protein quality parameters. Barnyard millet is superior to Rice and Wheat in protein, fiber, and fat quality parameters, superior to Rice in mineral profile, and superior to Wheat in carbohydrate quality parameters. The superiority of Barnyard millet in vitamin and mineral profiles over Rice was reported by Rao et al. (2017), and its superiority in protein quality over Rice was reported by Devi et al. (2018).

Last ranked rice

Rice secured the least rank of 10 with an overall score of 339. This was primarily because Rice ranked last (10th) in fiber quality parameters and mineral profile, ninth in protein quality, eighth in vitamin profile, and seventh in fat quality parameters. However, Rice secured the first rank in carbohydrate quality parameters. Rice is superior to all millets as well as Wheat in carbohydrate quality parameters, superior to Sorghum in protein quality, superior to Pearl millet, Kodo millet, and Finger millet in fat quality, and superior to Proso millet and Barnyard millet in vitamin profile. The

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

inferiority of Rice in overall nutritional quality was supported by Zhang et al. (2015), Devi et al. (2018), Rao et al. (2017), Hasan et al. (2019), and Anitha et al. (2021).

Conclusion

In this review cum comparative statistical analysis study of eight millets alongside Rice and Wheat, the overall rankings for all six nutritional attributes were statistically derived using the Smith selection index principle. The analysis identified Finger millet as the highest-ranked millet, followed by Pearl millet, Wheat, Foxtail millet, and Kodo millet. Finger millet emerged as superior to Rice and Wheat for protein quality, fiber quality, and mineral profile, while also excelling in vitamin profile compared to Rice and in carbohydrate quality compared to Wheat. Additionally, Finger millet outperformed other millets in carbohydrate quality, was superior to Sorghum in protein quality, and ranked higher than Kodo millet, Proso millet, Pearl millet, and Sorghum for fiber quality, as well as Sorghum for mineral profile. Pearl millet demonstrated superiority over Rice and Wheat for protein quality, fiber quality, and both vitamin and mineral profiles, and surpassed Wheat in carbohydrate quality. Moreover, Pearl millet outperformed all millets except Proso millet in protein quality, Sorghum in fiber quality, Kodo millet and Finger millet in fat quality, all millets in vitamin profile, and all except Finger millet in mineral profile. Wheat, which ranked third, showed better performance than Finger millet, Sorghum, and Rice in protein quality, outperformed Sorghum and Rice in fiber quality, and exceeded Rice, Pearl millet, Kodo millet, and Finger millet in fat quality. Wheat also demonstrated superiority over all millets except Pearl millet, and Rice in vitamin profile, and outperformed all millets except Finger millet and Pearl millet, and Rice in mineral profile. Foxtail millet ranked fourth, surpassing Sorghum, Proso millet, Kodo millet, Pearl millet, and Rice in carbohydrate quality, and Finger millet, Sorghum, Wheat, and Rice in protein quality. Foxtail millet also excelled over all millets, Rice, and Wheat in fiber quality, was superior to all except Barnyard millet in fat quality, and outperformed Sorghum, Kodo millet, Little millet, and Rice in vitamin profile. Additionally, Foxtail millet ranked higher than Little millet, Kodo millet, Sorghum, Proso millet, Barnyard millet, and Rice in mineral profile. Kodo millet, securing the fifth rank, showed superiority over Pearl millet and Rice in carbohydrate quality, and outperformed all millets except Proso millet and Pearl millet, as well as Rice and Wheat, in protein quality. Kodo millet also ranked higher than Proso millet, Pearl millet, Sorghum, Rice, and Wheat in fiber quality, Finger millet in fat quality, Little millet, Proso millet, Barnyard millet, and Rice in vitamin profile, and Sorghum, Proso millet, Barnyard millet, and Rice in mineral profile. In contrast, Rice took the last rank, indicating its inferiority to all millets and Wheat for the overall nutritional score. However, Rice was superior to all millets and Wheat for carbohydrate quality parameters, though it was inferior to all millets except Sorghum in protein quality, to all millets and Wheat in fiber quality, to all except Pearl millet, Kodo millet, and Finger millet in fat quality, to all except Proso millet and Barnyard millet in vitamin profile, and to all millets and Wheat in mineral profile. This analysis provides a comprehensive comparison of the nutritional quality of various millets, Rice, and Wheat, highlighting the nutritional superiority of Finger millet and Pearl millet.

Conflict of interests. The authors declared no conflicts of interest with this research work.

REFERENCES

[1] Aggett, P. J. (2012): Iron. – In: Erdman, J. W., Macdonald, I. A., Zeisel, S. H. (eds.) Present Knowledge in Nutrition. 10th Ed. Wiley-Blackwell, Washington, DC, pp. 506-520.
[2] Ajibona, O. S. S., Idowu, A. A., Hamama, A. A., Bhardwaj, H. (2021): Preliminary study of nutritional quality of five drought tolerant millets. – Journal of Agricultural Science 13(5).
[3] Alpert, J. E., Mischoulon, D., Nierenberg, A. A., Fava, M. (2000): Nutrition and depression: focus on folate. – Nutrition 16: 544-581.
[4] Amadou, I., Gounga, M. E., Le, G.-W. (2013): Millets: nutritional composition, some health benefits and processing. - A review. – Emirates Journal of Food and Agriculture 25: 501-508.
[5] Anitha, S., Kane-Potaka, J., Tsusaka, T. W., Botha, R., Rajendran, A., Givens, D. I., Parasannanavar, D. J., Subramaniam, K., Prasad, K. D. V., Vetriventhan, M., Bhandari, R. K. (2021): A systematic review and meta-analysis of the potential of millets for managing and reducing the risk of developing diabetes mellitus. – Frontiers in Nutrition 8: 687428.
[6] Chaddha, A., Kim, A. E. (2015): Omega-3 fatty acids and heart health. – Circulation. https://doi.org.10.1161/circulationaha.
[7] Chandra, D., Chandra, S., Pallavi, Sharma, A. K. (2016): Review of finger millet (*Eleusine coracana* (L.) Gaertn): a power house of health benefiting nutrients. – Food Science and Human Wellness 5(13): 149-155.
[8] Devi, S., Varkey, A., Sheshshayee, M. S., Preston, T., Kurpad, A. V. (2018): Measurement of protein digestibility in humans by a dual-tracer method. – The American Journal of Clinical Nutrition 107(6): 984-991.
[9] EFSA (2013): Scientific opinion on dietary reference values for energy. – EFSA Journal 11(1): 3005. https://efsa.onlinelibrary.wiley.com/doi/abs/10.2903.
[10] EFSA (2019): Scientific opinion on dietary reference value for phosphorus. – EFSA Journal 17(9): 5778.
[11] FAO (1991): Protein Quality Evaluation. – Expert Consultation for WHO, Food and Nutrition Paper 51. FAO, Rome.
[12] FDA (2010): OTC Ingredients List. – www.fda.gov/downloads.about.
[13] Fishman, S. M., Christian, P., West, K. P.2000. The role of vitamins in the prevention and control of anaemia. – Public Health Nutr. 3(2): 125-150.
[14] Gbenga-Fabusiwa, F. J., Oladele, E. P., Oboh, G., Adefegha, S. A., Oshodi, A. A. (2018): Nutritional properties, sensory qualities and glycemic response of biscuits produced from pigeon pea-wheat composite flour. – J. Food Biochem. 12-505.
[15] Geervani, P., Eggum, B. O. (1989): Nutrient composition and protein quality of minor millets. – Plant Foods Hum Nutr. 39: 201-208.
[16] Gloria Tsang, R. D. (2021): Fiber 101: soluble fiber vs insoluble fiber. – Health Castle. https://www.healthcaste.com.
[17] Haris, W. (2010): Omega-6 and omega-3 fatty acids: partners in prevention. – Current Opin. Clin. Nutr. Metab. Care 13(2): 125-129.
[18] Hasan, M., Maheswari, C., Garg, N. K., Kumar, M. (2019): Millets: Nutri-Cereals. – Biotech Express 6(69): 18-21.
[19] Huizen, J. (2023): Soluble and insoluble fibre: differences and benefits. – Medical News Today. https://www.medicalnewstoday.com.
[20] IM FNB (Institute of Medicine, Food and Nutrition Board) (2000): Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium and Zinc: A Report of the Panel on Micronutrients. – National Academy Press, Washington, DC. https://www.ncbi.nlm.nih.gov/books/nbk222317.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

[21] Kent, N. L. (1983): Cereal Grain Lipids - An Overview. Technology of Cereals. Third Ed. – Pergamon Press Ltd. Oxford.
[22] Konings, E. J. (2006): Committee on Food Nutrition, Water soluble Vitamins. – JAOAC Int. 89(1): 285-288.
[23] Krishna Kumari, S., Thayumanavan, B. (1998): Characterization of starches of proso, foxtail, barnyard, kodo, and little millets. – Plant Foods Hum Nutr. 53(1): 47-56.
[24] Lopez, M. J., Mohiuddin, S. S. (2023): Biochemistry, essential amino acids. – Stat Pearls. https://www.ncbi.nlm.nih.gov/books/NBK557845/.
[25] Mitchell, H. H. (1923): A method of determining the biological value of protein. – J. Biol. Chem. 58(3): 873.
[26] NAM (National Academy of Medicine) (2019): Dietary References Intakes for Sodium and Potassium. – National Academies Press (US), Washington, DC.
[27] NMCD (2011): Vitamin B_6. – Natural Medicine Comprehensive Database.
[28] Norris, T. (2023): Soluble vs. Insoluble Fibre. What's the difference? – https://www. Heathline.com.
[29] Rao, B. D., Bhaskarachry, K., Christina, G. D. A., Devi, G. S., Tonapi, V. A. (2017): Nutritional and Health Benefits of Millets. 2nd Ed. – ICAR - Indian Institute of Millets Research (IIMR) Rajendranagar, Hyderabad.
[30] Rude, R. K. (2012): Magnesium. – In: Ross A. C., Caballero B., Cousins, R. J., Tucker K. L., Ziegler T. R. (eds.) Modern Nutrition in Health and Disease. 11th Ed.. Lippincott Williams & Wilkins, Baltimore, MD, pp. 159-175.
[31] Saldivar, S. (2023): Cereals: Dietary Importance. – In: Caballero, B., Trugo, L., Finglas, P. (eds). Encyclopedia of Food Sciences and Nutrition. Academic Press, London, pp. 1027-1033.
[32] Sarmila, K. C. (2023): Determination of Crude Fibre in Food Sample. – The Science Notes. https://thesciencenotes.com.
[33] Shenkin, A. (2006): Micronutrients in Health and Disease. – Podtgrad Med. J. 82: 559-567.
[34] Singh, P., Singh, U., Eggum, B. O., Kumar, K. A., Andrews, D. J. (1987): Nutritional evaluation of high protein genotypes of pearl millet (*Pennisetum americanum* (L.) Leeke). – J. Sci. Food Agric. 38: 41-48.
[35] Schneemann, B. O. (1999): Fibre, inulin and oligo fructose: similarities and differences. – J. Natr. 129: 1424S-1430S.
[36] Stipanuk Martha, H., Caudill Marie, A. (2013): Biochemical, Physiological and Molecular Aspects of Human Nutrition. – E Book. Elsevier Health Sciences, Amsterdam.
[37] Sukhija, S. S., Singh, C. S., Riar, 2016. Isolation of starches from different tubers and study of their physicochemical, thermal, rheological and morphological characteristics. – Starch-Stärke 68(1-2): 160-168.
[38] Taber, M. G. (2006): Vitamin E. – In: Shils, M. E., Shike, M., Ross, A. C., Caballero, B., Cousins, R. (eds.) Modern Nutrition in Health and Disease. 10th Ed. Lippincott Williams & Wilkins, Baltimore, MD, pp. 396-411.
[39] Thomas, A. (2000): Fats and Fatty Oils. – In: Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH, Weinheim.
[40] Thor, K. (2019): Calcium - nutrient and messenger. – Front. Plant Sci. 10. https://doi.org/10.3389/fpls 201900040.
[41] Tiwari, M., Tiwari, A., Chauhan, K. (2023): Millets starch and its functionality. – Just Agriculture 3(8): 346-354.
[42] Trowell, H. C., Burkit, D. P., Heaton, K. W., Doll, R. (1985): Definitions of Dietary Fibre and Fibre Depleted Foods and Disease. – Academic, London, pp. 21-30. Cir.nil.ac.jp.
[43] UNICEF (2015): Vitamin A Deficiency. – Retrieved 3 June. https://data.unicef.org/topic/nutrition/vitamin-a-deficiency/
[44] USDA (U.S. Department of Agriculture) (2019): Agricultural Research Service. – Food Data Central. https://fdc.nal.usda.gov/

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561

[45] Zhang, A., Liu, X., Wang, G., Wang, H., Liu, J., Zhao, W., Zhang, Y. (2015): Crude fat content and fatty acid profile and their correlations in foxtail millet. – Cereal Chemistry 92(5).
[46] Zhu, T., Lu, X. T., Liu, Z. Y., Zhu, H. L. (2022): Dietary linoleic acid and the ratio of unsaturated to saturated fatty acids are inversely associated with significant liver fibrosis risk: a nationwide survey. – Front. Nutr. 9: 938645.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_45414561