# Nutritional and Health Benefits of Nutri Cereals


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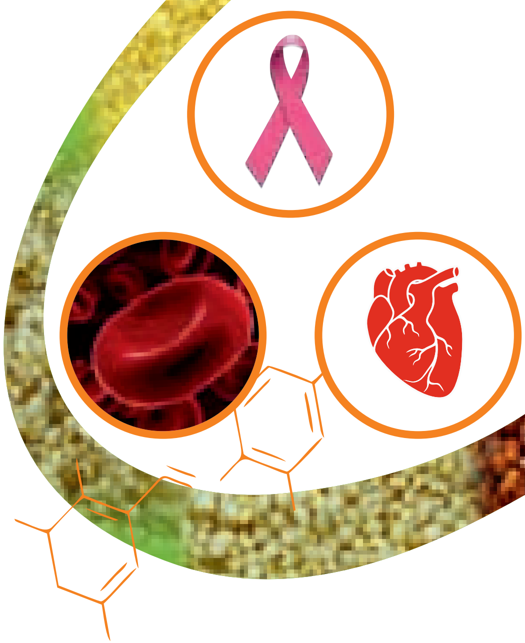

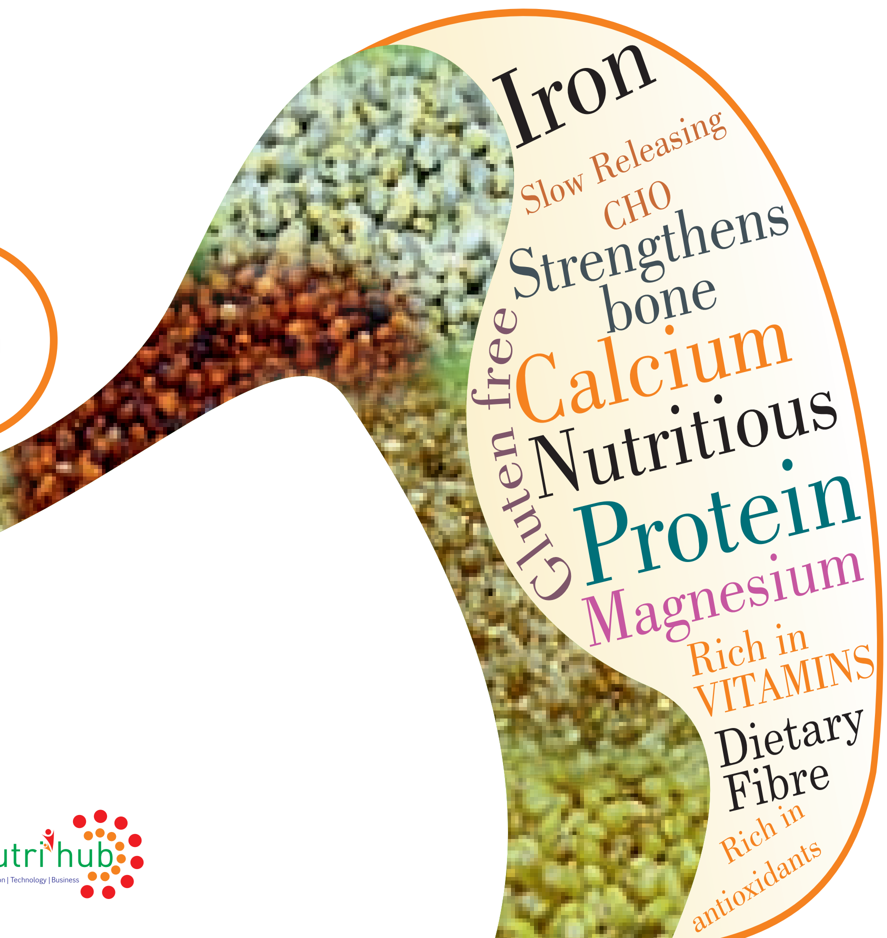


2018 NATIONAL YEAR OF MILLETS
Nutricereals For Nutritional Security

भाकृअनुप ICAR

IIMR
भाकृअनुप - भारतीय कदन्न अनुसंधान संस्थान
ICAR-Indian Institute of Millets Research

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# Profile

Indian Institute of Millets Research (IIMR), formerly Directorate of Sorghum Research (DSR) is a premier agricultural research institute engaged in basic and strategic research on sorghum under Indian Council of Agricultural Research (ICAR). ICAR-IIMR coordinates and facilitates millets research at national level through All India Coordinated Research Projects on Sorghum, Pearl millet and Small millet and provides linkages with various national and international agencies.

IIMR's primary vision and goals encompass the objective to promote economic growth by generating and disseminating ready-to-use technologies which create markets, respond to current and future economic demands and maintain the long term sustainability value addition and marketing to meet significant food, feed, fodder and fuel (bio-energy) requirements of the country.

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अधिसूचना

**MINISTRY OF AGRICULTURE AND FARMERS WELFARE**

**(Department of Agriculture, Cooperation and Farmers Welfare)**

**NOTIFICATION**

New Delhi, the 10th April, 2018

**F.No. 4-4/2017-NFSM (E).**—Whereas, millets hold great potential in contributing substantially to food and nutritional security of the country and thus they are not only a powerhouse of nutrients, but also are climate resilient crops and possess unique nutritional characteristics;

And whereas, recent research findings also show that millets contain anti-diabetic properties and millet based food have low GI and reduces the postprandial blood glucose level and glycosylated haemoglobin;

And whereas, a Committee constituted by the Central Government for examination of inclusion of millets in the Public Distribution System (PDS) for improving nutritional support has recommended for inclusion of millets in PDS across the country and the same has been accepted by the Central Government;

Now, therefore, the Central Government hereby declare millets comprising Sorghum (Jowar), Pearl Millet (Bajra), Finger Millet (Ragi/Mandua), Minor Millets i.e. Foxtail Millet (Kangani/Kakun), Proso Millet (Cheena), Kodo Millet (Kodo), Barnyard Millet (Sawa/Sanwa/ Jhangora), Little Millet (Kutki) and two Pseudo Millets (Black-wheat (Kuttu) and Ameranthus (Chaulai) which have high nutritive value as "Nutri-Cereals" for production, consumption and trade point of view.

Dr. B. RAJENDER, Jt. Secy. (Crops)

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# FOREWORD

Millets are a traditional staple food of the dry land regions of the world. In India, millets are grown on about 17 million ha with annual production of 18 million tonnes and contribute 10 percent to the country's food grain basket. They are nutri-cereals which are highly nutritious and are known to have high nutrient content which includes protein, essential fatty acids, dietary fibre, B-Vitamins, minerals such as calcium, iron, zinc, potassium and magnesium. They help in rendering health benefits like reduction in blood sugar level (diabetes), blood pressure regulation, thyroid, cardiovascular and celiac diseases. However, the direct consumption millets as food has significantly declined over the past three decades.

The major reasons of decrease in consumption is the lack of awareness of nutritional merits, inconveniences in food preparation, lack of processing technologies, and also the government policy of disincentives towards millets and favoring of supply of fine cereals at subsidized prices. It has become imperative to reorient the efforts on the sorghum and millet crop to generate demand through value-addition of processed foods through diversification of processing technologies, nutritional evaluation and creation of awareness backed by backward integration. In that context it is important to explore ways for creating awareness on nutritional merits of millets.

The importance of nutrition as a foundation for healthy development is underestimated. Now-a-days people are very conscious about their healthy living practices to overcome metabolic disorders and life style diseases. This publication deals with the review on the scientific empirical studies on the nutritional aspects, functional aspects and health benefits of millets from seed structure to processed products, which are conducted in India and elsewhere across the globe. Further, it deals elaborately with nutritional evaluation of the value added sorghum product technologies that have been developed and standardized under the IIMR-led consortium of NAIP sub-project on millets value chain conducted by NIN. The products have shown to have high nutritional values and the micronutrient studies conducted have reported, these to have relatively low glycemic index and glycemic load. Sorghum/millet processed products recipes and the method of preparation are embedded with content that can be of some use to various stakeholders, researchers, academic fraternity, consumers and entrepreneurs which is timely and is expected to help the researchers. It is hoped that the results published will create awareness and ensure that the highly nutritious millets consumption is popularized worldwide.

Lastly, I congratulate Dr. B. Dayakar Rao, Principal Scientist and his co-authors for their efforts in bringing out this valuable publication. This will go a long way in millet promotion in the country, given its potential for offering nutritional security. I hope the publication will be read and used widely.

**M S Swaminathan**

Foxtail Millet

# PREFACE

Millets are important crops for dry land farmers. They are highly nutritious and climate compliant crops. But due to drudgery in preparation, their consumption is decreased over the years in India. In order to revive the demand of millets in India, there is need to enable to bring all the stakeholders in production to consumption system value chain on a common platform and link poor dry land farmers with market and the consumers at large. Under the NAIP sub-project on Millets Value Chain, an institutional mechanism was established to form consortium of stakeholders in public-private partnership ensuring a win-win situation for each stakeholder. The processing interventions were led to product development on sorghum products whose nutritional values were quite encouraging. Further quite a bit of data on nutrition and health benefits were generated under supervision of National Institute of Nutrition, Hyderabad. The micronutrient studies conducted were reported in terminal report. It was reported that these products have relatively low glycemic index and glycemic load compared to wheat based products.

Now the commercialization of products have extended for other millets too. Though the millet food products are known for nutrition, its awareness among the consumers is scanty especially on their nutritional and therapeutic values. The health branding was not exploited enough to commercialize millet foods in the past, despite the fact that, millets are known to have rich composition of nutrients and minerals.

Therefore, this publication has been timely which deals with the review on empirical studies on the nutritional aspects, functional aspects and health benefits of millets from seed structure to processed products, which are conducted in India and elsewhere across the globe. Further, it deals elaborately with nutritional evaluation of the value added sorghum product technologies that have been developed and standardized under the IIMR-led consortium of NAIP sub-project on millets value chain conducted by NIN. This will go a long way in millet promotion in the country, given its potential for offering nutritional security. I hope the publication will be read and used widely.

**V.A. Tonapi**
**ICAR - Indian Institute of Millets Research (IIMR) Hyderabad**

# Abbreviation

| | | | |
|---|---|---|---|
| ABTS | 2,2′-Azinobis-3-Ethylbenzothiozoline-6-Sulfonic Acid | N | Nitrogen |
| ADA | American Diabetes Association | NA | Not Available |
| +iAUC | Positive Incremental Area under Curve | NAIP | National Agricultural Innovative Programme |
| β | Beta | NCD | Non-Communicable Diseases |
| BMI | Body Mass Index | NEJM | New England Journal of Medicine |
| CD | Celiac Disease | NIDDM | Non-Insulin Dependent Diabetes Mellitus |
| CVD | Cardio Vascular Diseases | NIN | National Institute of Nutrition |
| DPPH | 2, 2-diphenyl-1-picrylhydrazyl | ORAC | Oxygen Radicle Absorbance Capacity |
| DSR | Directorate of sorghum Research | PCS | Public Chain System |
| DXA | Deoxyanthosyanins | PDS | Public Distribution System |
| EAG | Empowered Action Groups | PER | Protein Efficiency Ratio |
| FAO | Food and Agricultural Organization | RBC | Red Blood Cells |
| FRAP | Ferric Reducing Ability of Plasma | RDS | Rapidly Digestible Fiber |
| GI | Glycemic Index | RS | Resistant Starch |
| GL | Glycemic Load | RTC | Ready to Cook |
| HDL | High Density Cholesterol | RTE | Ready to Eat |
| ICAR | Indian Council of Agricultural Research | SDF | Soluble Dietary Fiber |
| ICMR | Indian Institute of Medical Research | SDS | Slowly Digestible Fiber |
| IDF | Insoluble Dietary Fiber | TDF | Total Dietary Fiber |
| IIMR | Indian Institute of Millets Research | UK | United Kingdom |
| kg | Kilo gram | UN | United Nations |
| LDL | Low density cholesterol | w.b. | Wet basis |
| mg | Milli gram | WHO | World Health Organization |

# Executive Summary

Millets are a staple food for the population living in dry land regions of the world, particularly Asia and Africa. However, their consumption and cultivation in India has gradually declined over the past three decades because of a multitude of reasons.

For instance, in India, production of sorghum came down from 7.0 million tonnes during 2010-11 to 4.2 million tonnes during 2015-16, *bajra* production has reduced from 10.4 million tonnes to 8.1 million tones, production of *ragi* reduced from 2.2 million tonnes to 1.8 million tonnes while production of small millets came down to 0.39 million tonnes from 0.44 million tonnes during the same period.

This bulletin highlights that the prevalence of non-communicable diseases was mainly because of an overwhelming shift in food habits from traditional to modern foods that usually consists of high fat, refined cereals and lack in vitamins and minerals.

Daily consumption of millets can significantly reduce incidences of non-communicable diseases. Millets are rich in many functional compounds like dietary fiber, slow digestible carbohydrates, high protein content, B-complex vitamins, calcium, iron, magnesium, manganese, copper and phyto-chemicals. Apart from possessing specific characteristics like being gluten-free. They are non-acid forming, easy to digest and non-allergenic. Each goes a long way in enhancing health benefits.

In this illustration and graphic-rich bulletin, a scientific approach has been evolved in order to explain how functional components of millets help obesity, diabetes and heart related issues and also an anemic group, to restore a healthy well-being.

The comparative data on nutritional profile of different millets, the adverse effect of supplementation of millet foods on hemoglobin levels and reduction in blood sugars levels have been presented in a table format for an easier understanding of the pros and cons of the tendency to go in for modern foods.

IIMR has done a commendable research on various value-added sorghum-rich products without much loss of nutritional value. Now the research is not just limited to sorghum as it has widened to other millets too.

The recipes formulated at Indian Institute of Millets Research (IIMR) (formerly Directorate of Sorghum Research (DSR)), cover all aspects of millets and go beyond sorghum when undertaking research and development processes.

The sub-project of NAIP-Millets Value Chain focuses on research efforts on selected millet foods with a thrust on sorghum. Given the model is successful, it could be replicated to other millets and help benefit consumers, households and entrepreneurs. All these beneficiaries can subsequently prepare alternative methods to prepare value added products having innumerable health benefits which are not available in the market. The focus should be on the ability to combat and contain nutritional deficiency disorders.

The production of such value-added products by entrepreneurs, self-help groups (SHGs) and small-scale industries (SSIs) can boost their earnings and socio-economic status, along with, it can improve the health status of the consumer. Consequent to the synergic efforts that have been put in, various nutritionally rich convenient sorghum product technologies were developed and successfully commercialized on a pilot-basis in Hyderabad.

Chapter-I

# An overview on Non-Communicable Diseases

The dietary structure, levels of physical activity, obesity and diet related non-communicable disease patterns are undergoing a sea-change across the developing world.

It is equally pronounced in India. Alas for all these 'developments, a large percentage of the rural population continues to live an impoverished lifestyle because of extreme economic deprivation. Whereas their economic and nutritional transition is different, both face comparable rapid increase in diet-related NCD problems, albeit manifested in different ways. India's has a dubious distinction when it comes to malnutrition and rural population *vis-à-vis* developing nations.

Food consumption shift from traditional to modern foods is presumed to be one of the main reasons for diet-related non-communicable illnesses, including malnutrition, in India. There has been a large shift from consumption of coarse grains such as sorghum and other millets to partake of rice and wheat among all economic groups. Of course, some varieties are determined by geographical locations like in Maharashtra, where intake of coarse grain remains high. By and large, however, diets of all income groups have moved from cereals to other food groups, with a greater shift among the elite sections living in urban areas. Energy intake has risen for poor and dropped for the rich whereas intake of fat substances has been high among all income groups. While staple foods such as wheat and rice are subsidized by the government, the availability of affordable and nutritious alternative grains and legumes could help alleviate poverty and nutritional insecurity in rural India, particularly among the vulnerable lot like women and children.

According to a spine-chilling 2017 WHO data, NCDs are the leading cause of death globally and responsible for 70 percent fatalities worldwide.

In India, a total of 58, 17,000 deaths were estimated from diseases like cancer, diabetes and heart problems in 2016. While the percentage of deaths from NCDs is still lower compared to many other countries, experts are concerned that the burden is increasing at a rapid pace because of changing lifestyle and factors like pollution.

The Four risk factors include tobacco, unhealthy diet, physical inactivity and alcohol abuse. Major metabolic risk factors are obesity, and abnormal blood pressure, blood glucose and blood cholesterol levels, the report findings point out.

In 1990, non-communicable diseases (NCD) accounted for 37.9% of all deaths causing about four in ten deaths in India. In 2016, the share of non-communicable diseases rose up to 61.8% causing six in ten deaths, an increase of 23.9% from 1990 (Fig. 1).

Cardiovascular diseases (coronary heart disease, stroke, and hypertension) contribute to 24% of all NCD deaths, followed by chronic respiratory disease (11%), cancer (6%) and diabetes (2%) (Fig. 2). Moreover, despite having a lower percentage of deaths from NCDs, the share of premature deaths in India due to such diseases is alarming. Cancer, diabetes and heart diseases alone account for 55% of the premature mortality in India's 30-69 years age-group. "Strong political action is needed to address constraints in controlling NCDs, including the mobilization of domestic and external resources and safeguarding communities from the interference by powerful economic operators (World Health Statistics (2017).

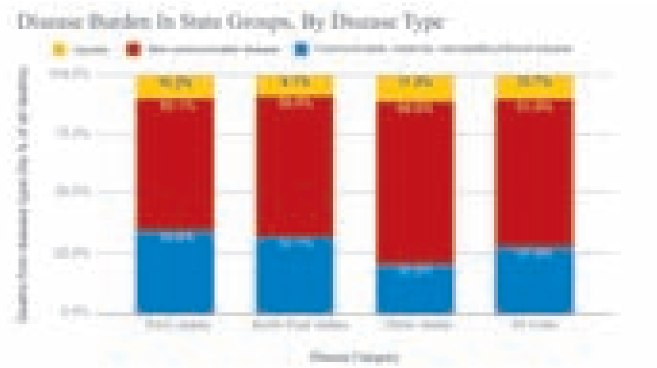

**Figure 1. Health status of India**

(*Source:* India: Health of the Nation's States 2017)

Note: EAG: Eight under developed states that form the Empowered Action Group - Madhya Pradesh, Uttar Pradesh, Uttarakhand, Rajasthan, Jharkhand, Chhattisgarh, Odisha, Bihar.

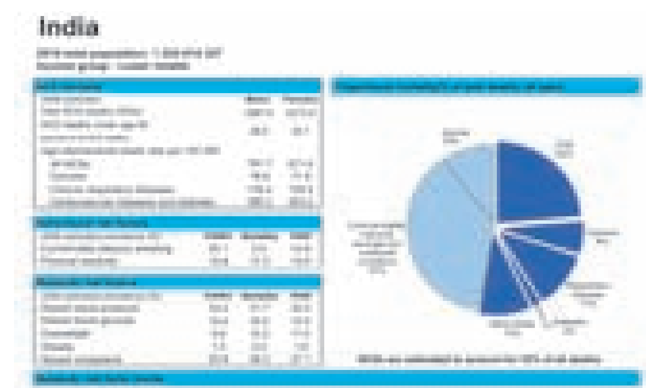


**Figure 2. NCD Country profile data of India**

(*Source:* World Health Organization - NCD Country Profiles, 2011).

# Chapter-II

# Millets Consumption: Key to a Healthy Life

From a humble crop that once satiated the poor to the base of a gourmet meal for the health-conscious fitness freaks, millets have made a comeback. While flavors of the grain may vary to suit modern palates, almost every doctor's 'healthy' recipe is still traditional in nature. Lest one forgets, several millets deemed lost or are on the 'fast disappearing' list are cultivated in typically localized regions or documented archaeologically, perhaps for posterity. Millets are traditional staple crops, which perform well in marginal environments and are superior in nutritional properties with high micro-nutrient and dietary fiber content and low glycemic indices.

Though belated, the advances in modern science have helped 'discover' the nutritional characteristics of millets. It is a tragic irony that the richness of millets was 'discovered' only after biochemical and food and health science studies were carried out, minutely and extensively.

The declining trend in millets consumption and nutritious cereals in general is attributed to the dietary pattern of consumption towards a balanced diet that includes livestock products, fruits and vegetables (Chand, 2007) which is mainly driven by an increase in income and urbanization where people race against time to run their daily chores. Secondly, the shift is due to the consumption of fine cereals which are supplied through PDS at subsidized prices (Table 1).

Food basket began to change from late 1960s when rice and wheat became available in more quantities and at an affordable cost. Later on, the government welfare schemes that provided rice and wheat at highly subsidized rates hastened the exit of millets in most household kitchens (Table 2).

**Table 1: Reasons for the decline in millets area and consumption in India**

| Demand side factors | Supply side factors |
|---|---|
| Rapid urbanization | Increasing marginalized cultivation |
| Changing consumer tastes and preferences due to rising per capita incomes | Low profitability – low remuneration for millets vis-à-vis competing crops |
| Government policies favoring other crops such as output price incentives and input subsidies | More remuneration crop alternative in *kharif* season competing with millets in question |
| Supply of PDS rice and wheat at cheaper price introduced in non- traditional areas of fine cereals | Decline in production and quality (as in *kharif)* sorghum because of poor quality of grains due to blackening of grains, fetching low prices to the farmers |
| Poor social status and inconvenience in their preparation (especially sorghum) | Lack of incentives for millet production |
| Lower shelf life of milled grain and flour of millets | Development of better irrigation infrastructure/ options as in small millet areas. |

(*Source:* The Story of Millets, 2018)

**Table 2: Trends in direct consumption of sorghum *vs.* major cereals in India (kg/person/year)**

| Commodity | 1973-74 | 1983- 84 | 1993-94 | 2004-05 | 2011-12 |
|---|---|---|---|---|---|
| Rural | | | | | |
| Rice | 84.0 | 80.7 | 85.4 | 78.0 | 71.7 |
| Wheat | 42.8 | 54.3 | 53.5 | 51.0 | 51.5 |
| Sorghum | 19.0 | 12.5 | 9.7 | 5.16 | 2.4 |
| Urban | | | | | |
| Rice | 65.5 | 64.7 | 64.2 | 57.0 | 53.8 |
| Wheat | 52.6 | 58.6 | 57.4 | 53.0 | 48.1 |
| Sorghum | 11.0 | 6.0 | 4.9 | 2.7.0 | 1.56 |

(*Source:* The Story of Millets, 2018)

Although millets are healthy with immense nutritional values, they being a vast area, the Government alone cannot address it at all levels. Subsequent to innumerable awareness campaigns and interactive sessions at the behest of government and non-governmental organisations (NGOs), the myriads health benefits of millets are reaching out to every section of the population, which is realizing the importance of this wonder product to stay healthier. Scientific evidences of millets being superior nutritious cereals are coming as morale-boosters. A welcome off-shoot has been that pride of place is being given to millets in the food plate.

A WHO-ICMR study based on non-communicable diseases' risk factor surveillance showed that the prevalence of diabetes is 10.4% of the population. A research paper tracked its impact on people with diabetes (Janani Narayan *et al.*, 2016). The study, undertaken by M V Hospital for Diabetes, found that replacing rice-based *dosas* with ones made of foxtail millet (*Thinai*) can significantly bring down sugar levels in those suffering from type-2 diabetes. The research, published in the Indian Journal of Medical Research, is based on a survey undertaken on 105 type-2 diabetics in Chennai.

The thrust of the study was that "It wanted to estimate the effect of a single change in the diet in one of the meals and check the rise in their sugar levels".

In summers, diabetes-related emergencies spike by 25%, with many complaining of exhaustion and dehydration. The respondents, aged between 35 and 55 years, were divided into two groups. While one group was given rice *dosa* for breakfast on a given day, the others ate *dosas* made of millets. Two days later, the plates were swapped between the groups. On both days, researchers first measured their blood glucose levels and 90 minutes after breakfast, their levels were checked again. While the glycaemic index of the food's effect on a person's blood sugar level was 59.25 for those who had millet *dosa*, it was 77.96 for those who ate rice-*dosas*.

This shows millets don't just help manage diabetes but also cardiovascular diseases as postprandial hyperglycemia (high blood sugar following a meal) is a major risk factor. The research attributes the low glycaemic index of foxtail millet *dosa* to high levels of soluble dietary fibre in the millet. The high viscosity of the soluble fibre delays digestion and absorption. The recipe is easy on the palate too. 89% of the subjects said they liked millet-based *dosa*.

Foxtail Rice

Chapter-III

# Introduction on Millets

Millets are a group of highly variable small-seeded grasses, widely grown around the world as cereal crops or grains for fodder and human food. They do not form a taxonomic group, but rather a functional or agronomic one.

Millets are grown spontaneously or cultivated in almost all countries for use by humans as food grains and also as fodder for animals. Millets are creamy, red, brown and black in colour individual to the variety of crop. Millets have been cultivated since ancient civilizations by people across the globe. In East Asia, they date back to 10,000 years ago. Millets are an important crops in the semi-arid tropics of Asia and Africa (especially in India and Nigeria), with 97% of millet production originating in developing nations.

The crop is favored due to its productivity and short growing season under dry, high-temperature conditions. Millets are indigenous to many parts of the world; it is believed that they had an evolutionary origin in tropical western Africa, as that is where the greatest number of both wild and cultivated forms exist.

Millet crops are still the principal sources of energy, protein, vitamins and minerals for millions of the poorest people in these regions. Quite significantly, they are grown in harsh environments where the yield of other crops grown is substantially less. They are grown with limited water resources and usually without application of any fertilizers or other inputs by a multitude of small-holder farmers. Therefore, they are mostly consumed by disadvantaged groups; they are often referred to as “coarse grain” or “poor people’s crop”. They are not usually traded in the international markets or even in local markets in many countries. The farmers seldom, therefore, have an assured market in the event of surplus production.

## 3.1. Sorghum

Sorghum or *"Jowar"* cereal is perceived to be an important coarse-grained food crop. It is cultivated widely across Maharashtra, Madhya Pradesh, Uttar Pradesh, Haryana, Telangana, Andhra Pradesh, Tamil Nadu and Karnataka and in parts of Rajasthan. Sorghum is a traditional staple food of the dry-land regions of the world, a warm season crop intolerant to low temperatures, resistant to pests and diseases highly nutritious and a climate-compliant crop. It ranks fifth in cereals produced world-wide and fourth in India. Generally, sorghum grains (Fig. 3) act as a principal source of protein, vitamins, energy and minerals for millions of people especially in the semi-arid regions. On that count, they play a crucial role in the world's food economy. It has a nutritional profile that is better than rice which is the staple food of majority of the human population for its rich protein, fibre thiamine, riboflavin, folic acid, calcium, phosphorous, iron and β-carotene.

Sorghum is rich in potassium, phosphorus and calcium with sufficient amounts of iron, zinc and sodium. Due to this, it is being targeted as a means to reduce malnutrition globally. It helps to control heart problems, obesity and arthritis. Adding sorghum regularly in the meals of pregnant women helps them attain the dietary mineral and vitamin requirements. Sorghum helps to control heart problems, body weight and arthritis.

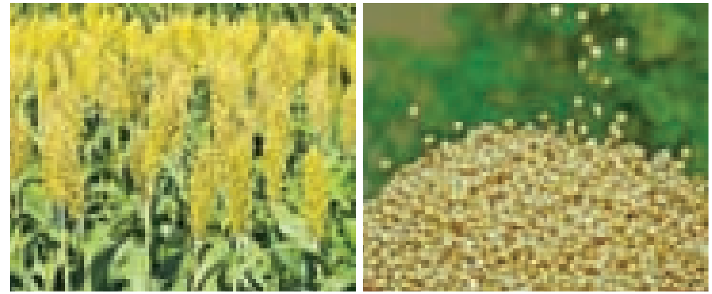

**Figure 3: Sorghum panicles and grain**

## 3.2. Pearl millet

Pearl millet or *"bajra"* is an extensively grown variety of millet (Fig. 4). It is being grown in the African and Indian subcontinent from ancient times. Known as 'bird feed', in India it is usually grown in Rajasthan, Gujarat and Haryana as it can adapt well to nutrient-poor, sandy soils in low rainfall areas. It is a tall, erect plant and grows from 6-15 ft in height. The plant produces an inflorescence with a dense spike-like panicle, which is brownish in colour. This millet is known to possess phyto-chemicals that lower cholesterol. It also contains folate, iron, magnesium, copper, zinc, and vitamins E and B-complex. Pearl millet has a high energy content compared to other millets. It is also rich in calcium and unsaturated fats, which are good for the body.

**Figure 4: Pearl millet panicles and grain**

## 3.3. Finger millet

Finger millet or *"ragi"* is a short, profusely tillering plant with characteristic finger like terminal inflorescences, bearing small reddish seeds. Maturity of crop is between three to six months depending on the variety and growing conditions. The crop is adapted to fairly reliable rainfall conditions and has an extensive but shallow root system. It is an annual plant extensively grown as a cereal in the dry areas of India, especially in the southern States. Finger millet (Fig. 5) contains high amount of calcium, protein with well-balanced essential amino acids composition along with Vitamin A, Vitamin B and phosphorous. It also contains high amount of calcium. Ragi flour in Karnataka is mostly prepared into balls, popularly known as "*ragi mudde*", made into flatbreads, leavened *dosa* and thinner, unleavened *rotis*. Its high fiber content also checks constipation, high blood cholesterol and intestinal cancer. Protein content in finger millet is high, thereby making it an important factor in preventing malnutrition. It is an ideal food for diabetics as it has demonstrated the ability to control blood glucose levels and hyperglycemia.

**Figure 5: Finger millet panicles and grain**

## 3.4. Foxtail millet

Foxtail millet or "Italian millet", is a gluten-free grain and the second most commonly grown species besides being one of the oldest cultivated millet. Generally grown in semi-arid regions, it has a low-water requirement, though it does not recover well from drought conditions because it has a shallow root system. Successful production is due almost entirely to its short growing season. It matures in 65-70 days. Ironically, foxtail millet can be planted when it is too late to plant most other crops. It forms a slender, erect, leafy stem varying in height from 1-5 ft. Seeds are borne in a spike-like, compressed panicle resembling yellow foxtail, green foxtail, or giant foxtail. The grains are very similar to paddy rice in grain structure. They contain an outer husk, which needs to be removed in order to be used. It has twice the quantity of protein content when compared to rice. Apart from controlling blood sugar and cholesterol, it increases disease resistant capacity and is recommended for people suffering from diabetes and gastric problem. Foxtail millet, (Fig. 6) with a sweet nutty flavour, provides a host of nutrients and is considered to be one of the most digestible and non-allergic grains available. It contains fibre, protein, calcium and vitamins. It is a nutritive food for children and pregnant women. It is rich in dietary fiber and minerals such as copper and iron that keep one's body strong and immune.

Figure 6: Foxtail millet panicles and grain

## 3.5. Kodo millet

Kodo millet was domesticated in India almost 3,000 years ago. It is an annual tufted grass that grows up to 90 cm high. The grain is enclosed within hard, corneous, persistent husks that are difficult to remove. The grain may vary in colour from light red to dark grey. It has the highest dietary fiber amongst all millets. It constitutes the mainstay of dietary nutritional requirements. It has high protein content (11%), low fat (4.2%) and very high fibre content (14.3%). Kodo millet is very easy to digest; it contains a high amount of lecithin and is excellent for strengthening the nervous system. It is rich in B vitamins, especially niacin, B6 and folic acid, as well as minerals like calcium, iron, potassium, magnesium and zinc. It contains no gluten and is good for people who are gluten-intolerant. Regular consumption of kodo millet (Fig. 7) is very beneficial for postmenopausal women suffering from signs of cardiovascular disease, like high blood pressure and high cholesterol levels.

Figure 7: Kodo millet panicles and grain

## 3.6. Barnyard millet

Barnyard millet is a good source of protein, which is highly digestible and is an excellent source of dietary fiber with good amount of soluble and insoluble fractions. The carbohydrate content of barnyard millet is low and slowly digestible, which makes the barnyard millet a nature's gift for the present-day people, who are engaged in sedentary activities. In this millet, the major fatty acid is linoleic acid followed by palmitic and oleic acid. It also shows a high degree of retrogradation of amylase, which facilitates the formation of higher amounts of resistant starches. Hence, it can be potentially recommended for patients with cardiovascular diseases and diabetes. Barnyard millet (Fig. 8) is most effective in reducing blood glucose and lipid levels. In today's scenario of increased diabetes, this millet could become an ideal food as it does for patients intolerant to gluten, which causes celiac disease.

**Figure 8: Barnyard millet panicles and rain**

## 3.7. Little millet

Little millet (Fig. 9) is grown throughout India and is one of the traditional crops of Karnataka. It is mostly mix cropped with other millets, pulses and oilseeds. It is generally consumed as rice and any recipe that demands staple rice can be prepared using little millet. This species of cereal is similar in habit to the proso millet except that grain is smaller. It is an annual herbaceous plant, which grows straight or with folded blades to a height of 30 cm to 1 m. The leaves are linear, sometimes with hairy lamina and membranous hairy ligules. Little millet is reported to have 37% to 38% of dietary fiber (Kumar *et al.*, 2018), termed as a nutraceutical and highest among cereals. Thus, it is a complete food ingredient suitable for large scale utilization as processed products, snacks, baby foods, among several such others, and also plays a major role in propagating food security in the Third World.

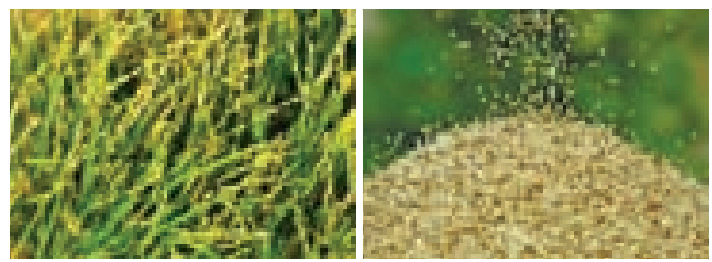

**Figure 9: Little millet panicles and grain**

## 3.8. Proso millet

Proso millet is a short season crop that grows in low rainfall areas. This millet can be cultivated along with red gram, maize and sorghum. The grain contains a comparatively high percentage of indigestible fibre because the seeds are enclosed in the hulls and are difficult to remove by conventional milling processes. It releases energy over a longer period of time after consumption allowing one to work for longer duration without fatigue. This has heavy protein content, crude fiber, minerals and calcium. A health benefit of proso millet (Fig. 10) comes from its unique properties as is entirely gluten-free and has significant amounts of carbohydrate and fatty acids. It is a cheaper source of manganese as compared to other conventional sources like spices and nuts. It contains high amounts of calcium, which is most essential for bone growth and maintenance. It is proven to reduce cholesterol levels and also reduces the risk of heart diseases besides preventing breast cancer among other diseases.

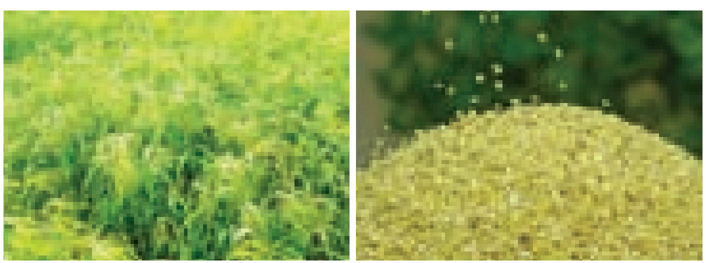

Figure 10: Proso panicles and grain

## 3.9. Millet grain structure and classification

Millet grain structure (Fig. 11) is similar to other cereal grains with three principal parts namely endosperm, germ and pericarp.


Figure 11. Structure of millet grain

Pericarp is the outermost component of the grain and is composed of three sub-layers: epicarp, mesocarp and endocarp. Epicarp can be 1-4 layers thick and may contain pigments which give color to the grains. Underneath the endocarp is the testa or seed-coat (Mcdonough and Rooney, 1989). The endosperm consists of the outer aleurone layer and starchy endosperm. The aleurone cells are located beneath the seed coat. The starchy endosperm can be classified into peripheral, floury and corneous components. The corneous part is hard and vitreous-like and mainly found in the outer layer while the floury component is soft and floury, pre-dominating the centre of the endosperm (Mcdonough *et al.*,1986).

Starch granules in the endosperm are embedded in a protein network and the protein matrix is continuous in the peripheral and corneous zones while discontinuous in the floury zone. The number of protein bodies decreases corresponding to the increase in starch content from the peripheral zone to the central core, where the floury endosperm is located. The shape or size of the starch granule and the nature of protein matrix differs according to the endosperm zone. The ratio of all these three components can vary among different millet types and may thereby affect kernel hardness and also enzyme susceptibility of the grains (Hadimani, 2001; FAO, 1995).

Pearl millet kernel comprises of 75% endosperm, 17% germ and 8% pericarp (Salvidar and Rooney, 1995). Pearl millet has a larger germ compared to other cereals and the endosperm to germ ratio is 4.5:1 (Fig. 12). Botanically millets are separated into caryopses and utricles. The seed coat in utricles is covered by the pericarp, which is attached at only one point resulting in its easy removal. In a caryopsis, the pericarp is strongly attached to the seed. Pearl millet and kodo (Fig. 13) millet is caryopsis-type while proso (Fig. 14), foxtail (Fig. 15), little (Fig. 16), barynyard and finger millets (Fig. 17) are being utricle type grain (Mcdonough and Rooney, 2000) The embryos of proso and finger millets are small with an endosperm to germ ratio of 11-12:1 (FAO 1995; Zarnkow *et al.* 2007).

Millets usually have a single layer thick seed coat except finger millet, which is unique with a very thick seed coat with five cell layers. The seed coat of finger millet is tightly attached to the aleurone layer and the starchy endosperm (Fig. 17.).

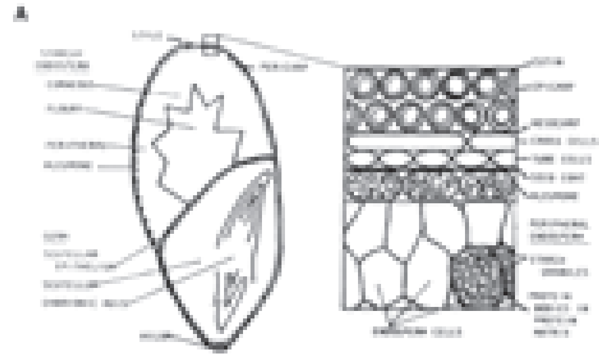

**Figure 12: Microstructure of Pearl millet**

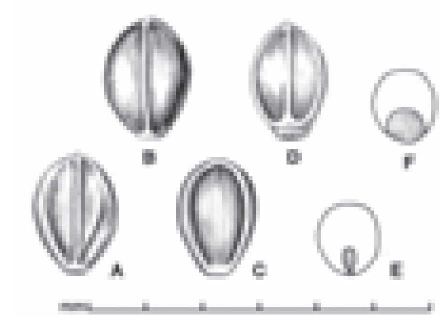

**Figure 13: E, caryopsis in ventral view; F, caryopsis in dorsal view**

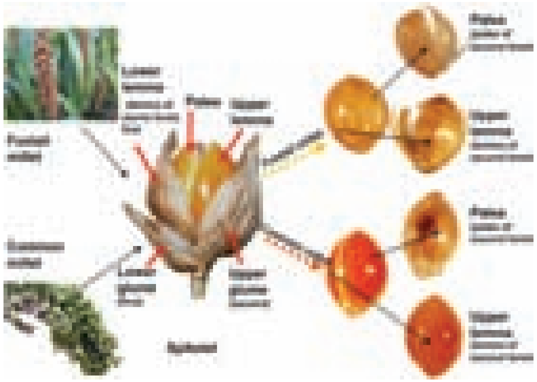

Figure 14: Illustrations of spikelet and grain of millets with botanical terms

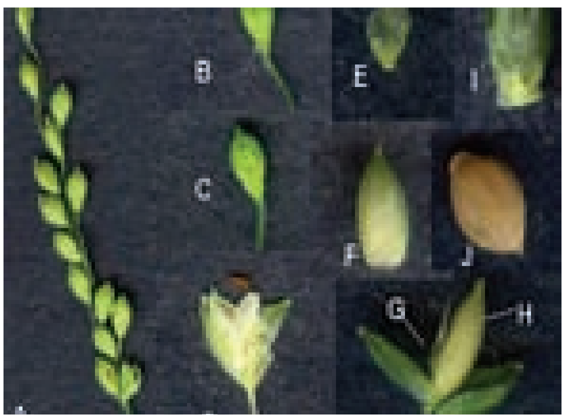


Figure 15: Grain enclosed in lemma and palea (J)

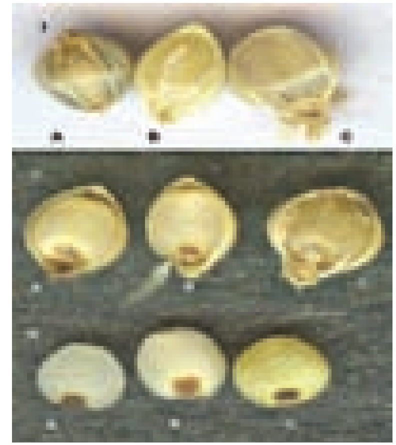

Figure 16: Enlarged grain enclosed by lemma and palea,

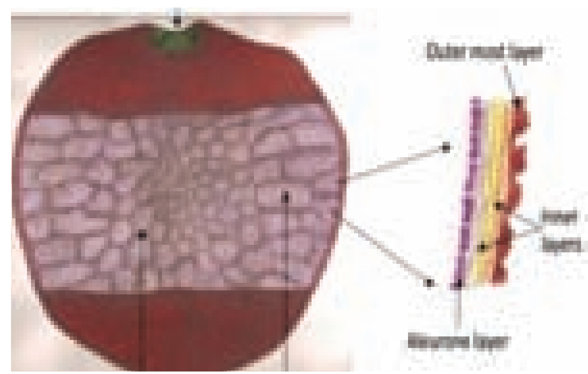


Figure 17: Finger millet kernel (Endosperm and Peripheral Portion) and 5 cell layer

Millets possess unique nutritional characteristics and specifically have complex carbohydrates, rich in dietary fiber as well as unique in phenolic compounds and phyto-chemicals boasting of medicinal properties. Epidemiological studies have shown that diets rich in plant foods, including whole grains, are protective against non-communicable diseases like diabetes, cancer and cardiovascular diseases, due to protective effects of health promoting phyto-nutrients. Being non-glutinous, millets are safe for people suffering from gluten allergy and celiac disease. Gluten-intolerant persons (celiac) allergic to gliadin, a prolamin specific to wheat and some other common grains, comprise a large segment of population. As millets are gluten-free, they could be useful dietary cereals. They are non-acid forming and hence easy to digest and are also non-allergenic. It is well recognized that the incidence of diabetes and gastro-intestinal tract related disorders are minimal among those consuming grains as staple food.

Millets are nutritionally comparable to major cereals and serve as good sources of protein, micronutrients and phyto-chemicals. The processing methods like soaking, malting, decortications, and cooking affects the anti-oxidant content and activity (Saleh *et al.*, 2013). Recently, an interest in both sorghum and millet in high-end food products, snack foods, gluten free foods and in health food markets has begun in regions of the world that have traditionally not used these grains. Millets complement well with lysine-rich vegetable (leguminous) and animal proteins and form nutritionally balanced composites of high biological value.

Finger Millet

# Chapter-IV

# Nutritional Value of Millets

By any nutritional parameter, millets are miles ahead of rice and wheat in terms of their mineral content. Each type of millet has more fiber than rice and wheat, including some as much as fifty times that of rice. Finger millet has thirty times more calcium than rice while every other millets have at least twice the amount of calcium, comparatively speaking.

In their iron content, foxtail and little millet are so rich that rice is rendered inconsequential on this singular count. While most of us seek a micronutrient such as β-carotene in pharmaceutical pills and capsules, millets offer them in abundance. The much-privileged rice, ironically, has zero quantity of this precious micronutrient. In this fashion, nutrient to nutrient, every single millet is extraordinarily superior to rice and wheat and therefore is the solution to combat and conquer malnutrition that affects a vast majority of the Indian population.

The proximate composition of the millet not only compares very well with other cereals but also is superior to wheat, maize, sorghum and rice with regard to dietary fiber, calcium and a few other micronutrient contents (Table 3).

Millets contain 6-8% protein, 1-1.7% fat, 65-75% starch, 2-2.5% minerals and 18-20% dietary fiber (Chethan and Malleshi, 2007). They are very effective sources of phyto-chemicals with neutraceutical properties.

**Table 3: Proximate and dietary fiber content of millets and major cereals (per 100 g)**

| Millets and Cereals | | Moisture (g) | Protein (g) | Ash (g) Total | Total Fat (g) Insoluble | Dietary Fibre (g) | | | Carbohydrates (g) | Energy (KJ) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Soluble | | | | |
| Bajra (*Pennisetum glaucum*) | | 08.97 ± 0.60 | 10.96 ± 0.26 | 1.37 ± 0.17 | 5.43 ± 0.64 | 11.49 ± 0.62 | 9.14 ± 0.58 | 2.34 ± 0.42 | 61.78 ± 0.85 | 1456 ± 18 |
| Sorghum (*Sorghum vulgare*) | | 09.01 ± 0.77 | 09.97 ± 0.43 | 1.39 ± 0.34 | 1.73±0.31 | 10.22± 0.49 | 8.49 ± 0.40 | 1.73 ± 0.40 | 67.68 ± 1.03 | 1398 ± 13 |
| Ragi (*Eleusine coracana*) | | 10.89 ± 0.61 | 07.16 ± 0.63 | 2.04 ± 0.34 | 1.92 ± 0.14 | 11.18 ± 1.14 | 9.51 ± 0.65 | 1.67 ± 0.55 | 66.82 ± 0.73 | 1342 ± 10 |
| Little Millet (*Panicum miliare*) | | 14.23 ± 0.45 | 08.92 ± 1.09 | 1.72 ± 0.27 | 2.55± 0.13 | 06.39 ± 0.60 | 5.45 ± 0.48 | 2.27 ± 0.52 | 65.55 ± 1.29 | 1449 ± 19 |
| Kodo Millet (*Setaria italica*) | | 14.23 ± 0.45 | 08.92 ± 1.09 | 1.72 ± 0.27 | 2.55 ± 0.13 | 06.39 ± 0.60 | 4.29 ± 0.82 | 2.11 ± 0.34 | 66.19 ± 1.19 | 1388 ± 10 |
| Foxtail Millet* | | 11.20 | 12.30 | - | 4.30 | - | - | - | 60.09 | 331 |
| Barnyard Millet* | | 11.90 | 06.20 | - | 2.20 | - | - | - | 65.55 | 307 |
| Proso Millet* | | 11.90 | 12.50 | - | 1.10 | - | - | - | 70.04 | 341 |
| Wheat | Whole | 10.58 ± 1.11 | 10.59 ± 0.60 | 1.42 ± 0.19 | 1.47 ± 0.05 | 11.23 ± 0.77 | 9.63 ± 0.19 | 1.60 ± 075 | 64.72 ± 1.74 | 1347 ± 23 |
| | Refined flour | 11.34 ± 0.93 | 10.36 ± 0.29 | 0.51 ± 0.07 | 0.76± 0.07 | 02.76 ± 0.29 | 2.14 ± 0.30 | 0.62 ± 0.14 | 74.27 ± 0.92 | 1472 ± 16 |
| | Atita | 11.10 ± 0.35 | 10.57 ± 0.37 | 1.28 ± 0.19 | 1.53 ± 0.12 | 11.36 ± 0.29 | 9.73 ± 0.47 | 1.63 ± 0.64 | 64.17 ± 0.32 | 1340 ± 07 |
| | Semolina | 08.94 ± 0.68 | 11.38 ± 0.37 | 0.80 ± 0.17 | 0.74 ± 0.10 | 09.72 ± 0.74 | 8.16 ± 0.58 | 1.55 ± 0.18 | 68.43 ± 0.99 | 1396 ± 18 |
| Rice | Raw brown | 09.33 ± 0.39 | 09.16 ± 0.75 | 1.04 ± 0.18 | 1.24 ± 0.08 | 04.43 ± 0.54 | 3.60 ± 0.55 | 0.82 ± 0.15 | 74.80 ± 0.85 | 1480 ± 10 |
| | Raw milled | 09.93 ± 0.75 | 07.94 ± 0.58 | 0.56 ± 0.08 | 0.52 ± 0.05 | 02.81 ± 0.42 | 1.99 ± 0.39 | 0.82 ± 0.22 | 78.24 ± 0.68 | 1491 ± 15 |
| | Parboiled | 10.09 ±0.43 | 07.89 ± 0.63 | 0.65 ± 0.8 | 0.55 ± 0.08 | 03.74 ± 0.36 | 2.98 ± 0.35 | 0.76 ± 0.09 | 77.16 ± 0.76 | 1471 ± 8 |
| Quinoa (*Chenopodium quinoa)* | | 10.43 | 13.11 | 02.65 | 5.50 | 14.66 | 10.21 | 4.46 | 53.65 | 1374 |
| Amaranth Seed | Black | 09.89 | 14.59 | 02.78 | 5.74 | 07.02 | 5.76 | 1.26 | 59.98 | 1490 |
| | Pale brown | 09.20 ± 0.40 | 13.27 ± 0.34 | 3.05 ± 0.30 | 5.56 ± 0.3 | 07.47 ± 0.09 | 5.80 ± 0.17 | 1.67 ± 0.21 | 61.46 ± 0.60 | 1489 ± 10 |
| Maize | Dry | 09.26 ± 0.55 | 08.80 ± 0.49 | 1.17 ± 0.16 | 3.77 ± 0.48 | 12.24 ± 0.93 | 11.29 ± 0.85 | 0.94 ± 0.18 | 64.77 ± 1.58 | 1398 ± 25 |

(*Source*: Indian food composition tables, NIN – 2017 and *Nutritive value of Indian Foods, NIN -2007)

## 4.1 Carbohydrates

The millet grain contains about 65% carbohydrate, a high proportion of which is in the form of non-starchy polysaccharides and dietary fiber, which help in prevention of constipation, lowering of blood cholesterol and slow release of glucose to the blood stream during digestion. Lower incidence of cardiovascular diseases, duodenal ulcer and hyperglycemia (diabetes) are reported among regular millet consumers.

Millets have total starch ranging from 64-79% (Geervani and Eggum, 1989; Krishnakumari and Thayumanavan, 1995). Millets vary largely in the composition of carbohydrates as proportions of amylose and amylopectin content vary from 16-28% and 72-84%, respectively. The free sugars found in millet are glucose, fructose, sucrose and raffinose and their contents ranges from 1-1.4% with sucrose (0.3-1.2%) being the predominant sugar (Malleshi *et al*; 1986). Total sugars in small millets ranged from 1.4 to 2% (Table 4 & 5).

## 4.2 Dietary fiber

Millets are rich sources of insoluble (IDF) and soluble (SDF) dietary fiber and has comparable or even higher total dietary fiber (TDF) than other cereals.

Studies on barnyard, kodo, foxtail and little millets have revealed IDF at 18-30% and SDF as 0.6-2% in whole form. Decortication decreased the amount of IDF to 1.5-3% and SDF to 0.3-0.9% (Geervani and Eggum, 1989).

Reports on proso millets have shown that TDF of 12–20% in whole grain varieties decreased to 3–5% after decortications (Bagdi *et al*., 2011). Wide variations (7–21.2%) in TDF content of ten varieties of whole grain finger millet have been reported (Premavalli *et al*., 2004). Therefore, millet type, variety and extent of decortications have an important effect on the IDF and SDF content.

**Table 4: Starch and individual sugars profile of millets and major cereals**

| Millets and Cereals | Total Available CHO (g) | Total Starch (g) | Fructose (g) | Glucose (g) | Sucrose (g) | Maltose (g) | Total Free Sugars (g) |
|---|---|---|---|---|---|---|---|
| Bajra (*Pennisetum glaucum*) | 56.02 ± 2.57 | 55.21 ± 2.57 | 0.21 ± 0.01 | 0.60 ± 0.02 | - | - | 0.81 ± 0.01 |
| Sorghum (*Sorghum bicolor*) | 60.96 ± 1.70 | 59.70 ± 1.70 | 0.57 ± 0.07 | 0.10 ± 0.01 | 0.60 ± 0.04 | - | 1.27 ± 0.05 |
| Ragi (*Eleusine coracana*) | 62.47 ± 1.24 | 62.13 ± 1.13 | - | 0.25 ± 0.06 | 0.12 ± 0.02 | - | 034 ± 0.06 |
| Little millet (*Panicum miliare*) | 56.43 ± 4.09 | 56.07 ± 4.12 | - | 0.24 ± 0.10 | 0.13 ± 0.01 | - | 0.37 ± 0.09 |

(*Source:* Indian food composition tables, NIN – 2017)

| Millets and Cereals | | Total Available CHO (g) | Total Starch (g) | Fructose (g) | Glucose (g) | Sucrose (g) | Maltose (g) | Total Free Sugars (g) |
|---|---|---|---|---|---|---|---|---|
| Wheat | Whole | 58.60 ± 2.68 | 56.82 ± 2.69 | 0.72 ± 0.03 | 0.78 ± 0.05 | 0.30 ± 0.02 | - | 1.80 ± 0.06 |
| | Refined flour | 71.82 ± 1.07 | 70.03 ± 1.01 | 064 ± 0.03 | 0.75 ± 0.02 | 0.40 ± 0.05 | - | 1.79 ± 0.08 |
| | Atta | 58.62 ± 2.68 | 56.82 ± 2.69 | 0.72 ± 0.03 | 0.78 ± 0.05 | 0.30 ± 0.02 | - | 1.80 ± 0.06 |
| | Semolina | 59.85 ± 2.99 | 58.20 ± 2.95 | 0.60 ± 0.04 | 0.55 ± 0.03 | 0.50 ± 0.04 | - | 1.65 ± 0.08 |
| Rice | Raw brown | 72.00 ± 1.87 | 71.31 ± 1.91 | - | 0.55 ± 0.08 | 0.14 ± 0.02 | - | 0.69 ± 0.08 |
| | Raw milled | 76.39 ± 2.76 | 75.70 ± 2.70 | - | 0.54 ± 0.25 | 0.15 ± 0.06 | - | 0.69 ± 0.28 |
| | Parboiled | 76.80 ± 5.71 | 76.14 ± 5.73 | - | 0.51 ± 0.24 | 0.16 ± 0.06 | - | 0.67 ± 0.25 |
| Quinoa (*Chenopodium quinoa*) | | 49.825 | 48.41 | - | 1.41 | - | - | 1.41 |
| Amaranth Seed | Black | 56.71 | 55.83 | 0.10 | 0.22 | 0.46 | 0.10 | 0.88 |
| Amaranth Seed | Pale brown | 60.13 ± 1.30 | 59.33 ± 1.31 | 0.10 ± 0.01 | 0.22 ± 0.04 | 0.48 ± 0.04 | - | 0.80 ± 0.07 |
| Maize | Dry | 61.01 ± 0.76 | 59.35 ± 0.83 | 0.16 ± 0.03 | 0.80 ± 0.01 | 0.70 ± 0.03 | - | 1.66 ± 0.04 |

**Table 5: Amylose and Amylopectin content of millets and cereals**

(proportion of total carbohydrate)

| Cereal grain | Amylose (%) | Amylopectin (%) |
|---|---|---|
| Proso millet | 28.2 | 71.8 |
| Foxtail millet | 17.5 | 82.5 |
| Kodo millet | 24.0 | 76.0 |
| Finger millet | 16.0 | 84.0 |
| Sorghum | 24.0 | 76.0 |
| Bajra | 21.1 | 78.9 |
| Short Grain Rice | 12-19 | 88-81 |
| Wheat | 25.0 | 75.0 |

*(Source*: *MILLET in your Meals*, http://www.sahajasamrudha.org)

## 4.3 Protein

The average protein content of millet is reported to be from 7.7-11.8% (Hulse *et al.,* 1980). Protein in millets has three main fractions: Fraction I - albumin+globulin, Fraction II-true prolamin+prolamin like, Fraction III - 8 true glutelin+glutelin like. The albumin and globulin fraction forms 8.5-16.26%, prolamin fraction forms 15-30%, while glutelin forms 45-55% of the total protein in small millets except foxtail, which has higher prolamin (60%) than glutelin (15.23%) content. Pearl millets had prolamins from 33-49.5%, glutelins 30-45% and globulins plus albumins from 18-26% (Chandna and Matta 1990; Parmeswaran and Thaymanavan 1995).

Millets generally contain significant amounts of essential amino acids, particularly sulphur containing amino acids (methionine and cysteine); Millets also contain high quantities of methionine, an amino acid that is deficient in most grains, giving millet a valuable place in a vegetarian diet (Table 6). Finger millet proteins are unique because of the sulphur-rich amino acid contents.

In general, cereal proteins, including millets, are limited in lysine and tryptophan content and vary with cultivar. However, most cereals contain the essential amino acids as well as vitamins and minerals (FAO, 2009, Devi *et al*., 2011).

The essential amino acid profiles of the millet protein is better than maize. Differences in the amino acid composition have been shown in different millet types. Lysine is the limiting amino acid in millets that is similar to other cereals. Glutamic acid (16-23%) and leucine (12-22.3%) were the major amino acids in the prolamin fraction. However, barnyard had higher content of alanine (18%) than leucine (Parameswaran and Thayumanavan, 1995; Kumar and Parameswaran 1998). Millets complement well with lysine-rich vegetable (leguminous) and animal proteins form nutritionally balanced composites of high biological value.

**Table 6: Amino acid profile of millets and major cereals (mg/g of N)**

| Millets and Cereals | | Histidine | Isoleucine | Luecine | Lysine | Methionine | Cystine | Phenylalanine | Threonine | Tyrptophan | Valine |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bajra (*Pennisetum glaucum*) | | 2.15 ± 0.37 | 3.45 ± 0.74 | 08.52 ± 0.86 | 3.19± 0.49 | 2.11 ± 0.50 | 1.23 ± 0.33 | 4.82 ± 1.18 | 3.55 ± 0.40 | 1.33 ± 0.30 | 4.79 ± 1.04 |
| Sorghum (*Sorghum bicolor*) | | 2.07 ± 0.20 | 3.45 ± 0.63 | 12.03 ± 1.51 | 2.31± 0.40 | 1.52 ± 0.50 | 1.06 ± 0.30 | 5.10 ± 0.50 | 2.96 ± 0.17 | 1.03 ± 0.21 | 4.51 ± 0.71 |
| Ragi (*Eleusine coracana*) | | 2.37 ± 0.46 | 3.70 ± 0.44 | 8.86 ± 0.54 | 2.83± 0.34 | 2.74 ± 0.27 | 1.48± 0.23 | 5.70± 1.27 | 3.84 ± 0.45 | 0.91 ± 0.30 | 5.65 ± 0.44 |
| Little Millet (*Panicum miliare*) | | 2.35 ± 0.18 | 4.14 ± 0.08 | 8.08 ± 0.060 | 2.42± 0.10 | 2.21 ± 0.10 | 1.85 ± 0.14 | 6.14 ± 0.10 | 4.24 ± 0.12 | 1.35 ± 0.10 | 5.31 ± 0.16 |
| Wheat | Whole | 2.65 ± 0.31 | 3.83 ± 0.20 | 06.81 ± 0.33 | 3.13± 0.26 | 1.75 ± 0.21 | 2.35 ± 0.23 | 4.75 ± 0.38 | 3.01 ± 0.17 | 1.40 ± 1.10 | 5.11 ± 0.05 |
| | Refined flour | 1.95 ± 0.23 | 3.19 ± 0.27 | 06.22 ± 0.46 | 2.05± 0.18 | 1.64 ± 0.20 | 2.03± 0.27 | 4.29 ± 0.28 | 2.34 ±0.08 | 1.04 ± 0.16 | 4.01 ± 0.44 |
| | Atta | 2.56 ± 0.25 | 3.78 ± 0.21 | 06.13 ± 0.48 | 2.42± 0.22 | 1.77 ± 19.4 | 2.24 ± 0.18 | 5.03 ± 0.14 | 2.58 ± 0.14 | 0.99 ± 0.16 | 5.12 ± 0.48 |
| | Semolina | 2.38 ± 4.28 | 3.43 ± 0.26 | 06.71 ± 0.59 | 2.54± 0.13 | 1.57 ± 0.23 | 1.79 ± 0.03 | 4.77 ± 0.32 | 2.71 ± 0.15 | 1.04 ± 0.12 | 4.47 ± 0.39 |
| Rice | Raw brown | 2.36 ± 0.18 | 4.08 ± 0.05 | 08.40 ± 0.55 | 3.63± 0.29 | 2.39 ± 0.26 | 2.02 ± 0.12 | 5.50 ± 0.49 | 3.38 ± 0.25 | 1.00 ± 0.17 | 6.72 ± 0.36 |
| | Raw milled | 2.45 ± 0.30 | 4.29 ± 0.23 | 08.09 ± 0.40 | 3.70± 0.39 | 2..60 ± 0.34 | 1.84 ± 0.18 | 5.36 ± 0.43 | 3.28 ± 0.27 | 1.27 ± 0.14 | 6.06 ± 0.02 |
| | Parboiled | 2.35 ± 0.18 | 4.14 ± 0.08 | 08.08 ± 0.06 | 3.42± 0.10 | 2.48 ±0.24 | 2.15 ± 0.08 | 5.14 ± 0.10 | 3.24± 0.12 | 1.15 ± 0.06 | 6.26 ± 0.13 |
| Quinoa (*Chenopodium quinoa*) | | 2.98 | 3.75 | 6.08 | 5.55 | 2.24 | 1.85 | 4.35 | 3.01 | 1.25 | 4.55 |
| Amaranth Seed | Black | 1.86 | 2.82 | 4.83 | 5.45 | 1.86 | 1.60 | 3.98 | 3.02 | 1.05 | 4.34 |
| | Pale brown | 1.98 ± 0.50 | 2.85 ± 0.04 | 04.94 ± 0.17 | 5.50± 0.35 | 1.95±0.12 | 1.51 ± 0.15 | 4.75 ±0.41 | 2.99± 0.21 | 1.69 ± 0.10 | 4.30 ± 0.27 |
| Maize | Dry | 2.70 ± 0.21 | 3.67 ± 0.22 | 12.24 ± 0.57 | 2.64± 0.18 | 2.10± 0.17 | 1.55 ± 0.14 | 5.14 ± 0.29 | 3.23 ± 0.29 | 0.57 ± 0.12 | 5.41 ± 0.71 |

(*Source*: Indian food composition tables, NIN – 2017)

**Table 7: Amino acid profiles of different millets**

| Amino acids (g/100g of protein) | Foxtail millet (defatted flour) [(a)] | Proso millet (dehulled grain) [(b, c)] | Pearl millet (true prolamine) [(c)] | Finger millet (native grain) [(d)] |
|---|---|---|---|---|
| **Essential amino acid** | | | | |
| Iso leucine | 4.59 | 4.1 | 5.1 | 4.3 |
| Leucine | 13.6 | 12.2 | 14.1 | 10.8 |
| Lysine | 1.59 | 1.5 | 0.5 | 2.2 |
| Methionine | 3.06 | 2.2 | 1 | 2.9 |
| Phenylalanaine | 6.27 | 5.5 | 7.6 | 6 |
| Threonine | 3.68 | 3 | 3.3 | 4.3 |
| Valine | 5.81 | 5.4 | 4.2 | 6.3 |
| Histidine | 2.11 | 2.1 | 1.7 | 2.3 |
| Tryptophan | NA | 0.8 | 1.2 | NA |
| **Non-essential amino acid** | | | | |
| Alanine | 9.3 | 10.9 | 8.1 | 6.1 |
| Arginie | 3 | 3.2 | 0.9 | 3.4 |
| Aspartic acid | 7.71 | 6.2 | 6.2 | 5.7 |
| Cysteine | 0.45 | NA | 0.8 | NA |
| Glutamic acid | 22 | 21.3 | 22.8 | 23.2 |
| Glycine | 2.91 | 2.1 | 0.7 | 3.3 |
| Serine | 4.56 | 6.3 | 5.4 | 5.3 |
| Tyrosine | 2.44 | 4 | 2.7 | 8.6 |
| Proline | 5.54 | 7.3 | 8.2 | 9.9 |
| *PER (b) | 0.8 | 1.1 | 1.6 | 2 |

*Source*: [(a)] Kamara *et al.* (2009); [(b)] Bagdi A, *et al.* (2011); [(c)] Saldivar (2003); [(d)] Devi *et al.* (2011); *PER Protein Efficiency Ratio; NA Not-available

## 4.4. Lipid profile

Lipids are concentrated in the germ, pericarp and aleurone layers of the millet grain. The essential fatty acids like linoleic, oleic and palmitic acids found in free form (60-70%) and monogalactosul, diacylglycerols, digalactosyl diacylglycerols, phosphatidylethanolamine, phosphatdyl serine and phosphatidyl choline in the bound form present in millets (Bagdi A, *et al.*, 2011) (Table 7). Other fatty acids like arachidic acid, behenic acid, erucic acid are found in trace amounts. Millet oil could be a good source of linoleic acid and tocopherols. The free lipid content for kodo, finger, barnyard, little, proso, foxtail millet have been reported to be 3.4%, 5.2%, 5.7%, 5.4%, 5.6% and 5% respectively (Sridhar and Laxminarayana 1992, 1994). Bound and structural lipids of small millets were reported to be 1.3- 5% and 0.4-0.9%, respectively. Linoleic (38-40%), oleic (27-37%), palmitic (16-22%) and linolenic (1-4%) are the major fatty acids found in millets (Table 8). Unsaturated fatty acids account for more than 85% of the total fatty acid content in millets (Lai and Martson, 1980; Sridhar and Laxminarayana, 1992). Millet pericarp and germ have considerable amount of lipids, which can be affected by the extent decortications of millets (Liang *et al.*, 2010). However, there is a dearth of information on evaluating the changes in lipid content and fatty acid profile of millets after decortications.

**Table 8: Fatty acid composition of millets and major cereals**

| Millets and Cereals | | Palmitic (mg) | Stearic (mg) | Palmitoleic (mg) | Oleic (mg) | Linoleic (mg) | Total Saturated Fatty Acids (mg) | Total Mono Saturated Fatty Acids (mg) |
|---|---|---|---|---|---|---|---|---|
| Bajra (*Pennisetum glaucum)* | | 729± 21.3 | 128± 19.6 | 6.97 ± 0.45 | 1040± 39.8 | 1844 ±56.7 | 875 ±34.5 | 1047 ± 39.9 |
| Sorghum (*Sorghum bicolor)* | | 149 ± 5.6 | 14.22± 0.79 | - | 3..14 ± 13.7 | 508 ± 18.3 | 163 ± 6.2 | 314 ± 13.7 |
| Ragi (*Eleusine coracana)* | | 290 ± 15.4 | 27.86 ± 2.43 | - | 585 ± 36.3 | 362 ± 15.3 | 317± 17.0 | 585± 36.3 |
| Little Millet (*Panicum miliare)* | | 487 ± 26.1 | 102±11.9 | - | 868 ± 24.2 | 1230± 42.9 | 589 ± 31.9 | 868 ± 24.2 |
| Foxtail Millet * | | 6.40 | 6.30 | - | 13.0 | 66.50 | - | - |
| Barnyard Millet * | | 10.80 | - | - | 53.80 | 34.90 | - | - |
| Wheat | Whole | 176± 7.4 | 14.83 ± 2.25 | - | 141 ± 9.4 | 616 ± 22.1 | 191 ± 8.0 | 141 ± 9.4 |
| | Refined flour | 91.24 ± 1.50 | 7.31 ± 0.73 | - | 50.64± 2.98 | 325 ± 6.8 | 98.55± 1.87 | 50.64 ± 2.98 |
| | Atta | 191± 5.6 | 14.55± 3.10 | - | 149 ± 7.5 | 697± 19.4 | 206 ± 82 | 149± 7.5 |
| | Semolina | 81.63 ± 4.28 | 7.24 ± 1.49 | - | 67.34± 3.25 | 306± 3.0 | 88.87 ± 5.16 | 67.34± 3.25 |
| Rice | Raw brown | 273 ± 14.99 | 33.01 ± 4.34 | 2.77± 0.46 | 197± 15.4 | 490 ± 33.2 | 346 ± 20.3 | 203 ± 15.7 |
| | Raw milled | 143 ± 28.0 | 14.50± 3.27 | 1.49 ± 0.47 | 109 ± 21.2 | 234± 45.8 | 184± 8.9 | 117 ± 6.6 |
| | Parboiled | 120 ±8.0 | 13.83 ± 1.67 | 1.19 ± 0.21 | 84.09 ± 6.47 | 209 ±12.8 | 150 ± 10.2 | 86.66 ± 6.38 |
| Quinoa (*chenopodium quinoa)* | | 434 | 52.88 | 56.79 | 1323 | 2203 | 570 | 1424 |
| Amaranth Seed | Black | 1043 | 155 | - | 1020 | 2259 | 1280 | 1033 |
| Amaranth Seed | Pale brown | 891 ± 54.5 | 172 ± 14.1 | - | 1030 ± 64.3 | 2223± 129 | 1140 ± 70.05 | 1043 ± 65.8 |
| Maize | Dry | 363 ± 4.6 | 42.45 ±2.76 | - | 700 ± 17.9 | 1565± 18.2 | 413 ± 5.6 | 706 ±17.4 |

(*Source*: Indian food composition tables, NIN – 2017 and *Nutritive value of Indian Foods, NIN -2007)

## 4.5. Vitamin content

Millet grains are also rich in important vitamins; Thiamine, riboflavin, folic acid and niacin (Vidyavati *et al*., 2004). The niacin content in pearl millet is higher than all other cereals. Kodo millet is rich in B vitamins, especially niacin, pyridoxine and folic acid. Sorghum and millets, in general, are rich sources of B-complex vitamins. Some yellow-endosperm varieties of sorghum contain ß-carotene, which can be converted to vitamin A by the human body. Detectable amounts of other fat-soluble vitamins, namely D, E and K, have also been found in millets. Millets are generally not a source of vitamin C. On germination, some amount of vitamin C is synthesized in the grain and on fermentation there is a further rise in the vitamin. Higher levels of dietary ascorbic acid apparently had a niacin-sparing effect on the millet-based diet. Among B-group vitamins, concentrations of thiamin, riboflavin and niacin in sorghum were comparable to those in maize (Table 9-11).

**Table 9: Fat soluble vitamins profile of millets and major cereals**

| Millets and Cereals | | Ergocalcife (µg) Alpha | Tocopherols (mg) | | | | Tocotrienols (mg) | | | α - Tocopherol (mg) | Phylloquinoes – K1 (µg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Beta | Gamma | Delta | Alpha | Gamma | Delta | | | |
| Bajra (*Pennisetum glaucum)* | | 05.65 ± 0.27 | 0.10 ± 0.010 | - | 1.42 ± 0.20 | - | | - | - | 0.24 ± 0.02 | 02.85 ± 0.63 |
| Sorghum (*Sorghum bicolor)* | | 03.96 ± 0.03 | 0.04 ± 0.010 | - | 0.27 ± 0.03 | - | | - | - | 0.06 ± 0.01 | 43.82 ± 4.84 |
| Ragi (*Eleusine coracana)* | | 41.46 ± 3.12 | 0.09 ± 0.010 | - | 0.66 ± 0.06 | - | | - | - | 0.16 ± 0.01 | 03.00 ± 0.44 |
| Little Millet (*Panicum miliare)* | | 03.75 ± 0.80 | 0.28 ± 0.140 | 0.67 ±0.40 | - | - | | 0.28± 0.09 | - | 0.55 ± 0.16 | 04.47 ± 0.38 |
| Wheat | Whole | 17.49 ± 0.07 | 0.60 ± 0.330 | 0.37 ± 0.12 | - | - | 0.07± 0.03 | 1.03± 0.58 | 30.09± 3.79 | 0.77 ± 0.35 | 01.75 ± 0.26 |
| | Refined flour | 06.73 ± 0.96 | 0.05 ± 0.010 | - | - | - | | - | - | 0.05 ± 0.01 | 01.00 ± 0.46 |
| | *Atta* | 13.42 ± 1.77 | 0.21 ± 0.090 | 0.06 ± 0.01 | - | - | 0.06± 0.03 | - | - | 0.26 ± 0.09 | 01.50 ± 0.47 |
| | Semolina | 0.290 ± 0.03 | 0.04 ± 0.004 | 1.13 ± 0.10 | 0.75 ± 0.08 | 0.11± 0..010 | | 0.44± 0.04 | 25.68± 3.64 | 0.69 ± 0.12 | 02.00 ± 0.83 |

| Millets and Cereals | | Ergocalcife ($\mu g$) | Tocopherols (mg) | | | | Tocotrienols (mg) | | | α - Tocopherol (mg) | Phylloquinoes – K1 ($\mu g$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Alpha | Beta | Gamma | Delta | Alpha | Gamma | Delta | | | |
| Rice | Raw Brown | - | 0.62 ± 0.080 | 0.05 ± 0.02 | 0.42 ± 0.57 | - | 0.03± 0.02 | - | 0.05 ± 0.02 | - | |
| | Raw milled | - | 0.04 ± 0.030 | - | 0.06 ± 0.02 | - | 0.03± 0.02 | - | 0.05 ± 0.02 | 0.06 ± 0.03 | 01.50 ± 0.40 |
| | Parboiled | - | 0.06 ± 0.040 | - | 0.13 ± 0.12 | - | 0.05± 0.02 | - | - | 0.09 ± 0.04 | 01.50 ± 0.50 |
| Quinoa (*Chenopodium quinoa)* | | - | 2.08 | 0.06 | 2.85 | - | - | - | - | 2.08 | 2.00 |
| Amaranth Seed | Black | 0.04 | 0.04 | 0.45 | 0.24 | 0.50 | | 1.92 | 27.44 | - | |
| | Pale brown | 53.98 ± 3.38 | 0.06 ± 0.00 | 0.22 ± 0.10 | 0.03 ± 0.01 | - | - | - | - | 0.15 ± 0.03 | 02.50 ± 0.87 |
| Maize | Dry | 33.60 ± 2.82 | 0.21 ± 0.04 | - | 1.29 ± 0.17 | 0.38±0.05 | 0.05± 0.00 | - | - | 0.36 ± 0.03 | 02.50 ± 0.76 |

(*Source*: Indian food composition tables, NIN – 2017 and *Nutritive value of Indian Foods, NIN -2007)

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**Table 10: Water soluble vitamins profile of millets and major cereals**

| Millets and Cereals | | Thiamine B1 (mg) | Riboflavin B2 (mg) | Niacin B3 (mg) | Pantothenic Acid – B5 (mg) | Total B6 (mg) | Biotin B7 (µg) | Total Folates B9 (µg) | Total Ascorbic acid (mg) |
|---|---|---|---|---|---|---|---|---|---|
| Bajra (*Pennisetum typhoideum*) | | 0.25 ± 0.044 | 0.20 ± 0.038 | 0.86 ± 0.10 | 0.50 ± 0.05 | 0.27 ± 0.09 | 0.64 ± 0.05 | 36.11 ± 5.05 | - |
| Sorghum (*Sorghum vulgare*) | | 0.35 ± 0.039 | 0.14 ± 0.014 | 2.10 ± 0.09 | 0.27 ± 0.02 | 0.28 ± 0.023 | 0.70 ± 0.06 | 39.42 ± 3.13 | - |
| Ragi (*Eleusine coracana*) | | 0.37 ± 00.041 | 0.17 ± 0.008 | 1.34 ± 002 | 0.29 ± 0.19 | 0.05 ± 0.007 | 0.88 ± 0.05 | 34.66± 4.97 | - |
| Little Millet (*Panicum miliare*) | | 0.26 ± 0.042 | 0.05 ± 0.008 | 1.29 ± 0.02 | 0.60 ± 0.07 | 0.04 ± 0.005 | 6.03± 0.57 | 36.20 ± 7.04 | - |
| Kodo Millet (*Setaria italica*) | | 0.29 ± 0.054 | 0.20 ± 0.018 | 1.49 ± 0.08 | 0.63 ± 0.07 | 0.07 ± 0.017 | 1.49 ± 0.18 | 39.49 ± 4.52 | - |
| Foxtail Millet* | | 0.59 | 0.11 | 3.20 | 0.82 | - | - | - | - |
| Barnyard Millet* | | 0.33 | 0.10 | 4.20 | - | - | - | - | |
| Proso Millet* | | 0.41 | 0.28 | 4.50 | 1.20 | - | - | - | |
| Wheat | Whole | 0.46± 0.067 | 0.15 ± 0.041 | 2.68 ± 0.19 | 1.08 ± 0.21 | 0.26 ± 0.036 | 1.03± 0.58 | 30.09 ±3.79 | - |
| | Refined flour | 0.15 ± 0.0.17 | 0.06 ± 0.08 | 0.77 ± 0.07 | 0.72± 0.08 | 0.08 ± 0.008 | 0.58 ± 0.09 | 16.25 ± 2.62 | - |
| | Atta | 0.42± 0.044 | 0.15 ± 0.010 | 2.37 ± 0.10 | 0.87 ± 0.04 | 0.25± 0.032 | 0.76± 0.12 | 29.22 ± 1.92 | - |
| | Semolina | 0.29 ± 0.025 | 0.04 ± 0.004 | 1.13± 0.10 | 0.75± 0.08 | 0.11± 0..010 | 0.44± 0.04 | 25.68 ± 3.64 | - |
| Rice | Raw Brown | 0.27 ± 0.023 | 0.06 ± 0.011 | 3.40 ± 0.12 | 0.16± 0.04 | 0.37 ± 0.035 | 1.38 ± 0.21 | 11.51 ± 1.69 | - |
| | Raw milled | 0.05 ± 0.019 | 0.05± 0.006 | 1.69± 0.13 | 0.57 ± 0.05 | 0.12± 0.012 | 0.60 ± 0.12 | 9.32 ± 1.93 | - |
| | Parboiled | 0.17 ±0.023 | 0.06 ± 0.018 | 2.51 ± 0.49 | 0.55 ± 0.06 | 0.22 ± 0.017 | 0.31 ± 0.02 | 9.75 ± 2.10 | - |
| Quinoa (*Chenopodium quinoa*) | | 0.83 | 0.22 | 1.70 | 0.62 | 0.21 | 0.62 | 1.73 | - |
| Amaranth Seed | Black | 0.04 | 0.04 | 0.45 | 0.24 | 0.50 | 1.92 | 27.44 | - |
| | Pale Brown | 0.04 ± 0.007 | 0.04 ± 0.07 | 0.52 ± 0.05 | 0.28 ± 0.03 | 0.33 ± 0.023 | 1.87 ± 0.24 | 24.65 ± 3.21 | - |
| Maize, Dry | | 0.33± 0.32 | 0.09 ± 0.009 | 2.69 ± 0.06 | 0.34 ± 0.03 | 0.34 ± 0.017 | 0.49 ± 0.05 | 25.81 ± 1.44 | - |

(*Source*: Indian food composition tables, NIN – 2017 and Nutritive value of Indian Foods, NIN -2007)

Kodo Millet

## Table 11: Carotenoids profile of millets and major cereals

| Millets and Cereals | | Lutein (µg) | Zeaxanthin (µg) | Lycopene (µg) | β-Cryptoxanthin | γ- Carotene | β-Carotene | Total Carotenoids |
|---|---|---|---|---|---|---|---|---|
| Bajra (*Pennisetum glaucum)* | | 29.69 ± 08.72 | 9.30 ± 1.23 | - | - | - | 28.23 ± 9.42 | 293 ± 55.7 |
| Sorghum (*Sorghum bicolor)* | | 09.08 ± 01.77 | 7.48 ± 2.41 | - | - | - | 08.29 ± 1.30 | 212 ± 48.9 |
| Ragi (*Eleusine coracana)* | | 25.53 ± 05.82 | 1.45 ± 0.23 | - | - | - | 01.53 ± 0.25 | 154 ± 25.6 |
| Little Millet (*Panicum miliare)* | | 07.82 ± 01.76 | 5.24 ± 1.66 | - | - | - | 01.91 ± 0.89 | 120 ± 09.0 |
| Wheat | Whole | 52.56 ± 05.67 | 1.47 ± 0.68 | - | - | - | 01.03 ± 0.58 | 30.1 ± 3.79 |
| | Refined flour | 24.41 ± 09.21 | 1.30 ± 0.72 | - | - | - | 03.03 ± 2.13 | 287 ± 40.0 |
| | Atta | 42.12 ± 11.27 | 1.31 ± 0.69 | - | - | - | 02.67 ± 1.29 | 284 ± 31.9 |
| | Semolina | 29.94 ± 07.39 | 1.13 ± 0.66 | - | - | - | 01.60 ± 0.59 | 276 ± 29.9 |
| Rice | Raw Brown | 13.15 ± 04.03 | - | - | - | - | - | 159 ± 13.9 |
| | Raw milled | 01.49 ± 00.46 | - | - | - | - | - | 16.9 ± 5.61 |
| | Parboiled | 01.46 ± 00.72 | - | - | - | - | - | 46.9 ± 8.29 |
| Quinoa (*Chenopodium quinoa)* | | 11.88 | 10.05 | - | - | - | 5.12 | 153 |
| Amaranth Seed | Black | 0.25 | - | - | - | - | - | 121 |
| | Pale brown | 04.11 ± 01.16 | - | - | - | - | - | 59.7 ± 3.09 |
| Maize | Dry | 186.0 ± 19.40 | 42.4 ± 15.70 | - | 110 ± 10.1 | - | 186.0 ± 19.2 | 893 ± 154 |

(*Source*: Indian food composition tables, NIN – 2017)

## 4.6. Mineral content

Small millets are more nutritious compared to fine cereals. Millets contain substantial quantities of several minerals, including calcium, iron, potassium and magnesium. Finger millet is the richest source of calcium (300-400 mg/100 g) and other small millets are good source of phosphorous and iron (Table 12). Magnesium is a micronutrient used for bone mineralization, teeth maintenance, building up of proteins, enzyme activities, normal muscular contractions and transmission of nerve impulses. Sorghum is considered a good source of potassium and is practically devoid of sodium. Whole grains are good sources of magnesium, iron, zinc, and copper. Black finger millet contains approximate 1830 $\mu$g/g of magnesium (Glew *et al*; 2008), while normal finger millet has about 130 mg/100g of magnesium (Amir Gull, 2014).

**Table 12: Trace elements of millets and major cereals (mg/100g)**

| Millets and Cereals | Aluminium (mg) | Arsenic (mg) | Cadmium (mg) | Calcium (mg) | Chromium (mg) | Cobalt (mg) | Copper (mg) | Iron (mg) | Lead (mg) | Lithium (mg) |
|---|---|---|---|---|---|---|---|---|---|---|
| Bajra (*Pennisetum glaucum*) | 2.21 ± 0.78 | 0.97 ± 0.24 | 0.003 ± 0.001 | 27.35 ± 2.16 | 0.025 ± 0.006 | 0.030 ± 0.015 | 0.54 ± 0.11 | 6.42 ± 1.04 | 0.008 ± 0.002 | 0..003 ± 0..001 |
| Sorghum (*Sorghum bicolor*) | 2.56 ± 0.59 | 1.53 ± 0.04 | 0.002 ± 0.002 | 27.60 ± 3.71 | 0.010 ± 0.003 | 0.012 ± 0.007 | 0.45 ± 0.11 | 3.95± 0.94 | 0.008 ± 0..003 | 0.001 ± 0.001 |
| *Ragi* (*Eleusine coracana*) | 3.64 ± 0.69 | - | 0.004 ± 0.004 | 364 ± 58 | 0.032 ± 0.019 | 0.022 ± 0.009 | 0.67± 0.22 | 4.62 ± 0.36 | 0.005 ± 0.002 | 0.003 ± 0.003 |
| Little millet (*Panicum miliare*) | - | 0.49 ± 0.15 | 0.001 ± 0.000 | 16.06 ± 154 | 0.016 ± 0.006 | 0.001 ± 0.00 | 0.34± 0.08 | 1.26± 0.44 | - | - |
| Foxtail millet * | - | - | - | - | 0.030 | - | 1.40 | | | |
| Barnyard millet * | - | - | - | - | 0.090 | - | 0.60 | | | |
| Proso millet * | - | - | - | - | 0.020 | - | 1.60 | | | |

| Millets and Cereals | | Aluminium (mg) | Arsenic (mg) | Cadmium (mg) | Calcium (mg) | Chromium (mg) | Cobalt (mg) | Copper (mg) | Iron (mg) | Lead (mg) | Lithium (mg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | Whole | 0.55 ± 0.23 | - | 0.002 ± 0.001 | 39.36 ± 5.65 | 0.006 ± 0.003 | 0.003 ± 0.002 | 0.49 ± 0.12 | 3.97 ± 0.78 | - | 0.005 ± 0.004 |
| | Refined flour | 0.94 ± 0.33 | - | 0.001 ± 0.000 | 20.40 ± 2.46 | 0.005 ± 0.002 | 0.001 ± 0.001 | 0.17 ± 0.02 | 1.77 ± 0.38 | 0.004 ± 0.002 | 0.003 ± 0.003 |
| | *Atta* | 1.54 ± 0.53 | - | 0.01 ± 0.001 | 30.94± 3.65 | 0.006 ± 0.005 | 0.006 ± 0.003 | 0.48 ± 0.11 | 4.10 ± 0.67 | 0.006 ± 0.003 | 0.002 ± 0.001 |
| | Semolina | 0.64 ± 0.19 | - | 0.002 ± 0.001 | 29.38 ± 2.11 | 0.006 ± 0.003 | 0.003 ± 0.002 | 0.46 ± 0.11 | 2.98 ± 0.34 | 0.004 ± 0.000 | 0.002 ± 0.002 |
| Rice | Raw Brown | 0.60 ± 0.18 | - | 0.002 ± 0.001 | 10.93 ± 1.79 | 0.005 ± 0..002 | 0.011 ± 0.003 | 0.37 ± 0.14 | 1.02 ± 0.35 | 0.002 ± 0.001 | - |
| | Raw milled | 0.44 ± 0.30 | - | 0.002 ±0..002 | 7.49 ± 1.26 | 0.005 ± 0..003 | 0.003 ± 0.002 | 0.23 ± 0.06 | 0.002 ± 0.66 | 0.002 ± 0.66 | 0.002 ± 0.66 |
| | Parboiled | 0.20 ± 0.06 | - | 0.002 ± 0.003 | 8.11 ± 1.01 | 0.005 ± 0..002 | 0.003 ± 0.001 | 0.27 ± 0.12 | 0.72 ± 0.20 | 0.006 ± 0..002 | 0.005 ± 0.002 |
| Quinoa (*Chenopodium quinoa*) | | - | 0.03 | 0.002 | 198 | 0.004 | - | 0.48 | 751 | - | - |
| Amaranth Seed | Black | 3.32 | - | - | 181 | 1.227 | 0.059 | 0.81 | 9.33 | 0.013 | 0.028 |
| | Pale brown | 2.73 ± 0.47 | - | 0.001 ± 0.000 | 162 ± 15.7 | 0.092 ± 0.045 | 0.021 ± 0.005 | 0.56 ± 0.09 | 8.02 ± 0.93 | 0.018 ± 0.012 | 0.008 ± 0.008 |
| Maize | Dry | 2.82±0.16 | - | - | 8.94 ± 0.61 | 0.010 ± 0.006 | 0..010 ±0.003 | 0.45 ± 0.23 | 2.49 ± 0.32 | - | 0.002 ± 0.001 |

(*Source*: Indian food composition tables, NIN – 2017 and *Nutritive value of Indian Foods, NIN -2007)

## 4.7. Phyto-chemicals

Phyto-chemicals, on the other hand, are the compounds that occur naturally in plants. Technically, though it refers to a wide variety of plant-based compounds, the term is mainly used for compounds that affect human health. Phyto-chemicals are virtually present in all the fruits, vegetables, pulses/legumes and grains which are commonly consumed, so it is quite easy to incorporate them in our daily diet. Although thousands of phyto-chemicals have been identified, only a small fraction of them have been studied closely. Some of the better-known phyto-chemicals include β-carotene and other carotenoids, ascorbic acid (vitamin C), folic acid, and vitamin E. Some phyto-chemicals may possess antioxidant activity or hormone-like actions too.

The edible component of millet kernel is rich in it having important role in aging and metabolic diseases components (Bravo, 1998), like phyto-chemicals. Phyto-chemicals such as phenolics (bound phenolic acid-ferulic acid, free phenolic acid-protocatechuic acid), lignans, β-glucan, inulin, resistant starch, phytates, sterols, tocopherol, dietary fiber, anthocyanins, carotenoids and pinacosanals are present in millets (Singh and Naithani, 2004) (Table 13 - 15).

The main polyphenols are phenolic acids and tannins, while flavonoids are present in small quantities; they act as antioxidants and play many roles in the body immune system. All millet grains, in particular, sorghum, fractions possess high antioxidant activity in vitro relative to other cereals and fruits (Awiks *et al*; 2004). Most sorghum do not contain condensed tannins but all do have phenolic acids. Pigmented sorghum contains unique anthocyanins that could be potential food colorants.

**Table 13: Phytochemical analysis of different millet samples**

| S.No. | Constituents | Barnyard millet | Little millet | Sorghum millet | Pearl millet | Foxtail millet |
|---|---|---|---|---|---|---|
| 1 | Alkaloids | - | - | - | - | - |
| 2. | Proteins | + | + | + | + | + |
| 3. | Amino acid | + | + | + | + | + |
| 4. | Carbohydrates | + | + | + | + | + |
| 5. | Flavonoids | + | + | + | + | + |
| 6. | Glycosides | - | - | - | - | - |
| 7. | Tannins & Phenolics | + | + | + | + | + |
| 8. | Triterpenoids | + | + | + | + | + |

*(+) and (-) signs indicate presence and absence of the compound respectively. (*Source*: Singh M and Naithani M, 2014)

**Table 14: Total Phenol and Flavonoid concentration of different millet samples**

| S.No. | Plant | Total phenolics (mg GAE/g) | Total flavonoids (mg QE/g) |
|---|---|---|---|
| 1. | Barnyard millet | 10.125 ± 0.03 | 47.55 ± 3.98 |
| 2. | Little millet | 12.33 ± 1.29 | 44.84 ± 1.52 |
| 3. | Sorghum | 34.65 ± 0.03 | 32.53 ± 1.26 |
| 4. | Pearl millet | 07.395 ± 0.52 | 38.61 ± 0.62 |
| 5. | Foxtail millet | 28.87 ± 1.03 | 16.53 ± 0.29 |

(*Source:* Singh M and Naithani M, 2014)

**Table 15: DPPH Assay IC50 values of different millet samples**

| S. No. | Plant | Total phenolics (mg GAE/g) |
|---|---|---|
| 1. | Barnyard millet | 495 |
| 2. | Little millet | 240 |
| 3. | Sorghum millet | 365 |
| 4. | Pearl millet | 350 |
| 5. | Italian millet | 395 |
| 6. | Standard (Ascorbic acid) | 300 |

(Source: Singh M and Naithani M, 2014)

## 4.8. Anti-nutrients

Millets are nutritionally comparable and even superior to major cereals in terms of energy value, proteins, fat and minerals (Malik *et al.*, 2002). However, due to the presence of anti-nutrients like phytate, polyphenols, oxalates and tannins, mineral bioavailability is affected. These anti-nutrients form complexes with dietary minerals, such as calcium, zinc and iron leading to a marked reduction in its bio-availability and make them biologically unavailable to human beings (Arora *et al.*, 2003). However, the negative impact of these anti-nutrients can be taken care by using common household food processing techniques like decortications, milling, soaking, malting, germination, fermentation, popping and cooking etc. These methods reduce the content of phytates, phenol, tannins and trypsin inhibitor activity, improve the digestibility of millets apart from enhancing bio-availability of minerals.


Little Millet Rice

Chapter-V

# Health Benefits of Millets

Millets have tremendous health benefits. Epidemiological studies have underscored that consumption of millets reduces risk of heart disease, protects from diabetes, improves digestive system, lowers the risk of cancer, detoxifies the body, increases immunity in respiratory health, increases energy levels and improves muscular and neural systems and are protective against several degenerative diseases such as metabolic syndrome and Parkinson's disease (Manach *et al.*, 2005; Scalbert *et al.*, 2005; Chandrasekara and Shahidi, 2012). The important nutrients present in millets include resistant starch, oligosaccharides, lipids, antioxidants such as phenolic acids, avenanthramides, flavonoids, lignans and phytosterols, which hold immense health benefits (Miller, 2001; Edge *et al.*, 2005).

## 5.1. Gluten sensitivity

Though the nutrients found in food can prevent disease and sustain life. At the same, one should be cautious as they can also cause health problems (Fig. 18) for susceptible people. Food allergies can wreak havoc on a person›s health and quality of life. Approximately 5% of individuals have a true food allergy. A true food allergy is an abnormal response to a food triggered by the body›s immune system. The top eight food allergen are groundnuts, milk, eggs, fish, crustacean shellfish, soybean, tree nuts, and wheat. According to latest findings, wheat allergy accounts for about 0.1% of all food allergies.

### Symptoms

Wheat allergy symptoms usually occur in the mouth, nose, eyes, and throat (swelling, itching, and irritation); the skin (rash, hives, swelling); respiratory tract (wheezing, difficulty in breathing, anaphylaxis); and gastrointestinal tract (cramps, nausea, emesis, gas, diarrhea, and abdominal pain).


Figure 18. Common problems of gluten sensitivity

### Role of millets in management of gluten sensitivity

Only wheat flour is required to be restricted and there should be no permanent damages caused by it. Millets and minor millets are safe cereals for celiac patients due to non-existence of gluten.

### Supported literature

- Sorghum products could not modify the level of anti-transglutaminase antibodies after prolonged consumption in humans (Carolina et al., 2007).
- As millets are gluten-free, they have considerable potential in foods and beverages and can meet the growing demand for gluten free foods. They are particular advised for those suffering from celiac disease. (Taylor *et al.,* 2006; Taylor and Emmambux, 2008; Chandrasekara and Shahidi, 2011b, 2011c).

## 5.2. Celiac disease

Celiac disease is also known as celiac sprue, nontropical sprue, and gluten-sensitive enteropathy. The exact cause of celiac disease is not clear, but it known to have a genetic (inherited) component. Celiac disease (Fig. 19 & 20) affects approximately one per cent of the population. A major cause of concern is that there has been a rise in incidences of celiac disease over the past decade. Celiac disease is an autoimmune disease, where the immune system starts attacking normal tissue, particularly the inner lining tissue of the small intestine, in response to eating gluten, the wheat protein. The specific reaction that leads to inflammation is called prolamins. They are found in certain grains; for example gliadin in wheat, secalin in rye, horedin in barley, and avenin in oats.

### Symptoms

In celiac disease body reacts to gluten or prolamins as if it were toxic. This reaction occurs in the small intestine and ends up damaging the inner lining of the small intestine (mucosal surface). When the mucosal surface is damaged, the small intestine is not able to absorb nutrients properly making people prone to nutritional deficiencies, including protein, fat, iron, calcium, and fat soluble vitamins (A, D, E, and K). It can also result in anemia, diarrhea, abdominal cramping, vomiting, failure to thrive, osteoporosis, and delayed growth.

Figure 19. Damage of small intestine in celiac disease and bloating

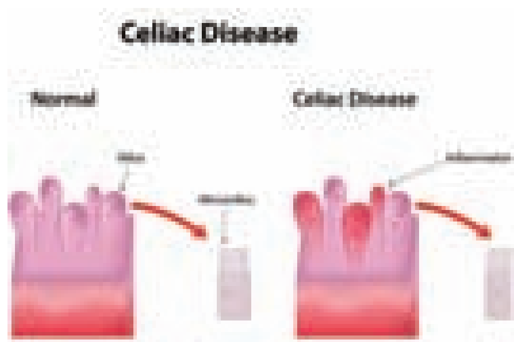


Figure 20. Classification of gluten related disorders

### Role of millets in treatment of celiac disease

A gluten-free diet is not optional for people with celiac disease. It is considered a necessary medical nutrition therapy.

### Supported literature

- Sorghum is considered safe for consumption by people with Celiac disease due to the gliadin–like peptides (Pontieri *et al.*, 2013).
- Replacing cereals like wheat, barley, rye-based foods made from gluten-free grains, including rice, corn, sorghum, millet, amaranth, buck wheat, quinoa, and wild rice may help people adhering to gluten-free diet. (Thompson, 2009).

## 5.3. Arthritis: Gluten - a trigger for joint pain

Joint pain and inflammation can be common symptoms for individuals who have celiac disease (CD) and possibly for millions more who may be sensitive to gluten. Like many types of arthritis, the immune system mistakenly attacks healthy tissue instead of viruses, bacteria and other pathogens. Inflammation outside the gut is especially likely to affect the joints whereas joint-pain is less in patients who are sensitive to gluten when they don't eat it. Autoimmune response also damages the small intestine and affects its ability to absorb nutrients like iron, B12, calcium and fat soluble vitamins. Gluten-sensitive people can have symptoms anywhere in the body when partially digested gluten fragments leak from the intestine into the bloodstream.

### Symptoms

The most common signs and symptoms of arthritis involve the joints. Depending on the type of arthritis, they may include pain, stiffness, swelling and redness at portions of joints and decreased range of motion.

### Role of millets in the treatment of arthritis

Patients with arthritis generally hope to manage inflammation without using drugs. To such people, millets are godsend opportunities as they can both contain and prevent inflammation, thanks to the curing abilities of gluten-free proteins that they possess.

## 5.4. Diabetes

Diabetes has become a highly problematic and increasingly prevalent disease worldwide. It has contributed towards 1.5 million deaths in 2012. Management techniques for their prevention in high-risk, as well as in affected individuals, beside medication, are mainly through changes in lifestyle and a revised dietary regulation. Swearing by an individual-specific diet can bring relief to diabetics. Dietary management of diabetes involves the reduction of postprandial hyperglycaemia and good glycaemic control. Heredity, obesity, stress, and a general lack of physical activity are some of the causes for diabetes.

### Symptoms

The higher or abnormal blood glucose levels are reported either because of inadequate insulin production or because the body's cells do not respond properly to insulin, or both. The other common symptoms of diabetes are unintentional weight loss, tiredness that does not go away, blurred eye vision, feeling of excessive thirst and frequent urination (Fig. 21). Prolonged exposure to diabetes, damages important organs like the eye, kidney, heart and nerves because of the damage to small blood vessels.


Figure 21. Common signs and complications of diabetes

## Role of millets in management of diabetes

The consumption of millet-based food items produce the lowest post-prandial glucose levels after a meal. Thus millets make a good substitute for rice for Type II diabetics (Fig. 22). Millet's high fiber content slows digestion and releases sugar into the bloodstream at a more even pace. This helps diabetics avoid dangerous spikes in blood sugar that lead to glucose spilling over into the urine, known as glucosuria. Millet is also a good source of B vitamins that the body uses to process carbohydrates. Result of study on glycemic index and glycemic load in case of test foods based on sorghum *vs.* wheat is presented in Table 16. Mean glycosylated hemoglobin and lipid profile of diabetic patients before and after supplementation of Sorghum is presented in Table 17.

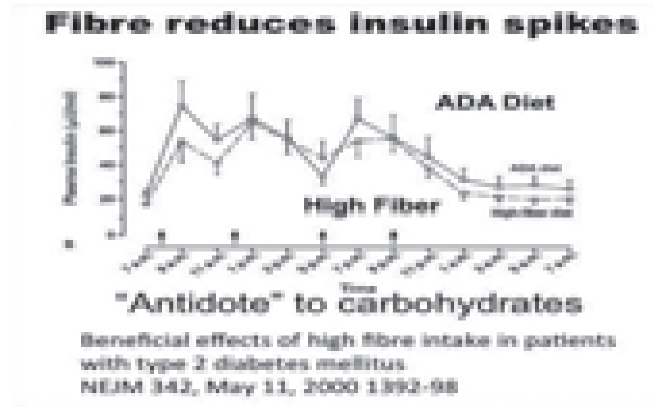


**Figure 22. Reduction in insulin spikes**

(*Source*: Chandalia et *al*; 2000)

**Table 16: GI and GL of Test Foods and ± iAUC**

| Foods | ± i AUC (mg/dl) | | GI | | GL | |
|---|---|---|---|---|---|---|
| | Sorghum | Wheat | Sorghum | Wheat | Sorghum | Wheat |
| Multigrain *Roti* | 146 ±8.16 | 138±6.28 | 68±8.63 | 64±9.24 | 35±6.2* | 32±4.62* |
| Coarse semolina *upma* | 114±1.93* | 125±4.65* | 53±2.84* | 58±6.85* | 23±1.24** | 27±3.21** |
| Fine semolina *Upma* | 119±7.04** | 144±8.77** | 56±9.83** | 67±10.80** | 26±4.87** | 46±7.3** |
| Flakes *Poha* | 96 ±4.28** | 158±8.17** | 45±5.27** | 74±4.87** | 50±5.85** | 75±3.5** |
| Pasta | 100±3.58** | 154±3.71** | 46±6.47** | 72±6.51 | 60±2.8** | 108±6.2** |
| Biscuits | 115± 4.39 | 122±4.42 | 54±6.30 | 57±11.40 | 23±8.4** | 31±11.51** |

Results are Mean ± SE; * Significant at 5 % level; ** Significant at 1 % level; (*Source*: Rajendra Prasad *et al.*, 2014)

**Table 17: Mean glycosylated hemoglobin and lipid profile of diabetic patients before and after supplementation of sorghum**

| Parameter | Before | After |
|---|---|---|
| Glycosylated Hemoglobin (g %) (Normal - <7.0) | 7.9 ± 2.0* | 7.3 ± 1.5* |
| Fasting glucose (mg %) | 161.3 ± 50.35* | 150.4 ± 54.16* |
| Insulin (μ/ml) | 24.9 ± 16.54 | 24.6 ± 18.2 |
| Creatinine (mg %) | 1.02 ± 0.21 | 1.0 ± 0.19 |
| Cholesterol (mg %) | 189 ± 47.15 | 190 ± 33.78 |
| HDL Cholesterol (mg %) | 54.3 ± 13.38 | 54.9 ± 16.01 |
| Triglycerides (mg %) | 139.2 ± 73.75 | 138.0 ± 74.92 |

Results are Mean ± SD; * Significant at 5% level;

(*Source:* Data generated under NAIP subproject on Creation of demand for sorghum foods through PCS value chain, 2008-2012)

The phenolics present in millets inhibits like alpha-glycosidase, pancreatic amylase reduce postprandial hyperglycemia by partially inhibiting the enzymatic hydrolysis of complex carbohydrates, Inhibitors like aldose reductase prevents the accumulation of sorbitol and reduce the risk of diabetes induced cataract diseases. Thus, a diet with millets provides the highest quality of nutrients with low fat, moderate calories that benefits diabetics and helps manage blood glucose, blood pressure and cholesterol.

Millet flour have 15-25 per cent lower starch digestibility than normal rice, wheat or maize flour, regardless of whether the endosperm types was floury, dense floury, or vitreous. Neither the starch itself nor the outer layer materials of sorghum seeds appeared to be related to poor starch digestibility. The increase in starch digestibility when the miller flour was pepsin-pretreated before cooking or by cooking with a reducing agent suggests that protein plays a large role in its low starch digestibility (Genyi and Bruce, 1998). Millet grain starch digestibility depends on two scenarios: First, as Chandrashekar and Kirieis (1988) suggested millet endosperm protein may restrict the starch granules from fully gelatinizing, thereby resulting in lower digestibility. However, there was less soluble starch in gelatinized millet, including the cooked millet and other cereal starches. Second, a starch-protein interaction may occur during cooling that causes gelatinized sorghum starch to be in less digestible state.

For nutritional purpose, starch is generally classified into rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS), depending upon the extent of digestion. Prolonged consumption of millets helps in controlling blood glucose levels due and thereby is best for treating Type II diabetes.

## Supported literature

- Sorghum is rich in dietary fiber and has low glycemic index, which could help in prevention and control of type 2 diabetes among Indians. The fiber, magnesium, vitamin -E, phenolic compounds and tannins present in foods reduces the risk of diabetes as they slower the sudden increase of blood glucose and insulin levels (Montonen *et al*., 2003).
- Finger millet-based diets have shown lower glycemic response due to high fiber content and also alpha amylase inhibition properties which are known to reduce starch digestibility and absorption (Kumari and Sumathi, 2002).
- Proso millet showed to improve glycemic responses and insulin in genetically obese type 2 diabetic mice under high fat feeding conditions (Park *et al*., 2008).
- National Institute of Nutrition (ICMR) in 2010 assessed GI of sorghum-based foods in collaboration with the Indian Institute of Millets Research, Hyderabad under National Agricultural Innovation Project (NAIP). The results revealed that those foods have low GI and reduce the postprandial blood glucose level, glycosylated hemoglobin. Another study also points to the fact that blood glucose level of non-obese patients with non-insulin-dependent diabetes mellitus (NIDDM), who consumed sorghum bran papadi, showed considerable reduction. (Shinde, 2004). Studies performed on processing and cooking of white and yellow sorghum varieties showed that boiled yellow sorghum flour (coarse) had lower glycemic index compared to flour prepared from the same. Similarly chapatti prepared from white Sorghum flour showed low glycemic index over ones made of yellow Sorghum flour. These changes in GI play an important role in diets followed in dietary management of diabetes. (Vahini and Bhaskarachary, 2013).
- Diets rich in whole grain foods tend to decrease LDL cholesterol, triglycerides, blood pressure, and increase HDL cholesterol (Anderson, 2003). The concept of GI emerged as a physiological basis for ranking carbohydrate foods according to the blood glucose response they produce on ingestion, and was introduced by Jenkins *et al*., (1981). Mani *et al*., (1993) have reported that pearl millet has the lowest GI (55) as compared to kodo millet alone and in combination with whole and dehusked greengram, Sorghum and Finger millet. Foods with a low GI are useful to manage maturity onset diabetes, by improving metabolic control of blood pressure and plasma low density lipo protein cholesterol levels due to less pronounced insulin response (Asp, 1996). Several pearl millet based novel food products can be developed and traditional recipes need to be promoted for the diabetic patients.

## 5.5. Obesity

Obesity has reached global epidemic proportions with more than one billion adults affected by this chronic disorder. Coronary artery disease, stroke, insulin resistance, type 2 diabetes, hypertension, and metabolic syndrome are well-known medical co-morbidities associated with excess body weight (Fig. 23). Many studies have examined the potential of diets and dietary components as a first-line intervention in the prevention and treatment of metabolic syndrome.

### Symptoms

Body Mass Index (BMI) > 35 indicates obesity in a person. The metabolic syndrome is also defined by a combination of three or more of the following: (a) abdominal circumference > 102 cm (40″) for men and 88 cm (35″) for women, (b) hypertension, (c) hyperglycemia, and (d) dyslipidemia (elevated triacylglyceride concentrations and low levels of high-density lipoproteins (HDL) in blood). It is directly associated with increased risk of type 2 diabetes and cardiovascular diseases (Fig. 24).

Figure 23. Metabolic syndromes of obesity

| Weight Categories | BMI (kg/m2) |
|---|---|
| Underweight | < 18.5 |
| Healthy Weight | 18.5 - 24.9 |
| Overweight | 25 - 29.9 |
| Obese (Class I) | 30 - 34.9 |
| Severely Obese (Class II) | 35 - 39.9 |
| Morbidly Obese (Class III) | 40 - 49.9 |
| Super Obese (Class IV) | >50 |

Figure 24. BMI Classification

### Role of millets in management of obesity

Eating millet or other whole grains in place of refined grains like white flour, white rice or packaged snacks is recommended for weight loss and overall health. Millets are rich in dietary fiber and has unique physical and chemical characteristics like bulk to the diet, viscosity, water holding and absorption capacity which determine the subsequent physiological behavior (Fig. 25). The diet with high dietary fiber increase satiety thereby reducing the risk of over eating. While animal proteins contain high amount of saturated fatty acids, millets provide fat-free protein. The amino acid, tryptophan present in it regulates appetite thereby preventing overeating and consequent excessive weight gain by the body.


Figure 25. Flow chart showing role of dietary fiber in maintaining body weight

### Supported literature

- Empirical evidences suggest that intake of high dietary fiber decreases incidence of obesity (Alfieri *et al., 1995;* Burkitt and Trowel, 1975)
- Foods rich in dietary fibre improve the large bowel function and slows the digestion and absorption process, thereby reducing the risk of chronic diseases (Ali *et al.*, 1982; Schneeman and Tietyen, 1994)

## 5.6. Cardiovascular diseases

Cardiovascular disease generally refers to conditions that involve narrowed or blocked blood vessels that can lead to a heart attack, chest pain (angina) or stroke. Other heart conditions, such as those that affect the heart's muscle, valves or rhythm, also are considered forms of heart disease. Worldwide morbidity and mortality statistics have documented the increase of chronic diseases in developed nations. Of these, cardiovascular disease (CVD) remains the most prevalent.

### Symptoms

Cardiovascular disease symptoms may be different for men and women. For instance, men are more likely to have chest pain while also suffer from shortness of breath, nausea and extreme fatigue. Other symptoms include numbness, weakness or coldness in the legs or arms if the blood vessels in those parts of your body are narrowed and pain in the neck, jaw, throat, upper abdomen or back.

### Role of millets in management of CVD and hypertension

Millets are good sources of magnesium that is known to be capable of reducing the effects of migraine and heart attack. Millets are rich in phyto-chemicals containing phytic acid, which is known for lowering cholesterol. Tannin content of millets is also beneficial in lowering cholesterol.

Millet extract prevent the oxidation of LDLs (bad cholesterols). Oxidized LDL is believed to result in the formulation of fatty streaks after being taken up by macrophages, leading to the development of atherosclerosis. The prevention of LDL oxidation is therefore important in the prevention of CVD and hypertension. The prevention of LDL oxidation by millets is attributed to their antioxidant property resulting from photochemical present mainly in the seed coat (Dayakar *et al.*, 2016). Millet also has increased levels of high-density lipoprotein, HDL, the good form of cholesterol.

There are two types of dietary fibres, namely, soluble (eg, pectins, some hemicelluloses, mucilages and gums) and insoluble (eg, cellulose and many hemicelluloses), each with varying physiological and pharmacological properties (Fig. 26).

Soluble fibres are gel forming and help in lowering blood cholesterol (specifically LDL). Fibres stimulate saliva production in the mouth and the lubrication of food. As food passes to the stomach, fibres give a feeling of fullness; displace high-fat foods from the diet and delay gastric emptying to permit optimal digestion and nutrient absorption. In the small intestine, fibres dilute the contents and delay absorption of dietary fat, cholesterol and glucose.

Bile salts (glycocholate and taurocholate) and minerals may also be adsorbed and trapped on the fibres. The trapping or adsorption by fibres has a direct effect on cholesterol absorption and metabolism. Cholesterol is the precursor of bile salts which are synthesized in the liver, stored and concentrated in the gall bladder, and then released into the small intestine. Bile salts are involved in the emulsification of fat and make the lipids more readily absorbable by the intestine.

The trapping of bile salts by dietary fibres impedes their enterohepatic circulation. Consequently, more cholesterol stores are mobilized in the body to produce bile salts. To accomplish this process, the liver takes up more lipids from the blood to replenish cholesterol stores. The de novo synthesis of bile acids from cholesterol coupled with decreased absorption of lipids from the intestine helps to lower plasma triglyceride concentrations and produce beneficial effects for the cardiovascular system. The lignin and phyto-nutrients in millet act as strong antioxidants thus preventing heart related diseases. It is in this context that pearl millet is considered good for a healthy heart (Ahmed *et al.*, 2009).

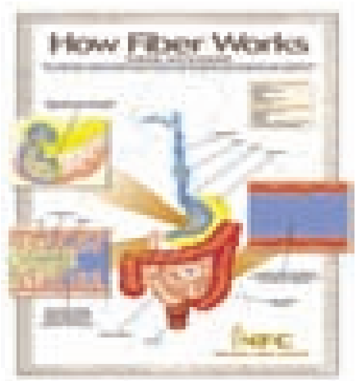


Figure 26. Role of soluble and insoluble fiber in CVD

## Supported literature

- Empirical evidences (Slavin, 2003; Slavin and Slavin, 2004) suggest that regular consumption of whole grains reduces risk of CVD (Anderson and Hanna, *1999)*.
- A long-term prospective study by Heidermann *et al.*, (2008) showed that regular consumption of balanced diet, which includes whole grains, vegetables and fruits, reduce the risk of CVD and total mortality.
- In 2004, Harvard professionals (Jensen *et al.*, 2004) analyzed the diet records of 27,000 men aged between 40 and 75 years for a period of 14 years and found intake of whole grains 40g/day reduces the risk of CHD by 20%.
- A study was done on the effect of cholesterol absorption and plasma non-HDL cholesterol concentration in hamsters fed with grain sorghum lipid extract. The hamsters were fed with grain sorghum lipid extract (GSL) comprising of different proportions of the diet and compared with control. Liver cholesterol ester concentration was also significantly reduced in hamsters fed with GSL as it is capable of lowering non-HDL cholesterol, at least in part, by inhibiting cholesterol absorption; GSL extract consist plant sterols that reduce cholesterol absorption efficiency significantly and policosano (Carr *et al.*, 2005).
- The finger millets and proso millets have also shown to lower significantly the concentrations of serum triglycerides than white rice and sorghum fed rats. Finger millet and proso millet may prevent cardiovascular disease by reducing plasma triglycerides in hyper-lipidemic rats (Lee *et al.*, 2010).
- Foods rich in dietary fiber improve the large bowel function and slow the digestion and absorption process, thereby reducing the risk of chronic diseases (Ali *et al.*, 1982; Schneeman and Tietyen, 1994).
- Rats fed with diet of treated starch from barnyard millet showed lower blood glucose, serum cholesterol and triglycerides compared with rice and other minor millets (Kumari and Thayumanavan, 1997).

- Improved plasma levels of adiponectin, high density lipoprotein (HDL) cholesterol in genetically obese type -2 diabetic mice under high fat conditions were observed on feeding Proso millet (Park *et al.*, 2008).
- Sorghum is rich in dietary fiber and low GI, which could help in prevention and control of type 2 diabetes in Indians. The fiber, magnesium, vitamin E, phenolic compounds and tannins present in the food reduces the risk of diabetes as they slower the sudden increase of blood glucose and insulin levels (Montonen *et al.,* 2003).

## 5.7. Cancers

The word cancer is derived from carcinoma – a crab. This is due to growth of cells. In the absence of a specific treatment, it is taking a heavy toll of human life. However, if defected early then cure is possible. Cancer Research UK says an unhealthy diet is linked to six types of cancer – mouth, upper throat, larynx, lung, stomach and bowel. Obesity has been linked to cancers of the oesophagus, liver, upper stomach, gallbladder, pancreas, colon, breast (after menopause) endometrium, uterus, ovaries and kidneys.

### Symptoms

Symptoms of cancer depend on the site of cancer bleeding from nose, mouth, haemoptysis, haematemesis and emesis, sore throat which shows no signs of healing, hoarseness of voice, change in the bowel and urination, immediate loss of weight, difficulty in swallowing, unhealed ulcer either external or internal, chronic diarrhea, breast enlargement, loss of appetite, ascitis, sleeplessness, headache, brain tumor, irregular menstruation and other free radicals (Fig. 27 - 29).

### Role of millet in prevention of cancer

Millets are a major source of dietary fiber and contain germ, endosperm and bran, in contrast with refined grains which contain only the endosperm.

The germ and bran contain numerous nutrients that are removed during the refining process. In addition, whole grains or partially dehulled millets are a major source of several vitamins, minerals, and phyto-chemicals, which have anti-cancer properties and could plausibly reduce the risk of colorectal cancer by several potential mechanisms. Millets are rich sources of fermentable carbohydrates (resistant starch), which are converted by the intestinal bacteria into short-chain fatty acids which help to protect against colon cancer in the gut.

These fatty acids can reduce the activity of certain cancer-causing factors. Whole grain fibers also increase faecal bulk and bind carcinogens, which can then be speedily removed from the bowel before causing health problems. Millets, including prized lignins, which have shown to be effective in preventing breast and hormone related cancer.

The 3-Deoxyanthoxyanins (3-DXA) present in Sorghums are believed to prevent proliferation of the colon cancer cells. Studies show that darker-colored Sorghums contain more amount of 3-DXA. Moreover, millets are known to be rich in phenolic acids, tannins, and phytate that act as "anti-nutrients".

However; these anti-nutrients reduce the risk for colon and breast cancer in animals. It has been found that millet phenolics may be effective in the prevention of cancer initiation and progression. (Chanrasekara A. and Shahidi F, 2011c).


Figure 27. Free radicals

Figure 28. Sources of free radicals

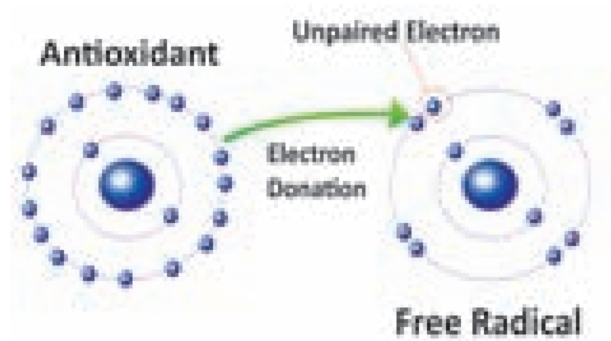


Figure 29. Role of antioxidants in prevention of free radicals effects

## Supported literature

- Anti-carcinogenic properties of sorghum have been well documented. In Vivo and In Vitro, studies have shown that consumption of sorghum has positive health impacts on cancer. The polyphenols and tannins present in sorghum have anti-mutagenic and anti-carcinogenic properties (Grimmer *et al*., 1992) and can act against human melanoma cells, as well as positive melanogenic activity (Gomez-Cordovez *et al*., 2001).
- Parbhoo *et al.,* (1995) reported that in rat liver procyanidin extracts may induce cytochrome P-450, a protein that is capable of converting certain promutagens to mutagenic derivatives.

- Epidemiological data from Sachxi Province, China, and in different parts of the world (Van Rensburg, 1981) showed that incidence of oesophageal cancer was low with sorghum consumption. In each country, the authors studied 21 communities over a period of six years and found consumption of sorghum showed lower mortality from oesophageal cancer than wheat and corn. It can be concluded that anti-carcinogenic compounds present in sorghum lowered risk of oesophageal cancer.
- The foxtail millet varieties have significant antioxidant activity by (DPPH) method (Devi *et al.*, 2011). The copper and iron-rich foxtail millet is calculated to be 364 Kcal per 100 gm.
- The anti-nutrients such as phenolic acid, tannins and phytate reduce the risk for colon and breast cancer in animals (Graf and Eaton, 1990). The fiber present in sorghum and millet and also the phenolic compounds have been attributed for lower incidence of esophageal cancer than those consuming wheat or maize (Van Rensburg, 1981). Recent research has revealed that fiber as one of the best and easiest ways to prevent the onset of breast cancer in women. They can reduce their chances of breast cancer by more than 50% by eating more than 30 gm of fiber every day.

## 5.8. Constipation

Constipation is really more of a symptom that an actual disease. It refers to a disease in bowel movements or difficulty in passing the stool. In some cases, diarrhea can be considered a form of constipation. Constipation can lead to diverticular disease and hemorrhoids, not to mention a wide variety of ailments. Recently the notion that despite regular bowel movements one can still be constipated has received more attention. This idea is based on the incomplete evacuation of the bowel even when bowel movements are frequent. This implies that waste residue builds up on the colon walls and is not properly excreted with the movement of the muscle.

### Symptoms

The common symptoms of constipation involves passing fewer than three stools a week, having lumpy or hard stools, straining to have bowel movements, feeling as though there's a blockage in the rectum while evacuation that prevents bowel movements, feeling of unkemptness in the rectum etc.

### Role of millets in prevention of constipation

Millet is abundant in dietary fiber, whose intake of 40 grams each will reduce constipation (Fig. 30). Adequate dietary fiber can be achieved by consuming about two to three servings of whole grains/millets grains and around five servings of fruits and vegetables per day.

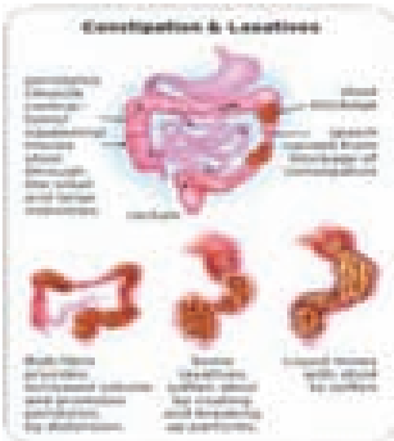

Figure 30. Role of fiber in prevention of constipation

## 5.9. Anemia

Anemia is a decrease in the total amount of red blood cells (RBCs) or hemoglobin in the blood, or a lowered ability of the blood to carry oxygen.

When anemia comes on slowly, the symptoms are often vague and may include tiredness, shortness of breath or a poor ability to exercise. A recent report by the UN's Food and Agriculture Organization (FAO) finds that India is home to 194.6 million under-nourished people, the highest in the world and the country is ranked 112 among 141 nations with reference to the Child Development Index.

### Symptoms

The symptoms of anemia includes fatigue and loss of energy, unusually rapid heart-beat, shortness of breath and headache, difficulty in concentrating, dizziness, pale skin, leg cramps and insomnia.

### Role of millets in prevention of anemia

Dietary intervention using millets can aid in preventing anemia in children (Kathy M, *et al.*, 2013). The results of sorghum supplementation in school going children are given in Tables 18 and 19.

Table 18: Nutritional status of school going children (girls) before and after sorghum supplementation

| Group | Experimental | Control | Experimental | Control |
|---|---|---|---|---|
| Intervention | Before | | After | |
| BMI (kg/m$^2$) | 15.2±1.63$^{NS}$ | 15.5±1.64$^{NS}$ | 15.4±1.48$^{NS}$ | 15.8±1.64$^{NS}$ |
| Hemoglobin (g/dl) | 10.9±1.88** | 11.9±1.64** | 12.4±1.57 ** | 11.1 ±1.51** |
| Total Protein (g/dl) | 9.30±0.61** | 11.0±1.25** | 8.20±0.52 ** | 9.0±0.81** |
| Ferritin (ng/ml) | 26.9±13.19** | 43.8±118.6 ** | 39.6±26.17$^{NS}$ | 34.5±12.23$^{NS}$ |
| Folic acid (mg/ml) | 4.80±1.71** | 4.50±1.57** | 5.10±1.48$^{NS}$ | 5.20±1.53$^{NS}$ |

| Group | Experimental | Control | Experimental | Control |
|---|---|---|---|---|
| Intervention | Before | | After | |
| Iron (µg/dl) | 54.8±26.91** | 53.7±21.2** | 68.9±41.09* | 58.2±22.8* |
| Retinol binding protein | 89.6±26.28** | 61.6± 15.46** | 98.9±26.0** | 72.8± 15.02** |
| Vitamin B12 (mg/ml) | 295.0±44.93 | 216.5± 35.60* | 375.0±176.70* | 261.9 ±163.93 |

Results are Mean±SD; NS Not significant; *Significant at 5% level; **Significant at 1% level; (*Source*: Rajendra Prasad *et al.*, 2015)

**Table 19. Nutritional status of school going children (boys) before and after sorghum supplementation**

| Group | Experimental | Control | Experimental | Control |
|---|---|---|---|---|
| Intervention | Before | | After | |
| BMI (kg/m$^2$) | 14.9±1.33** | 14.9±1.57** | 14.7±2.02** | 15.6±2.17** |
| Hemoglobin (g/dl) | 11.8±1.65** | 12.2±1.31** | 12.6±1.15** | 11.4±1.73** |
| Total Protein (g/dl) | 8.80±0.83** | 9.30± 1.40** | 8.80±0.61** | 8.60±0.58** |
| Ferritin (ng/ml) | 40.9 ± 23.45** | 65.3±15.43** | 79.1±36.99** | 44.3±14.02** |
| Folic acid (mg/ml) | 4.30±1.45** | 5.20±4.19** | 5.20±2.52$^{NS}$ | 5.20±4.19$^{NS}$ |

| Group | Experimental | Control | Experimental | Control |
|---|---|---|---|---|
| Intervention | Before | | After | |
| Iron (µg/dl) | 53.2± 21.25** | 74.2±36.79** | 58.2±25.60$^{NS}$ | 61.70±22.9$^{NS}$ |
| Retinol binding protein | 63.9± 10.92** | 33.6±17.10** | 71.1±13.93$^{NS}$ | 77.7±14.04$^{NS}$ |
| Vitamin B12 (mg/ml) | 295.0±44.93 | 216.5±35.60* | 375.0±176.70* | 261.9±163.93 |

Results are Mean±SD; NS: Not significant; *Significant at 5% level; **Significant at 1% level; (*Source*: Rajendra Prasad *et al.*, 2015)

## Supported literature

- Rajendra Prasad *et al.*, (2015) studied 160 boys and 160 girls aged between nine to 12 years who were given 60% sorghum diet and 40% rice diet. The growth rate was found significantly higher ($p < 0.01$) in girls. Hemoglobin, serum ferritin, albumin, retinol binding protein and iron levels had also improved substantially ($p < 0.05$) in both genders, with an increase in serum folic acid and calcium levels in boys when the meal was replaced with 60% sorghum.
- School-going children in the 12-16 years age-group were served *'bajra bhakris'* (a type of chapatti) during midday meals. The six-month trial found that eating iron-rich millet helped reverse iron deficiency in six months and the iron levels showed marked improvement in four

months. According to a study published in The Journal of Nutrition, "Those children who were iron-deficient at the start and ate iron-rich biofortified pearl millet '*bhakri*' were 1.6 times more likely to have resolved their iron deficiency problem compared with those who ate '*bhakri*' made from the ordinary pearl millet". A simple solution to a complex problem (Finkelstein *et al., 2015)*

## 5.10. Detoxification (Anti-oxidant properties)

Many of the antioxidants found in millet have beneficial impact on neutralizing free radicals, which can cause cancer and clean up other toxins from body such as those in kidney and liver. Quercetin, cucurmin, ellagic acid and various other beneficial catechins can help to clear the system on any foreign agents and toxins by promoting proper excretion and neutralizing enzymatic activity in those organs. Therefore, tremendous attention has been given to polyphenol due to their roles in human health (Tsao R, 2010) (Table 20).

The antioxidant, metal chelating and reducing powers are shown by soluble and insoluble-bound phenolic extracts of several varieties of millet (kodo, finger, foxtail, proso, pearl and little millets) (Chandrasekara and Shahidi, 2010).

Foxtail millet contains 47 mg polyphenolics/100 g and 3.34 mg tocopherol/100 g (wet basis); however, proso millet contains 29 mg polyphenolics/100 g and 2.22 mg tocopherol/100 g (wet basis).

In addition, a positive and significant correlation ($R^2 = 0.9973$, $P<0.01$) between polyphenolic content and radical cation scavenging activity was also noted. (Choi *et al.,* 2007).

Over 50 phenolic compounds belonging to several classes, including phenolic acids and their derivatives, dehydrodiferulates and dehydrotriferulates, flavan-3-ol monomers and dimers, flavonols, flavones, and flavanonols in 4 phenolics fractions of several whole millet grains (kodo, finger, foxtail, proso, little, and pearl millets) were positively or tentatively identified using HPLC and HPLC-tandem mass spectrometry (MS) (Chandrasekara and Shahidi, 2011a). Therefore, millet grains can be used as functional food ingredients and as sources of natural antioxidants.

Kodo millet consists of high protein and organoleptic quality (Kulkarm and Naik, 2000) and a rich source of phenolics, tannins and phytates which act as antioxidants (Hegde and Chandra, 2005). Furthermore, finger millet extracts were found to have a potent radical-scavenging activity that is higher than those of wheat, rice, and other varieties of millet (Dykes and Rooney, 2006). In addition, defatted foxtail millet protein hydrolysates also exhibited antioxidant potency (Mohamed *et al.,* 2012). Thus, millets may serve as a natural source of antioxidants in food applications and as nutraceuticals and functional food ingredient in health promotion and disease risk reduction.

**Table 20. Sorghums nutritional and functional attributes associated with metabolic disease effects**

| Component / property | Proposed benefits |
|---|---|
| Slow starch digestibility (slowly digestible starches, interactions with endosperm and polyphenolic compounds that reduce starch hydrolysis) | Potential to attenuate blood glucose and insulin responses and increase satiety through reduction of glycemic index of sorghum based foods. This has relevance in appetite regulation, weight management, and risk reduction of obesity-related diseases such as diabetes. |
| High antioxidant activity (phenolic acids, monomeric polyphenolic flavonoids, polymeric polyphenolic condensed tannins) | Potential to reduce oxidative stress that plays an important role in the pathogenesis of many chronic diseases such as diabetes, atherosclerosis, some cancers, and aging. Arthritis and neurological diseases. |
| High fiber (including resistant starch, ranging from 2.2g to 6.5 g per 100g dry matter | Offers benefits to gut micorbiome, metabolic disease risk and gastrointestinal diseases |
| High unsaturated fatty acid content of lipid (oleic acid, liolenic acid, linoleic acid and policosanols in wax) | Improving dyslipidemia and thus promoting heart health |

## 5.11. Health benefits of millets

- The chemical reaction between the amino group of proteins and the aldehyde group of reducing sugars, termed as non-enzymatic glycosylation, is a major factor responsible for the complications of diabetes and aging.
- Millets are rich in antioxidants and phenolics and like phytates, phenols and tannins which can contribute to antioxidant activity important in health, aging, and metabolic syndrome.
- Millets fraction and extract have been found to have antimicrobial activity and help in inhibiting the growth of bacteria especially *Rhizoctonia solani, Macrophomina phaseolina,* and *Fusarium oxysporum.*
- Ferulic acid is a very strong antioxidant, free radical scavenging and anti-inflammatory activity. Antioxidants significantly prevent tissue damage and stimulate the wound healing process. It is reported good antioxidant effects of finger millet on the dermal wound healing process in diabetes induced rats with oxidative stress-mediated modulation of inflammation.
- They are easily digestible for they are alkaline in character.
- The high level of protein in it makes it very beneficial to vegetarians as the sources of protein from other vegetarian foods might be inadequate.

- The rich magnesium content in it reduces menstrual cramps and has the potential to regulate menstrual cycle.
- Its amino acids lower cholesterol level in the blood by reducing the formation of plaques in the blood vessels.
- Presence of dietary fiber and phyto-nutrients in millets prevents the risk of colon cancer. Moreover the rich fiber content satiates hunger and prevents food craving. It is largely due to this phenomenon that millets are advised as substitutes for weight-loss program.
- Antioxidants present in it. Which are on par with those found in fruits and vegetables, fight free radicals in the body and neutralize them thereby slowing down the ageing process.
- Foxtail millet is a diuretic and a tonic to enhance the strength of the body. It cures phlegm, strengthens muscles and cures gastric disorders. Gruel made from the flour is consumed to reduce swellings in the body. The thick gruel has the potential to clean the uterus of mothers who have just delivered and enhances the strength of the body post-delivery (Anonymous, 2018).
- Consumption of millets, particularly finger millet, enhances production of milk in lactating mother.
- Finger millet is an extremely nutritious cereal that helps maintain overall healthiness. However, its high intake could increase quantity of oxalic acid in the body. Therefore, it is not advised for patients having kidney stones (Urinary Calculi).
- Green *Ragi* is recommended for conditions of blood pressure, liver disorders, *asthma* and heart weakness. It is also recommended for lactating mothers who have problems in milk production.
- Finger millet is rich in amino acids which are vital in normal functioning of body and are essential for repairing body tissues. Finger Millet contains Tryptophan, Threonine, Valine, Isoleucine and Methionoine amino acids. Isoleucine helps in muscle repair, blood and bone formation and improves the health of skin. Valine is an essential amino acid, which facilitates metabolism, helps in muscle coordination and repair of body tissues. It helps in balancing nitrogen in the body. Another essential amino acid, not found in most cereals, is Methionine, which is useful in various body processes, helps in eliminating fat from the body, and is main provider of sulphur in body. Sulphur is essential for production of Glutathione - body’s natural antioxidant.


Kodo Millet

# Chapter-VI

# Processing Technologies for Millets

Cereals or coarse cereals are not eaten as uncooked whole seeds in any human society. (Hulse *et al*., 1980). Millets are good for us because of their calorie and energy contributions. The focus on utilization of millets is on an upward swing given the proven understanding that they are good sources of phytochemicals and dietary fiber.

## 6.1. Need for processing of millets

The outer tough seed coat of millets is an associated characteristic flavour (Malleshi *et al*; 1986), cultural attachments and non-availability of processed millet products similar to rice or wheat (Malleshi and Hadimani, 1993) are the prime reasons for less popularity of millet foods among rice and wheat eaters (Table 21 & 22).

While there are many machines available for processing cereals, there is a poor availability of credible industrial process capable of making white products from coloured minor millets. The nutrient composition and technological properties of minor millet grains offer a number of opportunities for processing and value addition to use as next generation foods to satisfy the consumers of different culture, location and society.

Like many industrialized and developed countries, India, too is experiencing a nutritional transition. With more and more women joining the work-force annually, fast foods and 'eating out' habits are replacing the family cook, thus leading to a rapidly developing 'fast food' industry locally.

Nowadays, preparation technologies have changed mainly due to lack of time and with the advent of the fast food industry. The 'multitasking' consumers see eating as something to be done while engaged in other works as well!

Processing involves partial separation and/or modification of three major constituents of millets-germ, starch-containing endosperm and protective pericarp.

In general, primary operation in processing of cereal or coarse cereal is usually the separation of pericarp and sometimes the germ from the edible portion.

**Table 21: Need for millet processing**

| | |
|---|---|
| Digestibility | Processing is required to make dried grains edible and digestible |
| Food safety | Cooking inactivates natural toxins and heat prevents bacterial and food spoilage |
| Organoleptic properties | Processing optimizes the appearance, taste and texture of foods to meet the needs of consumers |
| RTE and Convenience | To meet consumer demand for quick and easy meal solutions and also nutritional supplement |
| Maximize nutritional availability | Processing can make it easier for nutrients from grains to be digested. Nutrients lacking in the diet can be added to staple grain-based foods (food fortification) (e.g. thiamin added to flour) |

Various traditional methods of processing are still widely used, particularly in those parts of the semi-arid tropics where millet is grown primarily for human consumption. Most traditional processing techniques are laborious, monotonous and manual. They are almost entirely left at the disposal of women. Traditional methods are applied to decorticate millet grains partially or completely before further processing and consumption. Whole grains may as well be directly dry-milled to give a range of products: broken or cracked grains, grits, coarse meal and fine flour. The flour thus obtained is used in the preparation of an extensive variety of simple to complex food products.

**Table 22: Structural features of millets**

| Grain | Type | Shape | Colour | 1000 grain mass* (g) |
|---|---|---|---|---|
| Sorghum | Caryopsis | Spherical | White, yellow, red, brown | 25.0 -30.0 |
| Pearl millet | Caryopsis | Ovoid, hexagonal, globose | Grey, white, yellow, brown, purple | 2.5 -14.0 |
| Foxtail millet | Utricle | Elliptical | Light purple | 1.86 |
| Common millet | Utricle | Globose | Yellow, white, red, brown, violet | 4.7-7.2 |
| Finger millet | Utricle | Globose | | 2.6 |

*Source*: FAO (1995); *at 12 per cent moisture content (w.b)

Traditional processing methods have reached a stage from where modern foods can be manufactured from millets that cater to the tastes of modern foods prepared from wheat and maize.

## 6.2. Primary processing methods

### 6.2.1. Decortication/ dehulling

Decortication is partial removal of outer layer of the millet grain. It is accomplished by hand pounding and using rice dehullers or other abrasive dehullers.

Figure 31. Traditional method of dehulling millets –Hand pounding

Figure 32. Millet dehullers / decorticator

#### 6.2.1.1. Hand pounding

Traditionally, dry, moistened or wet grain is normally pounded with a wooden pestle in a wooden or stone mortar. Moistening the grain by adding about 10 per cent of water facilitates not only the removal of fibrous bran, but also the separation of germ and endosperm, if desired. However, this practice produces slightly moist flour (Perten, 1983). Parboiling increases the dehulling efficiency of kodo millet (Shrestha, 1972) and also eliminates stickiness in cooked finger millet porridge (Desikachar, 1975).

In hand pounding, grain, which should be fairly dry, is crushed and pulverized by the backward and forward movement of the hand-held stone on the lower stone. Generally, women do this unpleasant and laborious work (Fig. 31). It has been reported that a woman working hard with a pestle and mortar can decorticate 1.5 kg per hour, providing a non-uniform poor keeping quality product. Dry, moistened or wet grain is normally pounded with a wooden pestle in a wooden or stone mortar. This regimen is capable of making the toilers lose their temper, at times.

#### 6.2.1.2. Dehulling

Dehulling is accomplished by using rice dehullers or other abrasive dehullers. Millets would probably be more widely used if processing were improved and if sufficient good-quality flour made available to meet the demand (Fig. 32). While there are many machines available for processing cereals, there is unfortunately no well-proven industrial process available to satisfy entirely for making white products from coloured minor millets.

**Table 23: Nutrient composition of whole sorghum grain and pearled sorghum grain (Per 100g)**

| S.No. | Parameters | Whole grain | Pearled grain |
|---|---|---|---|
| 1 | Moisture (%) | 11.90 | 10.00 |
| 2 | Ash (%) | 1.60 | 1.70 |
| 3 | Protein (%) | 10.40 | 6.56 |
| 4 | Fat (%) | 1.90 | 1.10 |
| 5 | Carbohydrates (%) | 72.60 | 76.15 |
| 6 | Iron (mg) | 4.10 | 2.90 |
| 7 | Calcium (mg) | 25.00 | 12.09 |
| 8 | Zinc (mg) | 1.60 | 1.10 |
| 9 | Riboflavin (mg) | 0.13 | 0.80 |
| 10 | Energy (K cal) | 349 | 340 |

(*Source:* Data generated under NAIP subproject on Creation of demand for sorghum foods through PCS value chain, 2008-2012)

### 6.2.1.3. Benefits of dehulling in millets

Millets can be used for traditional as well as novel foods. Unprocessed or processed grain can be cooked whole or decorticated and if necessary ground to flour by traditional or industrial methods. However, there is a need to look into the possibilities of alternative uses.

Wheat has the unique property of forming an extensible, elastic and cohesive mass when mixed with water. Millet flours lack these properties when used alone. Hence, fortification brings many innovative 'Ready-To-Eat and Ready to Serve' minor millet based processed products. It is possible to fortify malted finger millet (70%) weaning food with green gram (30%) having low cooked paste viscosity and high energy density (Malleshi *et al*., 1986).

Pushpamma (1990) reported that decortication reduces total protein and lysine by 9 and 21%, respectively, but improves the remaining protein utilization. The loss of minerals was minimal. Decortication improves the biological availability of nutrients and consumer acceptability. Lorenz (1983) observed that the phytate content of proso millet varieties ranged from 170 to 470 mg per 100 g whole grain, and dehulling resulted in a 27 to 53% reduction in phytate content.

On dehulling, phytin phosphorus decreased by 12% in proso millet, 39% in little millet, 25% in kodo millet and 23% in barnyard millet (Sankara Rao *et al*., 1983).

Dehulling can remove 40 to 50% of both phytate and total phosphorus. Bio-availability of iron in sorghum for human subjects was found to be impacted more by phytin phosphorus than by tannin content of the grains (Radhakrishnan and Sivaprasad, 1980).

On pearling of sorghum grain, a significant increase in ionizable iron and soluble zinc content showed improved bioavailability of these two micronutrients, which was attributed partially to the removal of phytate, fibre and tannin along with the bran portion during pearling (Sankara Rao and Deosthale, 1980). Proximate composition of different sorghum value added products compared to flour is given in Table 24.

#### 6.2.1.4. Parboiling

Parboiling is basically the process of partial cooking the grain along with husk or bran. The raw grain is briefly steamed. The resultant product is dried, dehusked and decorticated.

#### 6.2.1.5. Milling

Milling is the process of separating bran and germ from the starchy endosperm so that the endosperm can be ground in to flour and rawa using different types of sieves in a hammer mill.

**Table 24: Proximate composition of sorghum processed foods (g/100g)**

| Name of product | Moisture (g) | Protein (g) | Fat (g) | Total Dietary fiber (g) | Insoluble DF (g) | Soluble DF (g) | Carbohydrates (g) | Energy (Kcal) |
|---|---|---|---|---|---|---|---|---|
| Sorghum Flour | 13.80 | 6.20 | 2.80 | 9.69 | 8.10 | 1.59 | 76.15 | 355 |
| Sorghum Soya blend | 7.89 | 11.92 | 2.62 | 12.71 | 9.77 | 2.94 | 63.22 | 330 |
| Sorghum Rawa | 8.97 | 7.15 | 1.20 | 9.23 | 7.92 | 1.31 | 77.74 | 350 |
| Sorghum Pasta | 11.47 | 8.39 | 1.38 | 5.56 | 4.82 | 0.74 | 76.21 | 355 |
| Sorghum Flakes | 13.80 | 5.09 | 2.40 | 5.97 | 5.43 | 0.54 | 74.90 | 342 |
| Sorghum Biscuits | 5.67 | 4.59 | 24.50 | 5.27 | 3.54 | 1.73 | 60.29 | 481 |

(*Source:* Data generated under NAIP subproject on Creation of demand for sorghum foods through PCS value chain, 2008-2012)

Milling to separate the seed coat or decortication reduces protein, dietary fiber, vitamins and mineral contents of the grains to some extent but this is compensated by better consumer acceptability, improved bio-availability of the nutrients and enhanced product making qualities. The bran fraction from the small millets (pearl millet) is a very good source of dietary fiber and edible oil (Kaur D.K., *et al.*, 2014).

The deoiled millet bran may be used as source of dietary fiber in formulating high- fiber foods as it contains negligible or less of silica compared to de-oiled rice bran. The changes in nutritional parameters upon milling and other processing interventions in sorghum are given in Tables 25-27. Biological value and digestibility of processed millets is given in Table 29.

**Table 25: Chemical, mineral and vitamin composition of upon milling process of sorghum (per 100g)**

| Parameters | Whole grain | Flour | Fine semolina (*idli rawa*) | Medium semolina (*upma rawa*) |
|---|---|---|---|---|
| Moisture (%) | 11.90 | 13.80 | 10.17 | 8.97 |
| Ash (%) | 1.60 | 1.60 | 0.73 | 2.03 |
| Protein (%) | 10.40 | 6.20 | 6.65 | 7.15 |
| Fat (%) | 1.90 | 2.80 | 1.70 | 1.20 |
| Carbohydrates (%) | 72.60 | 76.15 | 77.75 | 77.74 |
| Iron (mg) | 4.10 | 8.40 | 10.57 | 5.10 |
| Calcium (mg) | 25.00 | 10.03 | 7.55 | 5.75 |
| Chromium (mg) | 0.008 | 0.008 | 1.27 | 1.48 |
| Zinc (mg) | 1.60 | 1.30 | 1.21 | 1.38 |
| Riboflavin (mg) | 0.13 | 0.38 | 0.11 | 1.09 |
| Energy (Kcal/100 g) | 349 | 355 | 350 | 350 |

(*Source:* Data generated under NAIP subproject on Creation of demand for sorghum foods through PCS value chain, 2008-2012)

**Table 26: Nutrient composition of whole sorghum flour *vs.* multigrain flour (per 100g)**

| Parameters | Sorghum Flour | Multi grain Flour (3 grain) | Multi grain flour (5 grain) |
|---|---|---|---|
| Moisture (%) | 13.80 | 10.17 | 8.57 |
| Ash (%) | 1.60 | 1.53 | 1.50 |
| Protein (%) | 6.20 | 7.10 | 5.96 |
| Fat (%) | 2.80 | 2.40 | 2.60 |
| Carbohydrates (%) | 76.15 | 75.61 | 77.42 |
| Iron (mg) | 8.40 | 4.59 | 2.98 |
| Calcium (mg) | 10.03 | 10.61 | 15.94 |
| Chromium (mg) | 0.008 | 0.15 | 0.30 |
| Zinc (mg) | 1.30 | 0.55 | 0.81 |
| Magnesium (mg) | 171 | 76.25 | - |
| Riboflavin (mg) | 0.38 | 0.14 | BDL |
| Energy (K cal) | 355 | 345 | 339 |

(*Source:* Data generated under NAIP subproject on Creation of demand for sorghum foods through PCS value chain, 2008-2012)

**Table 27: Macro and micro nutrient changes during sorghum processing (per 100g)**

| Parameters | Medium rawa | Flakes | Vermi-celli | Pasta | Pops | Biscuits |
|---|---|---|---|---|---|---|
| Moisture (%) | 8.97 | 13.80 | 8.43 | 11.47 | 5.87 | 5.67 |
| Ash (%) | 2.03 | 0.63 | 0.77 | 0.77 | 0.63 | 2.00 |
| Protein (%) | 7.15 | 5.09 | 8.39 | 8.39 | 5.04 | 4.59 |
| Fat (%) | 1.20 | 2.40 | 1.38 | 1.38 | 2.60 | 24.50 |
| Carbohydrates (%) | 77.74 | 74.99 | 76.21 | 76.21 | 83.06 | 60.29 |
| Iron (mg) | 5.10 | 87.78 | 64.51 | 64.51 | 2.40 | 2.25 |
| Calcium (mg) | 5.75 | 93.15 | 54.51 | 64.51 | 10.26 | 68.80 |
| Chromium (mg) | 1.47 | 0.90 | 0.20 | 0.215 | 1.40 | 0.51 |
| Zinc (mg) | 1.38 | 8.78 | 7.49 | 5.74 | 4.51 | BDL |
| Magnesium (mg) | 86.02 | 80.51 | 67.48 | 67.48 | 86.77 | 56.10 |
| Riboflavin (mg) | 01.09 | 0.02 | 1.28 | 1.28 | 0.15 | 2.26 |
| Energy (Kcal/100 g) | 350 | 342 | 355 | 355 | 376 | 481 |

(*Source:* Data generated under NAIP subproject on Creation of demand for sorghum foods through PCS value chain, 2008-2012)

**Table 28: Biological value and digestible energy in dehulled millets (%)**

| Grain | True digestibility | Biological value | Net protein utilization | Digestible energy |
|---|---|---|---|---|
| Pearl millet* (Low protein) | 95.9 | 65.6 | 62.9 | 89.9 |
| Pearl millet* (High protein) | 94.6 | 58.8 | 55.7 | 85.3 |
| Foxtail millet+ | 95.0 | 48.4 | 46.3 | 96.1 |
| Little millet+ | 97.7 | 53.0 | 51.8 | 96.1 |
| Kodo millet+ | 96.6 | 56.5 | 54.5 | 95.7 |
| Proso millet+ | 99.3 | 52.4 | 52.0 | 96.6 |
| Barnyard millet+ | 95.3 | 54.8 | 52.2 | 95.6 |

(*Source*: * Singh *et al.*, *(1987)*; +Geervani and Eggum, 1989)

## 6.3 Effect of processing on antioxidant activity of millets

Different processing methods of foxtail millet made an effect on the Total Phenolic Content, Total Flavonoid Content, and the six kinds of phenolic acids. Compared with whole millet, the TPC of dehulled millet decreased and TFC of dehulled millet increased. Compared with dehulled millet, the TPC and TFC of cooked and steamed millet decreased ( Zhang, *et al.*, 2017). However, the total phenolic content and cinnamic acid content were rich in cooked millet. In addition, cooked millet demonstrated remarkable radical scavenging capacity, which was associated with its high contents of natural antioxidants found in the samples, such as phenolic compounds, cinnamic acid, and phytic acid. Correlations between the antioxidant activity and cinnamic acid ranged from 0.75 to 0.89, while the antioxidant activity and total phenolic content ranged from 0.83 to 0.91. Therefore, cooked millet was a good choice for human.

**Table 29: The antioxidant activity of 6 cultivars of foxtail millet with different treatment measured by FRAP, DPPH, methods**

| Foxtail millet | FRAP | | | | DPPH | | | |
|---|---|---|---|---|---|---|---|---|
| | Whole | Dehulled | Steamed | Cooked | Whole | Dehulled | Steamed | Cooked |
| **Longg12** | 20.06±0.03$^{dC}$ | 6.59 ±0.09$^{cC}$ | 3.92 ±0.23$^{aB}$ | 5.11± 0.13$^{bC}$ | 4.63 ±0.06$^{dC}$ | 2.34 ±0.11$^{cB}$ | 1.50 ±0.02$^{b}$ | 1.77 ± 0.03$^{aA}$ |
| **Jigu31** | 26.94 ±0.61$_{dD}$ | 7.16 ±0.14cD | 4.11 ±0.19$^{aB}$ | 4.89 ±0.21$^{bC}$ | 4.74 ±0.06$^{dC}$ | 3.14 ±0.15 | 1.37 ±0.02$^{bB}$ | 1.70 ±0.05$^{aB}$ |
| **Yugu01** | 16.60 ±0.62$^{dA}$ | 7.75 ±0.17$^{cE}$ | 4.09 ±0.09$^{bC}$ | 4.57± 0.04$^{aA}$ | 4.38 ±0.02$^{dA}$ | 4.02 ±0.11 | 0.93 ±0.03$^{bD}$ | 2.30 ±0.01$^{aC}$ |
| **Jinggu21** | 20.48 ±1.61$^{cC}$ | 5.79 ±0.08$^{bB}$ | 3.80 ±0.06$^{aB}$ | 4.19± 0.23$^{aB}$ | 4.60± 0.10$^{dBC}$ | 3.34 ±0.08 | 1.75 ±0.05$^{bD}$ | 2.07 ±0.04$^{aD}$ |
| **Jingfen02** | 18.38 ±1.23$^{dB}$ | 6.43 ±0.18$^{cC}$ | 3.02 ±0.20$^{aA}$ | 3.92± 0.25$^{bB}$ | 4.45± 0.08$^{dAB}$ | 3.32 ±0.01 | 1.15 ±0.04$^{bA}$ | 1.41 ±0.04$^{aE}$ |
| **Fenghonggu** | 19.87 ±0.32$^{cC}$ | 5.13 ±0.18$^{bA}$ | 3.98 ±0.33$^{aB}$ | 4.87± 0.29$^{bc}$ | 4.58 ±0.25$^{dBC}$ | 2.74 ±.002$^{aA}$ | 2.04± 0.05$^{cCE}$ | 2.39± 0.03$^{bF}$ |

The results were expressed as μmol equivalent dry weight (μmol TE/DW). Values ± SD of three determinations/ the different lower case letters indicate significant differences within processing methods of the cultivar ($p<0.05$). The different upper case letters indicate significant differences within different cultivars with the same treatment ($p<0.05$)

(*Source*: Zhang, *et al.,* 2017)

## 6.4. Secondary processing methods

Processing of primary processed raw material into product which is suitable for food uses or consumption such as Ready-to-Eat (RTE) and Ready-to-Cook (RTC) products which minimize cooking time and make it convenient foods. It has been reported that the traditional (popping and flaking) as well as contemporary methods (roller-drying and extrusion-cooking) of cereal processing could be successfully applied to millets to prepare ready-to-eat products, thereby increasing its utilization as a food (Ushakumari *et al.,* 2004). However, because of the rigid endosperm texture, nearly spherical shape and smaller size, heavy duty roller-flaker is essential for flaking unlike the edge runner used for flaking of rice.

The popping technology significantly reduces crude fat and crude fiber contents more significantly than raw millet, while the carbohydrate and energy values were significantly higher. This is mainly because fat and fiber contents are higher in outer coat of grains, thus more affected by processing compared with nutrients located in inner layer (Choudhury *et al*., 2011). Therefore, the use of new technology with optimization of puffing conditions, popping technique can be used as a strategy or in combination with other pre-treatments to produce RTE expands from millet grains on a commercial scale, thus promoting utilization of millet grains.

The hydrothermal treatments exploit the thermo-physical properties of starch and prepare flakes. During this process the Maillard reaction takes place in which the sugars present in the aleurone layer react with amino acids of the millet and gives a pleasant and highly desired aroma to the puffed product. In also reduces anti-nutrients like phytates, tannins, etc., increase bio-availability of minerals, give pleasing texture to the product, and enhances protein and carbohydrate digestibility (Nirmala *et al*., 2000).

In addition to these, baking technologies can also be used as affective alternatives. Several studies recommended millets as the nutritional composition, biological and sensory characteristic values are found to be on par with wheat-based products. This has come as a morale-booster and has upped the demand for millet-based food products.

Kodo Millet Rice

# Chapter-VII

# Summary and Conclusions

## Millets as potential future crops and industrial feedstocks

Millets supports different climatic conditions and agricultural ecology where food insecurity, malnutrition and non-communicable diseases are common. The versatile small millets would fit in any situations of climate change and save farmers' from a total crop failure and debt-traps (in the Indian context). The farmers who had shifted from millets to other crops are keen to come back to millets in view of the stable harvests, easy crop production, drought resistance, and eco-friendly production, provided an assured market is in place.

The scientific data on nutritional and health benefits of millets are now available. They are found to be superior nutritious cereals that are beneficial for human health. In addition, millet foods are being made available in RTE and RTC forms for the urban population (Table 30). The new demand for millets, leading to higher prices, can make their cultivation profitable, ensuring the legitimate place for millets in the national food basket.

Millets have good grain qualities suitable for processing. Processing of the grain for many end uses involves primary (wetting, dehulling and milling) and secondary (fermentation, malting, extrusion, flaking, popping and roasting) operations. Consumed at household levels, the processing must be considered at both the traditional and industrial levels, involving small, medium and large-scale entrepreneurs (Obilana and Manyasa, 2002; Hamad, 2012).

**Table 30: New generation RTE products from millets**

| Millet product | Raw material | Processing technique used |
|---|---|---|
| Energy bar | Dehulled grain | Flaking and binding |
| Breakfast cereals | Whole grains | Roasting, grinding, milling and extrusion |
| Puffed and expanded products | Semolina | Milling and extrusion |
| Multi grain biscuits, therapeutic biscuits | Dehulled grains | Milling and baking |
| Health drinks (weaning foods) | Whole grains | Roasting / malting and grinding |

The emerging principal uses of millets as an industrial raw material include production of biscuits and confectionery, beverages, weaning foods and beer (Laminu *et al.,* 2011; Anukam and Reid, 2009).

Grits, flour, and meals from cereals from pearl millet and sorghum are now common items in the urban market. Soft-biscuits and cookies are being made using sorghum, maize and wheat composites, while cakes and non-wheat breads have become a subject of increasing scientific and technological enquiry, and ones that are showing encouraging results (Akeredolu *et al*., 2005; Laminu *et al*., 2011; Vidya *et al*., 2012).

In view of the emerging awareness, Indian Institute of Millet Research, has developed and standardized a number of millet-based food products such as multigrain atta, semolina (fine and medium), flakes, biscuits and cold extruded products (pasta and vermicelli) and commercialized these products.

The pilot scale manufacturing and sale of millet-based products are facilitated at the institute. The transfer of technology for millet-based products to the farmers, entrepreneurs, and common people is also underway at IIMR. The quest has been to promote millet products in the community and usher in a lifestyle that reflects a vibrant all-round health of one and all.

## Chapter-VIII

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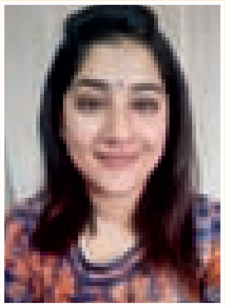

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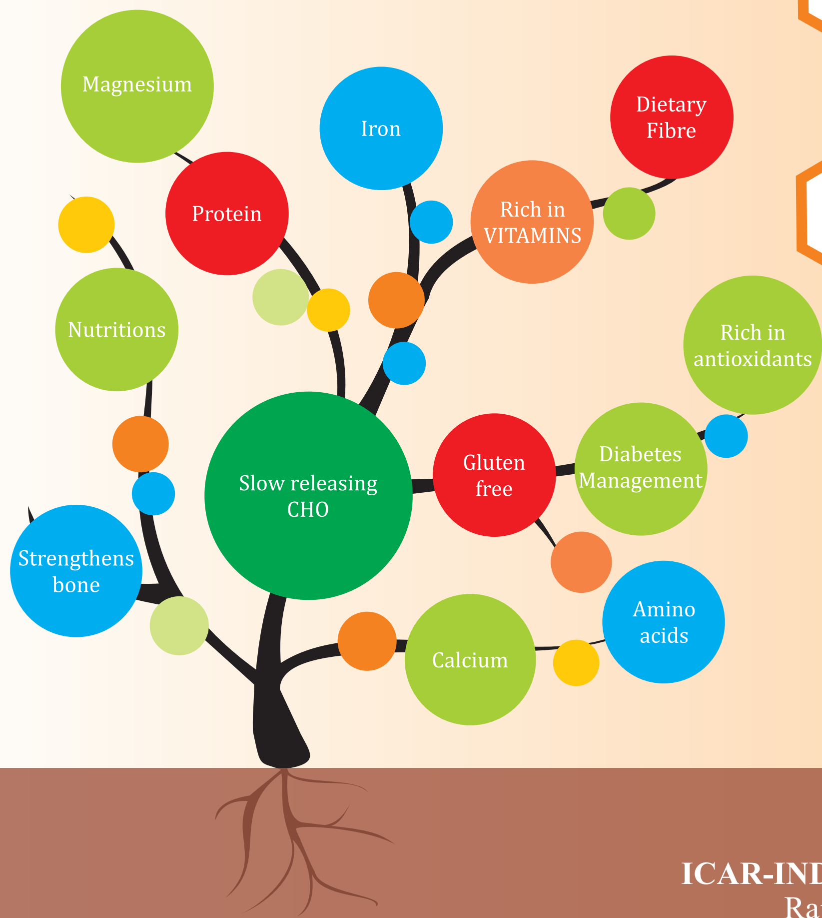



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