Nutritional and Health Benefits of Millets

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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

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.

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ABBREVIATION

+iAUC	Positive Incremental Area Under Curve
AAS	Amino Acid Score
ATP	Adenosine Tri Phosphate
AR	Aldose Reductase
ATL	Above the Line
BMI	Body Mass Index
BTL	Below the Line
CD	Celiac Disease
CFTRI	Central Food Technological Research Institute
CHD	Coronary Heart Disease
CHO	Carbohydrates
CVD	Cardio Vascular Disease
DPPH	2,2-diphenyl-1-picryl hydrazyl
FAO	Food and Agriculture Organization
FCI	Food Corporation of India
FP	Fecal Protein
GI	Glycemic Index
GL	Glycemic Load
GoI	Government of India
GSL	Grain Sorghum Lipid
ha	Hectare
HACCP	Hazard Analysis and Critical Control Points
HPLC	High Performance Liquid Chromatog-raphy
HDL	High Density Lipoproteins
ICAR	Indian Council of Agricultural Research
ICMR	Indian Council of Medical Research
IDF	Insoluble Dietary Fibre
ICDS	Integrated Child Development Services
ICRI-SAT	International Crop Research Institute for Semi-Arid Tropics
IIMR	Indian Institute of Millets Research
INSIMP	Initiative for Nutrition Security through Intensive Millets Promotion
Kg/ ha	Kilogram per hectare
LDL	Low Density Lipoproteins
MFP	Metabolic fecal Protein
MMA	Macro Management in Agriculture
MDM	Mid Day Meal
NAIP	National Agricultural Innovation Project
NSP	Non starchy polysaccharides
NGF	Nerve Growth Factor
NIN	National Institute of Nutrition
NIDDM	Non Insulin Dependent Diabetes Milletus
NVIF	Nutritive Value of Indian Foods
PD-CAAS	Protein Digestibility Corrected Amino Acid Score
PDS	Public Distribution System
PI	Protein Intake
q/ha	Quintal per hectare
R and D	Research and Development
RBP	Retinol Binding Protein
RTC	Ready to Cook
RTE	Ready to Eat
SDF	Soluble Dietary Fibre
SDS	Slow Digestible Starch
TDF	Total Dietary Fibre
VLDL	Very Low Density Lipoproteins
WHO	World Health Organization

Executive Summary

Millets offer nutritional security and there is a need for promoting millets as they are highly nutritious. These have been important food staples in human history, particularly in Asia and Africa. Sorghum and other millets consumption usage as direct food has significantly declined over the past three decades. The decline in demand has led to the decline in millets production considerably in India. Production of sorghum in India has come down from 7 million tonnes during 2010-11 to 4.2 million tonnes during 2015-16; bajra production was reduced from 10.4 million tonnes to 8.1 million tonnes, production of ragi reduced to 2.2 million tonnes to 1.8 million tonnes and small millets production came down to 0.39 million tonnes from 0.44 million tonnes during the same period. According to the FAO statistics, 2017 millets production in the world was Sorghum (Sorghum bicolor (L.) Moench) is the fifth major cereal of the world after maize, paddy, wheat and barley as per FAO production data of 2014.

This Nutritional Bulletin includes nutritional profile of Sorghum, Pearl millet, Finger millet, Foxtail millet, Common millet, Little millet, Barnyard millet and Kodo millet. Almost all the millets are used for human consumption in most of the developing countries, but their use has been primarily restricted to animal feed in developed countries. Sorghum and millets are gluten free, hence, are useful dietary cereals. In general millets are rich source of fibre, minerals and B-complex vitamins. High fibre content and presence of some anti-nutritional factors like phytates and tannins in millets affect bioavailability of minerals. Few studies in humans have suggested that absorption of iron tends to be lower from millets than from rice or even wheat. (Rao *et al*.,1983). Millets are also rich in health-promoting phytochemicals like polyphenols, lignans, phytosterols, phyto-oestrogens, phytocyanins. These function as antioxidants, immune modulators, detoxifying agents etc. and hence protect against age-related degenerative diseases like cardiovascular diseases (CVD), diabetes, cancer etc. (Rao *et al.,* 2011). Some of the known nutrients-vitamins, minerals, essential fatty acids also have benefits in terms of prevention of degenerative diseases besides their known functions of preventing nutritional deficiency diseases. Being non-glutinous, millets are safe for people suffering from gluten allergy and celiac disease. They are non-acid forming, easy to digest and non-allergenic (Saleh *et al.,* 2013). Millets have potential for protection against age-onset degenerative diseases. 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 are believed to be responsible for many health benefits (Miller, 2001; Edge *et al.*, 2005).

This context of emerging need for alternating meal, fill the gap in the absence of essential nutrients, IIMR has done a commendable research in various value added Convenient products without much loss of minerals in view sorghum with an upgradation of DSR to IIMR. Now the research is not just limited to Sorghum but widens to other millets too. The recipes formulated at Indian Institute of Millets Research (IIMR) upgraded from Directorate of Sorghum Research (DSR), a central agency under ICAR to work on Sorghum formerly but now with an upgradation, all the aspects of millets are included and research and development is undertaken. The sub-project of NAIP-Millets Value Chain focuses on such an effort on selected millet foods with special case of sorghum; given the model is successful, it can be replicated to other millets which can be of great use to consumers, households and entrepreneurs where they can practice and prepare different methods of preparation of value added products with health benefits which are not available in the market, these value added products can combat the nutritional deficiency disorders. The preparation and production of such products by households, entrepreneurs, self-help groups, small scale industries and large scale industries can raise their income level by promoting the value added products. By promotion of these Value added products can improve the socio- economic status and also health status of the consumers. The synergic efforts resulted various nutritionally rich convenient sorghum product technologies were developed and successfully commercialized on pilot scale at Hyderabad. Scientific empirical studies conducted on various products have shown that the recipes such as *idli, dosa*, etc with sorghum and other millets as that of rice, wheat etc. Implementation of effective promotional strategies and policy sensitization attracted entrepreneurs and policy makers to consider sorghum as priority

Chapter-1

Millet Nutrition: The Tradition of India

1. INTRODUCTION

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 important crops in the semi-arid tropics of Asia and Africa (especially in India and Nigeria), with 97% of millet production in developing countries. The crop is favoured due to its productivity and short growing season under dry, high-temperature conditions. The most widely grown millet is pearl millet, which is an important crop in India and parts of Africa. Finger millet, Proso millet, and Foxtail millet are also important crop species. In the developed world, millets are less important. For example, in the United States only Proso millet is significant, and it is mostly grown for bird seed. While millets are indigenous to many parts of the world, it is believed that they had an evolutionary origin

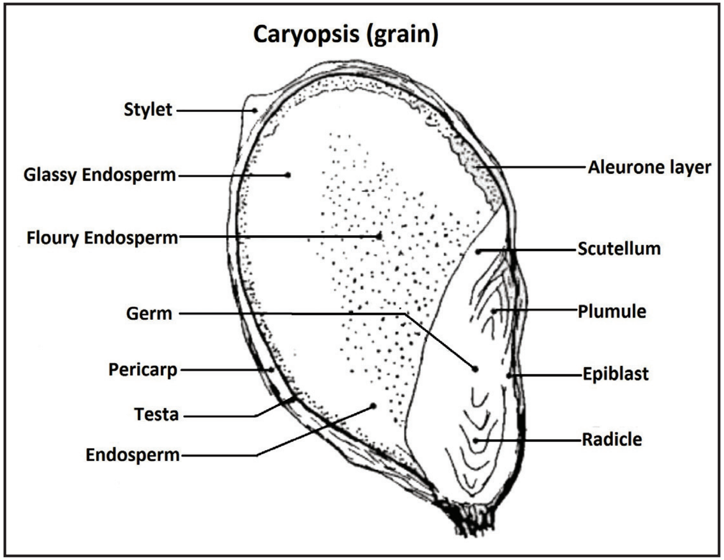

Fig. 1 General structure of millet grain

Fig. 2 Sorghum panicles

in tropical western Africa, as that is where the greatest number of both wild and cultivated forms exist. Millets have been important food staples in human history, particularly in Asia and Africa. They have been in cultivation in East Asia for the last 10,000 years.

Sorghum and millets have been important staples in the semi-arid tropics of Asia and Africa for centuries. These crops are still the principal sources of energy, protein, vitamins and minerals for millions of the poorest people in these regions. Sorghum and millets are grown in harsh environments where other crops grow or yield poorly. They are grown with limited water resources and usually without application of any fertilizers or other inputs by a multitude of small-holder farmers in many countries. Therefore, they are mostly consumed by disadvantaged groups; they are often referred to as "coarse grain" or "poor people's crops". 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. The cereals considered in this publication include sorghum, Pearl millet, Finger millet, Foxtail millet, Common millet, Little millet, Barnyard millet and Kodo millet. Teff (*Eragrostis tef*), which is extensively cultivated in Ethiopia, is not strictly a millet and is therefore not included. Other millets such as fonio (*Digitaria exilis*) and Job's tears (*Coix lancryma* -jobi) are of minor importance.

1.1 Global Distribution and Production of Millets

According to FAO statistics (2009), the world production of millets was 26.7 million metric tonnes from an area of 33.6 million hectare. Nearly a decade earlier (2002), the world production of millets was down to 23.3 million metric tons from an area of 33.3 million hectare. Africa was the largest producer of millet in 2009 (20.6 million metric tonnes), followed by Asia (12.4 million metric tonnes) and India (10.5 million metric tonnes). Relative to wheat, rice, maize and barley, sorghum ranks fifth in importance, in terms of both production and area planted, accounting for 5% of the world cereal production (Obilana, 2002)

Global Production

The global production of pearl millets has come down from 32.8 million tonnes in 2010 to 28.4 million tonnes during 2014. Asia and Africa are the major contributors of worlds total pearl millets production contributing more than 98%

Fig. 3 Finger millet panicles

of the global production. The share of African countries in global millets production has come down from 49.22% in 2010 to 43.72% during 2014, whereas the contribution from Asian countries has increased to 52.25% from 48.72% during 2010. Sorghum (Sorghum bicolor (L.) Moench) is the fifth major cereal of the world after maize, paddy, wheat and barley as per FAO production data of 2016. The world sorghum production increased significantly during 2014 to 68.9 million tonnes from 60 million tonnes in 2010, after a drastic reduction in 2011 to 57 million tonnes. African stood to be largest producer of sorghum during 2014 contributing about 42% of global production followed by Americas (39.75%) and Asia (14.04%).

1.2 Distribution of Millets in India

India is the top most producers of millets followed by Nigeria for the year 2000 and 2009. In India, eight millets species (Sorghum, Pearl millet,Finger millet, Foxtail millet, Kodo millet, Proso millet, Barnyard millet and Little millet) are commonly cultivated under rain fed conditions. Further, in each of the millet growing areas at least 4 to 5 species are cultivated either as primary or allied crop in combination with the pulses, oilseeds, spices and condiments. For instance, while pearl millet and sorghum are primary crop and allied crops respectively in the desert regions of Rajasthan, in the eastern parts of Rajasthan and Gujarat it is the opposite. Similarly, sorghum is sown as major crop in the Telangana, Andhra Pradesh, Maharashtra and parts of Central India, while it is considered as fodder crop in some of the Southern regions.

Likewise, Finger millet is a primary crop in Tamil Nadu and Gujarat, while the same is a minor crop in Telangana. Hence, the spatial distribution of millets either as a primary crop or as allied crops largely depends on the growing habitat and the amount of rainfall the region receives. While sorghum predominates in areas receiving annual rainfall beyond 400 mm, pearl millet rivals it in areas with annual rainfall of 350 mm. Further, the small millets like finger millet, foxtail millet, barnyard millet, little millet and proso millet are found in most of the southern and central states in India especially wherever annual rainfall is below 350 mm, perhaps where no other cereal crop can grow under such moisture stress.

Fig. 4 Pearl millet panicles

However, in spite of a rich inter/intra-species diversity and wider climatic adaptability cultivation of diverse millet species/varieties is gradually narrowing in the recent past. In a way, a lack of institutional support for millet crops in contrast to the institutional promotion of rice and wheat continue to shrink the millet-growing region. In spite of this, several communities in the dry/rain fed regions having known the food qualities of millets over generations continue to include a range of millets in the traditional cropping patterns, which recognize millet as an essential part of the millet diet.

Vernacular Names of Millets

English	Sorghum	Pearl Millet	Finger millet	Little millet	Kodo millet	Foxtail/ Italian millet	Barnyard millet	Proso millet
Hindi	Jowar	Bajra	Mandua	Kutki	Kodon	Kangni, Kakum	Sanwa, Jhangon	Barre
Sanskrit	-	-	Nandimukhi, Madhuli	-	Kodara	Kanguni	Shyama	Chiná
Kannada	Jola	Sajjai	Ragi	Same	Harka	Navane	Oodalu	Baragu
Tamil	Cholam	Kamboo	Kelvaragu	Samai	Varagu	Tenai	Kuthiravaali	Panivaragu
Telugu	Jonna	Sajjalu	Ragulu	Samalu	Arikelu, Arika	Korra, Korralu	Udalu, Kodisama	Varigulu, Varagalu
Malayalam	Cholam	Kamboo	Moothari	Chama	Varagu	Thina	-	Panivaragu
Marathi	Jcwari	Bajri	Nachni	Sava	Kodra	Kang, Rala	Shamul	Vari
Gujarati	Juar	Bajri	Nagli, Bavto	Gajro, Kuri	Kodra	Kang	Sama	Cheno
Bengali	Juar	Bajra	Mandua	Kangani	Kodo	Kaon	Shamula	Cheena
Punjabi	-	Bajra	Mandhuka, Mandhal	Swank	Kodra	Kangni	Swank	Cheena

Fig. 5 Proso millet panicles

1.3 Sorghum

Sorghum (*Sorghum bicolor* (L.) Moench) is a warm season crop, intolerant of low temperatures but fairly resistant to serious pests and diseases. It is known by a variety of names (such as great millet and guinea corn in West Africa, Asia and parts of Middle East). Most of the sorghum produced in North and Central America, South America and Oceania is used for animal feed (FAO, 1995).

The grain consists of naked caryopsis, made up of a pericarp, endosperm and germ. Although there is a huge range of physical diversity, sorghum are classed into four groups: (1) grain sorghum, (2) forage sorghum glum; (3) grass sorghum; or (4) Sudan sorghums and broomcorn (Macrae*et al.,* 1993) (Fig. 1). Sorghums are grouped using the following characteristics (Fig. 2).

- The color of the pericarp (white, yellow or red)
- Presence or absence of pigmented testa (with/without tannins)
- Pericarp thickness
- Endosperm color (white, hetero yellow or yellow)
- Endosperm type (normal, hetero waxy or waxy)

1.4 Finger Millet

Finger millet (*Eleusine coracana* (L.) Gaertn) is a cereal grass grown mostly for its grain (Fig. 3). Finger millet is a robust, tufted, tillering annual grass, up to 170 cm high (FAO, 2012; De Wet, 2006; Quattrocchi, 2006). The inflorescence is a panicle with 4-19 finger-like spikes that resembles a fist when mature, hence the name finger millet (de Wet, 2006; Quattrocchi, 2006). The spikes bear up to 70 alternate spikelets, carrying 4 to 7 small seeds (Dida *et al.,* 2006). The seed pericarp is independent from the kernel and can be easily removed from the seed coat (FAO, 2012).

Finger millet is a staple food in many African and South Asian countries. It is also considered a helpful famine crop as it is easily stored for lean years (FAO, 2012). The grain is readily digestible, highly nutritious and versatile, and

Fig. 6 Kodo millet panicles

can be cooked like rice, ground to make porridge or flour, or used to make cakes (De Wet, 2006). Sprouted grains are recommended for infants and elderly people. Finger millet is also used to make liquor (*arake* or *areki* in Ethiopia) and beer, which yields by-products used for livestock feeding (FAO, 2012). Finger millet grain is not widely used for livestock: it is primarily a food grain, but it is of lesser quality for livestock than maize, sorghum and pearl millet. In India, it is sometimes used for feeding infant calves, growing animals, as well as sick and convalescing animals (Sampath, 1986)

1.5 Pearl Millet

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) (Fig. 4) originated in Central tropical Africa and is widely distributed in the drier tropics and India. It was introduced into the Western state in the 1850's and became established as minor forage in the Southeast and Gulf Coast states. The plant was probably domesticated as a food crop some 4000 to 5000 years ago along the Southern margins of the Central highlands of the Sahara. It has since become widely distributed across the semiarid tropics of Africa and Asia. Pearl millet has traditionally been an important grain, forage, and stover crop primarily in the arid and subtropical regions of many developing countries. As pearl millet cultivation expands into non-traditional areas in temperate and developed countries, production constraints from diseases are assuming greater importance. Dissemination of accurate information on diseases of the crop has not kept pace with the increased interest in pearl millet as a viable crop in non-traditional areas. Pearl millet is well adapted to growing areas characterized by drought, low soil fertility, and high temperature. It performs well in soils with high salinity or low pH. Because of its tolerance to difficult growing conditions, it can be grown in areas where other cereal crops, such as maize or wheat, would not survive.

1.6 Proso Millet

Proso millet (*Panicum miliaceum* (L.)) is an annual grass, growing from seed each year (Fig. 5). Its origin goes back in history at least as far as 2000 B.C. when it is reported to have been grown in the Central regions of Europe. This plant is especially well suited to dry climates such as Central Russia, the Middle East, Northern India, Africa, Manchuria, and


Fig. 7 Foxtail millet panicles

the Great Plains area of North America. Proso millet was first introduced to Canada in the 17th century, and was used in a limited way as a forage crop in the early 1900's.

Proso millet is a relatively low demanding crop and diseases aren't known. That's why Proso millet is often used in organic farming systems in Europe. In the United States it is often used as an intercrop. Thereby, Proso millet can help to avoid a summer fallow, and continuous crop rotation can be achieved. Its superficial root system and its resistance to atrazine residue make Proso millet a good intercrop between two water and pesticide demanding crops. The stubbles of the last crop, by allowing more heat into the soil, result in a faster and earlier millet growth.

1.7 Kodo Millet

Kodo millet (*Paspalum scrobiculatum* (L.)) is widely distributed in damp habitats across the tropics and subtropics of the world (Fig. 6). It is indigenous cereal of India and is grown today in Uttar Pradesh in the North and Kerala and Tamilnadu in the South. This cereal is also known as *varagu*, *haraka* and *arakalu*. It forms the main stay of the 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. Kodo millets are rich in B vitamins, especially niacin, B6 and folic acid, as well as the minerals such as calcium, iron, potassium, magnesium and zinc. Kodo millets contain no gluten and is good for people who are gluten intolerant. Regular consumption of kodo millet is very beneficial for postmenopausal women suffering from signs of cardiovascular disease, like high blood pressure and high cholesterol levels.

1.8 Foxtail Millet

Foxtail millet (*Setaria italica* (L.) P. Beauvois) is regarded as a native of China, it is one of the world's oldest cultivated crops (Fig. 7). Foxtail millet ranks second in the total world production of millets and continues to have an important place in the world agriculture providing approximately six million tons of food to millions of people, mainly on poor or marginal soils in southern Europe and in temperate, subtropical and tropical Asia. It will grow in altitudes from sea level to 2000 m. It cannot tolerate water logging. Foxtail millet is fairly tolerant of drought; it can escape some droughts

Fig. 8 Barnyard millet panicles

because of early maturity. Due to its quick growth, it can be grown as a short-term catch crop. It is adapted to a wide range of elevations, soils and temperatures. Its grain is used for human consumption and as feed for poultry and cage birds.

1.9 Barnyard Millet

Barnyard millet (*Echinochloa crusgalli* (L.) P. Beauvois) is a multi-purpose crop which is cultivated for food and fodder (Fig. 8). It is also called by several other names viz., *Japanese* barnyard millet, *ooda, oodalu, sawan, sanwa* and *sanwank.* Nutritionally too, it is a good source of protein, which is highly digestible and is an excellent source of dietary fiber with good amount of solu ble 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 modern mankind who is engaged in sedentary activities. In barnyard 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 the patients with cardiovascular disease and diabetes mellitus. Barnyard millet is most effective in reducing blood glucose and lipid levels.

1.10 Little Millet

Little millet (*Panicum* sumatrense*)* was domesticated in India (Fig.9). It grown throughout India to a limited extent up to altitudes of 2100 m, but is of little importance elsewhere. The seeds of little millet are smaller than those of common millet. This species of cereal is similar in habit to the proso millet except that it 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. The panicles are from 4 to 15 cm in length with 2 to 3.5 mm long awn. The grain is round and smooth, 1.8 to 1.9 mm long. It can withstand both drought and water logging. It can be cultivated up to 2000 m above sea level. Little millet is another reliable catch crop in view of its earliness and resistance to adverse agro-climatic conditions. The stover is a good fodder for cattle.

Fig. 9 Little millet panicles

Chapter-2

Nutritional Importance and Health Benefits of Millets

2.1 Nutritional Importance of Millets

Sorghum and millets namely, Pearl millet, Finger millet, Kodo millet, Proso millet, Foxtail millet, Little millet, and Barnyard millet are important staples to millions of people world-wide. Generally, these are rain fed crops grown in areas with low rainfall and thus resume greater importance for sustained agriculture and food security. Almost all the millets are used for human consumption in most of the developing countries but their use has been primarily restricted to animal feed in developed countries. Millets are nutritionally comparable to major cereals and serve as good source of protein, micronutrients and phytochemicals. Processing methods like soaking, malting, decortications, and cooking affect the anti-oxidant content and activity (Saleh *et al*., 2013). While sorghum and most of the millets contains about 10% protein, 3.5% lipids, finger millet contains 12-16% protein and 2-5% lipids. Sorghum and millets are very good sources of micronutrients such as vitamins and minerals. Major portion of sorghum protein is prolamin (kaffirin) which has a unique feature of lowering digestibility upon cooking whereas, the millets have a better amino acid profile. It has been reported that sorghum proteins upon cooking are significantly less digestible than other cereal proteins, which might be a health benefit for certain dietary groups. On the other hand, millets contain fewer cross-linked prolamins, which may be an additional factor contributing to higher digestibility of the millet proteins.

The average of nutrient composition of some millet grains and other grains is summarized in Table 1. The amino acid contents of various millets are given in Table 2.

Table 1: Proximate Composition and Dietary Fibre (per 100 g)

Millets and Cereals		Moisture (g)	Protein (g)	Ash (g)	Total Fat (g)	Dietary Fibre (g)			Carbo hydrates (g)	Energy (KJ)
						Total	Insoluble	Soluble		
Bajra (*Pennisetum typhoideum)*		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 *		-	12.30	-	4.30	-	-	-	60.09	331
Barnyard Millet *		-	06.20	-	2.20	-	-	-	65.55	307
Proso Millet *		-	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 (*Cheno podium 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*

Table 2: Mineral and Trace Elements compared to fine cereals (mg/g of N)

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 typhoideum)*		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 vulgare)*		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	-	-
Kodo Millet *(Setaria italica)*		1.07 ± 0.83	-	-	15.27 ± 1.28	0.021 ± 0.027	0.005± 0.003	0.26± 0.05	2.34 ± 0.46	-	0.027 ± 0.003
Foxtail Millet *		-	-	-	-	0.030	-	1.40			
Barnyard Millet *		-	-	-	-	0.090	-	0.60			
Proso Millet *		-	-	-	-	0.020	-	1.60			
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*

About 5-8% of protein is present in finger millet, 65-75% carbohydrates, 15-20% dietary fiber and 2.5-3.5% minerals (Chethan and Malleshi, 2007a). The Naked caryopsis of finger millet with brick red coloured seed coat is generally used in the form of whole meal in the traditional food preparations such as roti, muddle and ambali (thin porridge). Regular consumption of whole grain cereals and their products have shown in epidemiological studies that they can protect against risk of diabetes mellitus, gastrointestinal diseases and cardiovascular risks (McKeown, 2002). The use of millets as whole grain makes the essential nutrients such as dietary fiber, minerals, phenolics and vitamins concentrated in the outer layer of the grain or the seed coat form the part of the food and offer their nutritional and health benefits (Antony *et al.,* 1996).

Millets are not only comparable to major cereals with respect to their nutritional features but are very good sources of carbohydrates, micronutrients and phytochemicals with nutraceutical properties. The millets contain 7-12% protein, 2-5% fat, 65-75% carbohydrates and 15-20% dietary fibre. Among them, pearl millet contains considerably high proportion of proteins (12-16%) as well as lipids (4-6%) whereas; finger millet contains lower levels of protein (6-8%) and fat (1.5-2%). The essential amino acid profiles of the millet protein is better than maize. The niacin content in pearl millet is higher than all other cereals whereas, finger millet proteins are unique because of the sulphur rich amino acid contents. Similar to cereal proteins, the millet proteins are poor sources of lysine, but they complement well with lysine-rich vegetable (leguminous) and animal proteins form nutritionally balanced composites of high biological value. Small millets are more nutritious compared to fine cereals. Finger millet is the richest source of calcium (300-350 mg/100 g) and other small millets are good source of phosphorous and iron.

Table 3: 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*

Table 4: Fat Soluble Vitamins profile of millets and major cereals

Millets and Cereals		Ergocalcife (μg) Alpha	Tocopherols (mg)				Tocotrienols (mg)			α – Tocopher-ol (mg)	Phylloqui-noes – K1 (μg)
			Beta	Gamma	Delta	Alpha	Gamma	Delta			
Bajra (*Pennisetum typhoideum)*		05.65 ± 0.27	0.10 ± 0.010	-	1.42 ± 0.20	-		-	-	0.24 ± 0.02	02.85 ± 0.63
Sorghum (*Sorghum vulgare)*		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
Kodo Millet (*Setaria italica)*		-	0.03 ± 0.010	-	0.43 ± 0.12	-		0.19 ± 0.05	-	0.07 ± 0.02	03.75 ± 0.63
Foxtail Millet *		-	-	-	-	-	-	-	-	-	-
Barnyard Millet *		-	-	-	-	-	-	-	-	-	-
Proso Millet *		-	-	-	-	-	-	-	-	-	-
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
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
Ama-ranth 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*

Table 5: Carotenoids profile of millets and major cereals

Millets and Cereals		Lutein (µg)	Zeaxanthin (µg)	Lycopene (µg)	β-Cryptoxanthin	ϒ-Carotene	β-Carotene	Total Carotenoids
Bajra (*Pennisetum typhoideum)*		29.69 ± 08.72	9.30 ± 1.23	-	-	-	28.23 ± 9.42	293 ± 55.7
Sorghum (*Sorghum vulgare)*		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
Kodo Millet (*Setaria italica)*		59.40 ± 07.01	3.91 ± 1.08	-	-	-	01.41 ± 0.29	272 ± 25.1
Foxtail Millet *		-	-	-	-	-	-	-
Barnyard Millet *		-	-	-	-	-	-	-
Proso Millet *		-	-	-	-	-	-	-
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 and *Nutritive value of Indian foods, NIN – 2007*

Table 6: 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 typhoideum)*		56.02± 2.57	55.21± 2.57	0.21 ± 0.01	0.60 ± 0.02	-	-	0.81 ± 0.01
Sorghum (*Sorghum vulgare)*		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
Kodo Millet (*setaria italica)*		66.25 ± 2.90	64.96 ± 2.93	-	0.89 ± 0.11	0.40 ± 0..02	-	1.29 ± 0.10
Foxtail Millet *		-	-	-	-	-	-	-
Barnyard Millet *		-	-	-	-	-	-	-
Proso Millet *		-	-	-	-	-	-	-
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

Source: *Indian Food Composition Tables, NIN – 2017 and *Nutritive value of Indian foods, NIN – 2007*

Table 7: Fatty Acid Profile 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 typhoideum)*		729± 21.3	128± 19.6	6.97 ± 0.45	1040± 39.8	1844 ±56.7	875 ±34.5	1047 ± 39.9
Sorghum (*Sorghum vulgare)*		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
Kodo Millet (*setaria italica)*		211 ± 0.9	28.40 ± 1.22	3.21 ± 0.11	291 ± 7.2	576 ± 17.8	246 ± 2.3	297 ± 6.8
Foxtail Millet *		6.40	6.30	-	13.0	66.50	-	-
Barnyard Millet *		10.80	-	-	53.80	34.90	-	-
Proso Millet *		-	-	-	-	-	-	-
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*

Table 8: Amino Acid Profile of millets and major cereals

Millets and Cereals		Histidine	Isoleucine	Luecine	Lysine	Methionine	Cystine	Phenylalanine	Threonine	Tyrptophan	Valine
Bajra (*Pennisetum typhoideum)*		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 vulgare)*		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	08.86 ± 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	08.08 ± 0.06	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
Kodo Millet (*Setaria italica)*		2.14 ± 0.07	4.55 ± 0.22	11.96 ± 1.65	1.42 ± 0.17	2.69 ± 0.16	1.92± 0.05	6.27 ± 0.34	3.89 ± 0.16	1.32 ± 0.19	5.49 ± 0.23
Foxtail Millet *							-	-			
Barnyard Millet *							-	-			
Proso Millet *							-	-			
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
	Par boiled	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 (*Cheno podium 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 and *Nutritive value of Indian foods, NIN – 2007*

Nutrient Composition

The millet grain contains about 65% carbohydrate, a high proportion of which is in the form of non-starchy polysaccharides and dietary fibre 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. Millet grains are also rich in important vitamins *viz*., Thiamine, riboflavin, folic acid and niacin. Millets are comparable to rice and wheat or rich in some of the minerals as well as fatty acids. Millets vary largely in composition of carbohydrates as proportion of amylose and amylopectin content vary from 16-28% and 72-84%, respectively.

The nutrient composition of Millet grain indicates that it is a good source of energy, protein, vitamins and minerals including trace elements. The edible component of millet kernel is the rich source of phytochemicals, such as dietary fiber and polyphenols (0.2-0.3%) (Hadimani and Malleshi 1993; Ramachandra *et al.,* 1977). Millets contribute to antioxidant activity with phytates, polyphenols and tannins present in it having important role in aging and metabolic diseases (Bravo, 1998). The highest calcium content is present is finger millet with 344 mg/100g among the cereals; Also rich in phytates 0.48g/100g, polyphenols, tannins 0.61% (Thompson, 1993).

Sorghum has 11.9 per cent of moisture and about 10.4 per cent of protein and a lower fat content of 1.9 per cent. The fibre and mineral content of grain sorghum is essentially similar, and is 1.6 per cent. It is a good source of energy and provides about 349 K cal and gives 72.6 per cent of carbohydrates (Gopalan *et al.*, 1996). Starch is the major carbohydrate of the grain. The other carbohydrates present are simple sugars, cellulose and hemicellulose. The amylose content of starch varies from 21.28 per cent. Sorghum is also rich in dietary fibre (14.3%). Calcium, phosphorous and iron content of sorghum is 25 mg, 222 mg and 4.1 mg (per 100 g of edible portion), respectively (Hosmani and Chittapur, 1997).

In addition, black finger millet contains 8.71 mg/g dry weight fatty acid and 8.47 g/dry weight protein (Glew *et al,* 2008). Kodo millet and little millet were also reported to have 37% to 38% of dietary fiber, which was once considered as ‘anti-nutrient’ and is now termed as a nutraceutical and highest among cereals (Hadimani and Malleshi, 1993; Hegde and Chandra, 2005). Thus, it makes millets a complete food ingredient suitable for large scale utilization as processed products, snacks, baby foods etc., and also plays a major role in propagating food security among under developed and developing countries.

NUTRITIONAL CHARACTERISTICS

Carbohydrates

The carbohydrate content in sorghum is composed of starch, soluble sugar and fiber (pentasons, cellulose and hemicellulose). Millet carbohydrates classified into non-structural (sugars, starch and fructosans) and structural (cellulose, hemicelluloses and pectin substances) carbohydrates. The chief non-structural carbohydrate (NSC) is starch. In normal sorghum it is mainly composed of amylopectin. The most common mutants contain waxy (only amylopectin) and high amylose starch (Boyer *et al,* 1983). Colour of sorghum starches is related to intensity of the pigments in the pericarp and in the leaves of the sorghum plant (Freeman & Watson, 1971; Subramanian *et al,* 1994). Starch is the most abundant component while soluble sugars are low.

Starch

From one half to three-fourths of the grain weight is starch. Starches exist in a highly organized manner in which amylase and amylopectin molecules are held together by hydrogen bonds and arranged radically in spherical granules. Starch is the main source of energy utilized during germination. It is composed of linear chains of glucose joined by α-1, 4-glycosidic bonds called amylopectin. Amylopectin is a much larger, branched polymer. The pigments of millet grain pericarp sometimes discolour the starch, yielding a light pink colour, green and yellow colours.

Millet endosperm in general contains about 23 to 30 % of amylase (Horan and Heider, 1964; Ring *et al*., 1982). Corneous endosperm starches have higher gelatinization temperature and intrinsic viscosity than those of starch isolated from the floury endosperm (Cagampang and Kirleis, 1985). The gelatinization temperature range for the starch is 71 to 80°C (Sweat *et al.,* 1984). The thermal properties and pasting behaviour indicates that the pastes prepared from are short and cohesive. The water binding capacity of millet starch is significantly lower than that of maize starch. They have high swelling power at 90°C but lower solubility than that of maize starch. Starch from waxy millet grain is notable for rapid cooking, highpeak viscosity, poor stability during cooking, paste clarity, high water binding capacity and resistance to gel formation and retrogradation (Akingbala *et al.,* 1982; Akingbala and Rooney, 1987; Watson, 1984; Aba Allah *et al.,* 1987; Subramanian *et al.,* 1994b;

Prerez *et al.,* 1997). Thermal transitions of waxy starch, however, occurred at similar or slightly higher temperatures. For sorghum waxy sorghum flour and isolated waxt starch have higher starch digestibility than that normal endosperm types (Hybberd *et al.,* 1982; Rooney and Pflugfleder, 1986; Kotarski *et al.,* 1992).

Soluble Sugars

The soluble sugar content of caryopses changes during development and is maximum, 5.2 % (Murthy *et al.,* 1985). At maturity the average soluble sugar content was 1.3 % (0.8-4.2%), with sucrose being 75% of the sugars (Subramanian *et al.,* 1980; Jambunathan *et al.,* 1984). Mature caryopses contain 2.2 to 3.8% soluble sugars, 0.9 to 2.5% free reducing sugars and 1.3 to 1.4% non reducing sugars (Bhatia *et al.,* 1972). Glucose and fructose ranged from 0.6 to 1.8% and 0.3 to 0.7% respectively. High lysine and sugary cultivars of millets contain more soluble sugars.

Carbohydrate Digestibility

For nutritional purposes, starch is generally classified into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS), depending on the rate and extent of digestion (Englyst et al 1992). Nutritional properties of SDS are very important for the treatment and prevention of various diseases. Elevated plasma glucose and insulin levels after a glucose load are associated with noninsulin dependent diabetes (Kraft and Nosal 1975) and cardiovascular diseases (Flodin 1986). Prolonged digestion and absorption of carbohydrates are favourable not only for the dietary management of metabolic disorders such as diabetes and hyperlipidemia (Asp 1994; Würsch 1994), but for healthy subjects due to positive effects on a number of physiological factors (Björck et al 1994). Therefore, much attention is being given to SDS as a new functional material.

Cooked millet flours had lower starch digestibility (15–25%) than normal rice, wheat or maize flour, regardless of whether the endosperm type 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 millet 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 & Bruce, 1998). Millet grain starch digestibility is depends on two possible scenarios. First, as Chandrashekar and

Kirleis (1988) suggested that 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, indicating that, after cooking, millet and other cereal starches may be found in different stages of the gelatinization process. Second, a starch-protein interaction may occur during cooking or cooling that causes gelatinized sorghum starch to be in a less digestible state.

Dietary Fiber

The dietary fibre contents of several Indian foods have been determined (Narasinga Rao, 1988; NIN, 2017) Dietary fibre components exert their beneficial effects mostly by way of their swelling properties, and by increasing transit time in the small intestine.

Table 9: Properties of Dietary Fiber and their Health consequences

Function	Health consequences	Millet
Water absorbing and bulking property	Energy diluents to formulate low calorie diets	All Millets
Increased transit time of food in the gut	Reduced risk of inflammatory bowel disease.	Sorghum and Finger Millet
Bile acid and steroid binding	Hypocholestero-laemic activity and reducing the risk of cardiovascular diseases	Pearl Millet, Sorghum and Finger Millet
Retardation of carbohydrate absorption and impaired glucose tolerance	Management of certain type of diabetes	Sorghum, Pearl Millet and Finger Millet
Binding of toxins	As a detoxifying agent	Sorghum
Binding of divalent cations	Reduced bioavailability of Ca, Mg, Zn, Fe	Proso Millet and Foxtail Millet (unprocessed)

Consequently, the increase in transit time reflects reduce the rate of release of glucose and its absorption, thus helping in the management of certain types of diabetes (e.g., non-insulin-dependent diabetes mellitus). DF components also bind bile salts, thereby promoting cholesterol excretion from the body and thus reducing blood cholesterol levels, and food toxins in the gut to reduce their toxicity. They can also have some adverse nutritional effects by binding dietary calcium, magnesium, zinc and iron, thereby reducing their bioavailability. The second mechanism by which dietary fibre exerts its beneficial effects is through undergoing fermentation in the large intestine (colon) and producing short-chain fatty acids such as butyrate, propionate and acetate. Butyrate helps in the regeneration of colon mucosal cells by serving as a source of energy, thereby reducing the risk of colon cancer and inflammatory bowel disease. The short-chain fatty acids produced are absorbed (especially propionate and acetate) into splenic circulation and transported to the liver where they are known to inhibit cholesterol synthesis by hepatocytes and also glucose release from the liver, thus contributing partly to the hypocholesterolaemic and hypoglycaemic effects of dietary fibre. While the soluble fibres are completely fermented, the insoluble fibres are only partially fermented (Narasinga Rao, BS, 2003).

The nature of carbohydrate is of considerable importance to reduce the risk of type II diabetes and cardiovascular disease. Starch is the main source of carbohydrates in the human diet. For nutritional purposes, starch is generally classified into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS), depending on the rate and extent of digestion (Englyst *et al,* 1992). Nutritional properties of SDS are very important for the treatment and prevention of various diseases. Elevated plasma glucose and insulin levels after a glucose load are associated with noninsulin dependent diabetes (Kraft & Nosal, 1975) and cardiovascular diseases (Flodin 1986). Prolonged digestion and absorption of carbohydrates are favourable not only for the dietary management of metabolic disorders such as diabetes and hyperlipidemia (Asp 1994; Würsch 1994), but for healthy subjects due to positive effects on a number of physiological factors (Björck et al 1994). Therefore, much attention is being given to SDS as a new functional material.

Bran of the millets is rich source of dietary fibre, which termed as complex unavailable polysaccharides. Due to higher viscosity, glycemic index and water holding capacity dietary fibres plays a key role in reduction of blood glucose level as well as insulin response (Easwaran *et al,* 1991; Kavitha *et al*, 2001). It also lowers the level of cholesterol (Potdar *et al,* 1994) and decreases the risk of bowel disorders. A study was done on blood glucose level of non insulin dependent diabetes mellitus (NIDDM) non obese patients fed with Jowar bran papadi. Results indicated that Jowar bran were prepared and evaluated in terms of its effect on the blood glucose response among 40 to 50 years old non obese, non-insulin dependent diabetes mellitus (NIDDM) patients. Investigators found that there is a significant impact on reducing the blood glucose level among of diabetic patient (Kamble & Shinde, 2004).

Fatty Acid (Lipids)

Lipids are relatively minor constitutes in millets. Most of the lipids are located in the scutellar area of the germ. Thus, lipid content is significantly reduced when the germ is removed during decortication or degermination. The typical fatty acid composition of sorghum lipid is similar to that of maize oil (Wall & Blessin, 1970; Rooney, 1978; Neucere & Sumrell, 1980; Agullo & Rodriguez, 1998). The lipids can be subdivided into polar, nonpolar and nonsaponifiable lipids. The most abundant by far are the nonpolar lipids, 70-80%. The composition of the nonpolar lipids was clearly dominated by triglycerides, 85%, followed by sterols, 4.1%, and diglycerides, 4.0%. Triglycerides serve as a reserve material for germination. The less abundant polar lipids (i.e., glycolipids 2.5 to 6.2 % and phospholipids, 17 to 25%) have important biochemical function. The nonsaponifiable compounds, 3 to 5%, include carotenoids, phytosterols and tocopherols.

A study was done on effect of cholesterol absorption and plasma non-HDL cholesterol concentration in hamsters fed with grain sorghum lipid extract. In this study, hamsters were fed with grain sorghum lipid extract (GSL) comprised different proportions of the diet and compare with control. Liver cholesteryl ester concentration was also significantly reduced in hamsters fed GSL. GSL diet lowers non-HDL cholesterol, at least in part, by inhibiting cholesterol absorption and GSL extract consist plant sterols and policosanols. Thus plant sterols reduce cholesterol absorption efficiency significantly; policosanols may inhibit endogenous cholesterol synthesis. Research findings further indicate that grain sorghum contains components that could be used as food ingredients or dietary supplements to manage cholesterol levels in humans (Carr *et al,* 2005).

Protein

Protein content and consumption vary due to agronomic conditions (water availability, soil fertility, temperatures and environmental conditions during grain development) and genotype. Millet proteins are located in the endosperm (80%), germ (16%) and pericarp (3%) (Taylor & Schussler, 1986). Kafirins or prolamins then glutelins comprise the major protein fractions in sorghum. These fractions are located primarily within the protein bodies and protein matrix of the endosperm, respectively. Protein quality of millet in terms of amino acid profile is poor when compared to other cereals. Lysine, an essential amino acid is limiting factor in millets. The germ is rich in albumins and globulins, while the endosperm contains the kafirins and glutelins. The albumin, globulin & glutelin fractions are rich in lysine and other essential amino acids. The grain storage proteins of maize, millets and sorghum can be defined as prolamins in that they are soluble in alcohol/water mixtures. The bran-germ material was relatively high in lysine, arginine, and glycine, but lower in other essential amino acids (isoleucine, leucine, and phenylalanine) than whole grain. Endosperm fractions represent a wide range in total protein content.

All amino acids in the fractions increased as total protein in the fractions increased. However, relative distribution of amino acids in the protein varied as protein content of the sample changed; consequently, protein efficiencies should differ from one fraction to another. Percentages of lysine, cystine, methionine, threonine, and tryptophan of the protein decreased as protein content of the endosperm fractions increased. In fraction3 the percentages of valine, isoleucine, leucine, and phenylalanine in the protein were less than those found in the higher-protein fractions. Protein of the bran-germ fraction contained approximately four times as much lysine and two times as much arginine and glycine as protein of endosperm fractions, in contrast, percentages of glutamic acid, proline, alanine, leucine, and tyrosine in the protein of the bran-germ fraction were approximately half those of the endosperm protein. As expected, amino acid values of the whole grain fell between those of the endosperm fractions and the bran-germ material. Lysine is the most limiting amino acid in diets containing millets as the only source of protein.

Protein Digestibility

A nutritional constraint to the use of millets as food is the poor digestibility of millet proteins on cooking. Digestibility may be used as an indicator of protein availability. It is essentially a measure of the susceptibility of a protein to proteolysis. A protein with high digestibility is potentially of better nutritional value than one of low digestibility because it would provide more amino acids for absorption on proteolysis. The effect of processing technologies and supplementation with other food sources will improve the apparent protein quality and digestibility of sorghum. The effect of decortications and extrusion on the apparent protein quality and digestibility of sorghum (S. *vulgare*) was evaluated in comparative balance studies in nine children 7-24 months of age. The composition of sorghum and control diets was presented in following table.

Table 9a: Composition of the sorghum and control diets[1]

Ingredients	Sorghum based diet	Control diet
	per 100 kcal	
Sorghum, *g*	18.84	-
Lysine, *mg*	39.68	-
Soybean-cottonseed (80:20) oil, *ml*	3.62	3.67
Sucrose, *g*	-	5.81
Dextrimaltose, *g*	-	6.00
Cornstarch, *g*	-	5.00
Casec[2], *g*	-	1.86
Calorie distribution		
Protein, %	8.00	6.40
Fat, %	29.00	30.00
Carbohydrate, %	63.00	62.60

[1]All diets were supplemented with a vitamin and trace mineral mixture of the following composition to meet Recommended Dietary Allowances.

[2] Casec : 1 g provides 0.86 g protein, 0.02 g fat & 3.70 kcal.

The results of this study clearly indicate that the digestibility of sorghum can be markedly improved by a combination processing of milling and extrusion cooking (William *et al,* 1983). Research on sorghum flour products revealed that safety and tolerability in celiac patients. Sorghum protein digests did not elicit any morphometric or immunomediated alteration of duodenal explants after 5 days feedingd with sorghum-derived food product did not experience gastrointestinal or non-gastrointestinal symptoms and the level of anti-transglutaminase antibodies was unmodified at the end of the 5-days challenge. Millet-derived products did not show toxicity for celiac patients in both in vitro and in vivo challenge. Therefore, millet can be considered safe for people with celiac disease.

Phytochemicals

Millets are a rich source of various phytochemicals including tannins, phenolic acids, anthocyanins, phytosterols and pinacosanols. These phytochemicals have potential positive impact on human health. All millet grain and especially sorghum fractions possess high antioxidant activity in vitro relative to other cereals and fruits (Awika & Rooney, 2004).

The major phytochemicals includes Phenolic compounds and others. Millets are a good source of phenolic compounds with a variety of genetically dependent types and levels of phenolic acids, flavonoids and condensed tannins. Most sorghum does not contain condensed tannins, but all contain phenolic acids. Pigmented sorghum contains unique anthocyanins that could be potential food colorants.

Condensed Tannins

Sorghum with specific gene (B_1 _B_2_) contains tannins, which are the major phenolic compounds in those varieties (Hahn *et al,* 1984). These compounds confer some resistance to moulds and deterioration of the grain (Waniska *et al,* 1989). Tannin levels vary among genotypes. Condensed tannins also known as proanthocyanidins or procyanidins are high molecular weight polyphenols. Processing tannin or black sorghums into food products affects phenol levels. For example, processing tannin sorghum bran to produce cookies, and breads decreased tannin content by 52% and 72%, respectively; the loss was mainly from the high-molecular weight tannins (Awika et al., 2003a). Awika et al. (2003a) also reported that extrusion of tannin sorghum caused an 85% decrease in polymeric tannins while the lower molecular weight tannins increased by 29–478%. The decrease in tannin level does not mean that the tannin is lost; it means that during processing, the tannins bind to other molecules (i.e. proteins, carbohydrates, minerals) making them difficult to extract. Phenol levels of maize tortillas containing black or brown sorghum bran decreased by 33–38% and 47–50%, respectively (Cedillo-Sebastian, 2005). Frying into tortilla chips reduced phenol levels by 52–55% (black sorghum bran) and 60–66% (tannin sorghum bran) compared to the tortillas (Cedillo-Sebastian, 2005). Thus, processing affects the extractability of phenolic compounds and phenol levels.

Phenolic Acids

Phenolic compounds in millet are divided into major categories: phenolic acids, tannins and flavonoids. All sorghum and millets contain phenolic acids, which are located in the pericarp, testa, aleurone layer and endosperm (Hahn *et al,* 1984; McDonough *et al,* 1986).

Table 10: Phenolic acids detected in sorghum and millet grains

Phenolic acid	References
Hydroxybenzoic acids: Gallic	Hahn *et al,* 1983; Subba Rao & Muralikrishna, 2002.
Protocatechuic	Hahn *et al,* 1983; McDonough *et al,* 1986; Subba Rao and Muralikrishna, 2002
p-Hydroxybenzoic	Hahn *et al,* 1983; McDonough *et al,* 1986.
Gentisic	McDonough *et al,* 1986; Waniska *et al,* 1989;
Salicylic[a]	Waniska *et al,* 1989.
Vanillic	Hahn *et al,* 1983; McDonough *et al,* 1986; Subba Rao and Muralikrishna, 2002.
Syringic	Waniska *et al,* 1989; McDonough *et al,* 1986.
Hydroxycinnamic acids: Ferulic	Hahn *et al,* 1983; McDonough *et al,* 1986; Subba Rao and Muralikrishna, 2002.
Caffeic	Hahn *et al,* 1983; McDonough *et al,* 1986; Subba Rao and Muralikrishna, 2002.
p-Coumaric	Hahn *et al,* 1983; McDonough *et al,* 1986; Subba Rao and Muralikrishna, 2002.
Cinnamic	Hahn *et al,* 1983; McDonough *et al,* 1986.
Sinapic	Waniska *et al,* 1989; McDonough *et al,* 1986.

[a] Reported only in sorghums.

Unlike these common anthocyanins, sorghum anthocyanins are unique since they do not contain the hydroxyl group in the 3-position of the C-ring and thus are called 3-deoxyanthocyanins. This unique feature increases their stability at high pH compared to the common anthocyanins (Awika et al, 2004a, b; Gous, 1989; Mazza and Brouillard, 1987; Sweeny and Iacobucci, 1983), which render these compounds as potential natural food colorants. They are also phytoalexins since they are produced as a response to mold invasion or other stresses in millets (Lo et al, 1999; Seitz, 2004; Waniska and Rooney, 2000). Seitz (2004) reported these compounds were more prevalent in purple-pigmented plant than in tan-pigmented varieties.

The fact that some millet cultivars produce large quantities of tannins, usually present in outer layer of grain, makes it unique among the cereals (Serna-Saldivar and Rooney, 1995). However, not all varieties contain condensed tannin. Anthocyanins have been extensively studied in fruits and vegetables due to their antioxidant properties and potential as natural food colours. However, limited data exist on the types and levels of anthocyanins in cereals, probably because cereals have never been regarded as a commercially significant source. The most common anthocyanins in sorghum are the 3-deoxyanthocyanidins (Sweeny and Iacobucci, 1981; Gous, 1989).

The 3-deoxyanthocyanidins were also reported to be more stable in acidic solutions relative to the anthocyanidins commonly found in fruits, vegetables and other cereals (Timberlake and Bridle, 1980; Sweeny and Iacobucci, 1981). This suggests a potential advantage of sorghum as a viable commercial source of anthocyanins. Sorghum is rich source of anthocyanin content, when compared with other food commodities (Table 12). Recent studies have shown that grain sorghum and its distillers dried grain with soluble (DDGS) contain valuable health promoting compounds, such as phenolic acids, tannins, anthocyanins, plant sterols (PS) and policosanols (PC) (Awika & Rooney, 2004; Hwang *et al,* 2002). The high demand for antioxidant and nutraceutical foods has increased during the past years to prevent oxidative stress associated to the development of chronic diseases such as cardiovascular, neuron degeneration, cancer, diabetes and hypocholesterolemia as well as being involved with the process of aging (Grundy, 2004; Wu *et al,* 2004).

Flavonoids: Flavonoids have been isolated and identified from sorghum grains (Table 11)

Table 11: Flavonoids and proanthocyanins reported in sorghum grains

Compound	References
Anthocyanins : Apigeninidin	Nip and Burns, 1971; Gous, 1989.
Apigeninidin 5-glucoside	Nip and Burns, 1969 & 1971; Wu and Prior, 2005.
Luteolinidin	Nip and Burns, 1971; Gous, 1989.
5-Methoxyluteolinidin	Seitz, 2004; Wu and Prior, 2005
5-Methoxyluteolinidin-7 glucoside	Wu and Prior, 2005.
7-Methoxyapigeninidin	Pale *et al,* 1997; Seitz, 2004; Wu and Prior, 2005.
7-Methoxyapigeninidin - 5-glucoside	Wu and Prior, 2005.
Luteolinidin 5- glucoside	Nip and Burns, 1971; Wu and Prior, 2005.
5-Methoxyapigeninidin	Seitz, 2004.
7-Methoxyluteolinidin	Seitz, 2004.
Flavan-4-ols : Luteoforol	Bate-Smith, 1969.
Apiforol	Watterson and Butler, 1983.
Flavones : Apigenin	Gujer *et al,* 1986, Seitz, 2004.
Luteolin	Seitz, 2004.
Flavanones : Eriodictyol	Kambal and Bate-Smith, 1976.
Eriodictyol 5-glucoside	Gujer *et al,* 1986.

Compound	References
Naringenin	Gujer *et al,* 1986.
Flavonols : Kaempferol 3- rutinoside-7-lucuronide	Nip and Burns, 1969.
Dihydroflavonols	Taxifolin Gujer *et al,* 1986.
Taxifolin 7-glucoside	Gujer *et al,* 1986.
Proanthocyanidin monomers/dimers : Catechin	Gupta and Haslam, 1978; Gujer *et al,* 1986.
Procyanidin B-1	Gupta and Haslam, 1978; Gujer *et al,* 1986.
Proanthocyanidin polymers Epicatechin (epicatechin) n-catechin	Gupta and Haslam, 1978, Gujer *et al,* 1986.
Prodelphinidin	Brandon *et al,* 1982; Krueger *et al,* 2003.
Proapigeninidin	Krueger *et al,* 2003.
Proluteolinidin	Krueger *et al,* 2003.

Plant sterols are widely recognized as serum cholesterol-lowering compounds (Ostlund, 2002). PC also referred to as fatty alcohols, area waxy material. Similarly to PS, Policosanols have been linked to potential serum lipid-lowering properties (Gouni-Berthold & Berthold, 2002). Primarily reported PC that have been suggested to contribute to the lowering serum cholesterol levels are octacosanol (C28), triacontanol (C30) and hexacosanol (C26) (Gouni-Berthold & Berthold, 2002).

Despite the high levels and diversity of phytochemicals in sorghum, research on this crop as a source of valuable health promoting compounds lags behind other commodities (e.g., fruits and vegetables). As a result, utilization of sorghum fractions in foods to improve nutrition is very limited. Millets have a big potential, given its agronomic properties, as well as the emerging evidence on the biological effects of the phytochemicals present in the grain.

Numerous reports on reduced weight gain of animals (rats, pigs, rabbits, poultry) fed high tannin sorghum are available (Jambubathan and Mertz, 1973; Featherson and Rogler, 1975; Cousins et al,, 1981; Lizardo et al,, 1995; Al-Mamary et al,, 2001; Muriu et al,, 2002). The mechanisms by which tannin sorghums reduce nutritive value include binding of food proteins (Haslam, 1974; Hagerman and Butler, 1981) and carbohydrates (Naczk and Shahidi, 1997) into insoluble complexes that cannot be broken down by digestive enzymes. Another mechanism involves the direct binding of digestive enzymes including sucrase, amylases, trypsin, chymotrypsin and lipases (Lizardo *et al,*, 1995; Carmona *et al,*, 1996; Nguz *et al,*, 1998; Al-Mamary *et al,*, 2001), thus inhibiting their activity. Inhibition of intestinal brush-border bound amino acid transporters by sorghum tannins was also reported (King *et al,*, 2000). There is evidence that the higher DP tannins are more involved in these interactions that the low DP ones (Bacon and Rhodes, 1998; Sarni-Manchado *et al,*, 1999).

Lipids are concentrated in the germ, pericarp and aleurone layers of the millet grain. Free lipids in many varieties of millet have been found to range from 2.8-8.0% (Rooney, 1978). The lecithin stabilizes the ingredients together until cooking at which the yolk coagulates and provides structural strength to the cookie. The structural component of the yolk was sufficient to maintain structural integrity for all of the gluten-free samples. Therefore, the main quality differences were determined by sensory evaluations. Apart from the strong color appearance with the buckwheat variety, all samples needed tasting to highlight characterization differences and palatability (Brown, 2011).

Pearl millet has a free lipids content range of 5.6-7.1% and bound lipids range of 0.57-0.90% (Lai and Varriano-Marston, 1980). The free lipid fraction is comprised of hydrocarbons, triglycerides, mono-glycerides, di-glycerides and free fatty acids, while the bound lipid fraction is made up of lecithin and other components but no free fatty acids (Rooney, 1978). The free lipid content of pearl millet is high in unsaturated fatty acids, accounting for 70.3% of the total free lipid content (Lai and Varriano-Marston, 1980). The main fatty acids found in free lipids are linoleic, oleic and palmitic (Lai and Varriano-Marston, 1980; Rooney, 1978).

The lipid content of pearl millet was considered to be higher than other cereals. Ahuja *et al.* (1979) estimated the nonpolar and polar fractions of the free lipids to range from 2.6 to 4.1% and from 0.17 to 0.31%, respectively. In case of bound lipids, the nonpolar and polar fractions ranged from 0.09 to 0.16% and from 0.23 to 0.29%, respectively. The ratio of nonpolar to polar fractions of total lipid is high (5.9 to 7.8%) which makes it less suitable for bread making. The nonpolar fraction of free and bound lipids contains the same components in different ratios. Hydrocarbons, esteryl esters, sterols, fatty acids and partial glycerides were present with triglycerides as the principal constituents. In the polar lipids, lecithin was found to be the major component. The principal fatty acids of pearl millet were linoleic, oleic, palmitic and stearic. The unsaturated acids averaged 70% of the free and 52% of the bound lipid fractions (Lai and Varriano-Marston, 1980). It is generally assumed that lipid components are responsible for the deterioration in the quality of pearl millet meal during storage (Carnovale and Quaglia, 1973).

Kodo millet is rich in B vitamins especially niacin, pyridoxine and folic acid as well as the minerals such as calcium, iron, potassium, magnesium and zinc. It is also rich in fiber and low in fat content. It contains a high amount of lecithin and is an excellent for strengthening the nervous system (Itagi S, 2003)

Finger millet is also a good source of essential amino acids like arginine, lysine, methionine, lecithin etc. and performs a number of essential health promoting functions like 1. Precursor for the synthesis of nitric oxide. 2. Stimulation of the release of growth hormone. 3. Improves immune function and reproductive ability. 4. Reduces healing time of injuries (particularly bone). 5. Quickens repair time of damaged tissue. 6. Reduces risk of heart disease and adipose tissue body fat. 7. Increases muscle mass and blood circulation. 8. Improve insulin sensitivity and helps in memory generation, etc. 9. Decrease blood pressure. 10. Alleviates male infertility, improving sperm production and motility. (Glew *et al.,* 2008): Phospholipids, total phospholipid present in ragi is found to be 0.36%. There were five phospholipids of which two were cephalins and the rest of lecithins. There was a band of galactolipid (Siddique, 2010).

The presence of good amounts of phospholipids consisting both lecithins and cephalins, also offer many advantages. Phospholipids of other cereals like rice, wheat, corn, etc. are not available to the consumer because they are removed & dissolved in oils. These compounds are having great role in general metabolism, being concentrated in brain are useful in brain function, behavioral disorders and stress. They help in regeneration of membranes and protect liver, lungs, kidneys, and gastrointestinal tract. These compounds are known to enhance the bioavailability of other nutrients and medicines.

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. Finger and teff millet are good source of dietary calcium. The percentage of available magnesium is higher in millet than in sorghum, and iron content is significant, (Iren Lader, 2010) Black finger millet contains approximate 1830 μg/g of magnesium (Glew, 2008). Finger millet has 130 mg/100g of magnesium (Amir Gull, 2014)

2.2 Health Benefits of Millets

Millets have potential health benefits and epidemiological studies have showed 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 are believed to be responsible for many health benefits (Miller, 2001; Edge *et al.*, 2005).

2.2.1 Cardiovascular Diseases

Being rich sources of magnesium, millets help in reducing blood pressure and risk of heart strokes especially in atherosclerosis. Also, the potassium present in millets helps in keeping blood pressure low by acting as a vasodilator and help to reduce cardiovascular risk. Also, the plant lignans present in millets have the ability to convert into animal lignans in presence of microflora in digestive system and protect against certain cancers and heart disease. The high fiber present in millets plays a major role in cholesterol lowering eliminating LDL from the system and increasing the effects of HDL.

In a study, rats fed with diet of treated starch from barnyard millet had shown to 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). 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 hyperlipidemic rats (Lee *et al.,* 2010).

Sorghum: A study was done on effect of cholesterol absorption and plasma non-HDL cholesterol concentration in hamsters fed with grain sorghum lipid extract. In this study, hamsters were fed with grain sorghum lipid extract (GSL) comprising different proportions of the diet and compare with control. Liver cholesterol ester concentration was also significantly reduced in hamsters fed with GSL. GSL diet lowers non-HDL cholesterol, at least in part, by inhibiting cholesterol absorption; GSL extract consist plant sterols that reduce cholesterol absorption efficiency significantly and policosano is that inhibit endogenous cholesterol synthesis. Research findings further indicate that grain sorghum contains components that could be used as food ingredients or dietary supplements to manage cholesterol levels in humans (Carr et al., 2005).

Empirical evidences (Slavin, 2003 and 2004) suggest that regular consumption of whole grains reduces the risk of CVD (Anderson and Hanna, 1999). A long term prospective study by Heidemann et al. (2008) showed that regular consumption of balanced diet which includes whole grains, vegetable, fruit, fish and poultry diet 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 40-75 years for a period of 14 years and found intake of whole grains 40g/ per day reduces the risk of CHD by 20%.

Pearl Millet: The lignin and phytonutrients in millet act as strong antioxidants thus preventing heart related diseases. This is why, pearl millet is considered good for heart health.

Finger Millet: 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 hyperlipidemic rats (Lee et al., 2010).

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Proso Millet: 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).

2.2.2 Diabetes Mellitus

Diabetes mellitus is a chronic metabolic disorder characterized by hyperglycemia with alterations in carbohydrate, protein, and lipid metabolism. It is considered as the most common endocrine disorder and results in deficient insulin production (type 1) or combined resistance to insulin action and the insulin-secretory response (type 2) (Saleh *et al.,* 2013). The efficiency of insulin and glucose receptors in the body is increased by the significant levels of magnesium content present in millets and help in preventing diabetes. 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).

Sorghum: It contains slow digestible starch (SDS) in good amounts, which has functional property, prolongs digestion and absorption of carbohydrates in intestine. This SDS is favourable for dietary management and also for metabolic disorders such as diabetes and hyperlipidemia (Asp, 1994; Wursch, 1997). Sorghum is rich in dietary fiber and low glycemic index, which could help in prevention and control of T2D in 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).

National Institute of Nutrition (ICMR) in 2010 assessed Glycemic Index (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 sorghum based foods have low GI and reduces the postprandial blood glucose level, glycosilated hemoglobin. Another study also points to the fact that blood glucose level of nonobese 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 jowar varieties showed that boiled Yellow Jowar flour (coarse) had lower glycemic index compared to flour prepared from the same. Similarly chapatti prepared from white Jowar flour showed low glycemic index over yellow Jowar flour. These changes in glycemic index due to processing and cooking play an important role in diets followed in dietary management of diabetes (Vahini and Bhaskarachary, 2013).

Pearl Millet: Pearl millets are known to increase insulin sensitivity and lower the level of triglycerides. Pearl millet is very effective for controlling diabetes. Because of its high fiber content, it digests slowly and releases glucose into the blood at a slower rate as compared to other foods. This effectively helps in maintaining the blood sugar level constant in diabetes patients for a long period of time.

Finger Millet: 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). Finger millet has shown significant results in dermal wound healing process. As shown in few studies done on rats which also showed that it improves antioxidant status and controlled blood sugar levels (Rajasekaran et al., 2004). The polyphenols of finger millets in a study were found as major antidiabetic and antioxidant components, when evaluated for aldose reductase (AR) - inhibiting activity the reason being the phenolic with an OH group present at the 4th position which are responsible for this inhibitory activity. The gallic, protocatechuic, p-hydroxy benzoic, pcoumaric, vanillic, syringic, ferulic, trans-cinnamic acids, quercetin inhibited cataract eye lens effectively. Therefore, these studies show strong evidence for finer millets protein in inhibiting the cataractogenesis in humans (Chethan et al., 2008).

Finger millet has shown significant results in dermal wound healing process. As shown in few studies done on rats which also showed that it improves antioxidant status and controlled blood sugar levels (Rajasekaran *et al.*, 2004). Barnyard millet has been reported to be beneficial for type 2 diabetics especially the dehulled varieties, as the glycemic index for dehulled millet (50.0) and heat treated was 41.7 (Ugare *et al.*, 2011). The rapidly digestible carbohydrate and slowly digestible carbohydrates were reduced significantly in the invitro studies performed in the extruded products made from amaranth, buckwheat and millet combination food products (Brennan *et al.*, 2012).

The polyphenols of finger millets in a study were found as major antidiabetic and antioxidant components, when evaluated for aldose reductase (AR) - inhibiting activity the reason being the phenolic with an OH group present at the 4^{th} position which are responsible for this inhibitory activity. The gallic, protocatechuic, p-hydroxy benzoic, p-coumaric, vanillic, syringic, ferulic, trans-cinnamic acids, quercetin inhibited cataract eye lens effectively. Therefore, these studies show strong evidence for finer millets protein in inhibiting the cataractogenesis in humans (Chethan *et al.*, 2008). The strong inhibition on α-glucosidase and pancreatic amylase were found by few other phenolic compounds from the millet seed coat. (Shobana *et al.,* 2009). The aqueous extracts of foxtail millets have excellent anti-hyperglycemic activity (Sireesha *et al.,* 2011). Proso millet had shown to improve the glycemic responses and insulin in genetically obese type 2 diabetic mice under high fat feeding conditions (Park *et al.,* 2008). Therefore, millet grains have the potentials to be useful in preventing and treating diabetes.

Barnyard Millet: Barnyard millet has been reported to be beneficial for type 2 diabetics especially the dehulled varieties, as the glycemic index for dehulled millet (50.0) and heat treated was 41.7 (Ugare et al., 2011).

Foxtail Millet: The aqueous extracts of foxtail millets have excellent anti-hyperglycemic activity (Sireesha et al., 2011).

Proso Millet: Proso millet had shown to improve the glycemic responses and insulin in genetically obese type 2 diabetic mice under high fat feeding conditions (Park et al., 2008).

2.2.3 Gastrointestinal Disorders

Regulating digestive process can increase nutrient retention and reduce chances of more serious gastrointestinal conditions like gastric ulcers or colon cancer. Fiber content in millets helps in eliminating disorders like constipation, excess gas, bloating and cramping. An immune mediated enteropathic disease called celiac disease which is usually triggered by the ingestion of gluten in susceptible individuals (Catassi and Fasano, 2008). A gluten free diet primarily plays a major role in affecting food consumption in the grain food group.

Replacing cereals like wheat, barley, rye-based foods made from gluten free grains, including rice, corn, sorghum, millet, amaranth, buck wheat, quinoa, wild rice may help people adhering to gluten free diet. (Thompson, 2009). As millets are gluten free, they have considerable potential in foods and beverages and can meet the growing demand for gluten free foods and will be suitable for individuals suffering from celiac disease. (Taylor *et al.,* 2006; Taylor and Emmambux, 2008; Chandrasekara and Shahidi, 2011b and 2011c)

2.2.4 Cancer

Millet grains based on literature values are known to be rich in phenolic acids, tannins, and phytate (Thompson, 1993). These nutrients 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 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.

Sorghum: Anti-carcinogenic properties of sorghum have been well documented. In Vivo and In Vitro studies have shown 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 6 years and found consumption of sorghum showed lower mortality from oesophageal cancer than wheat and corn.

2.2.5 Detoxification (Anti-oxidant Properties)

Many of the antioxidants found in millet have beneficial impact on neutralizing the 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).

The antioxidant, metal chelating and reducing powers are shown by the 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 47mg 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 observed (Choi *et al.,* 2007).

Over 50 phenolic compounds belonging to several classes, namely, 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, finger millet, little millet, foxtail millet, barnyard millet, and sorghum bicolorgrown in India and their white varieties were screened for free radical quenching of 1,1, diphenyl-2-picrylhydrazyl (DPPH) by electron spin resonance (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 species 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 a nutraceuticals and functional food ingredient in health promotion and disease risk reduction.

Chapter-3

Sorghum

3.1 Nutritional Importance of Sorghum

Grain sorghum has certain properties which makes it suitable to be consumed by population suffering from chronic disorders. Each sorghum nutrient has specific nutritional significance, which is suggestible to prevent and control life style diseases and disorders.Protein content and composition of sorghum varies from cultivar to cultivar due to agronomic conditions (water availability, soil fertility, temperatures and environmental conditions during grain development) and genotype. Sorghum proteins are chiefly located in the endosperm (80%), germ (16%) and pericarp (3%) (Taylor and Schussler, 1986). Kaffirin or prolamins and glutelins comprise the major fractions in sorghum (Warsi and Wright, 1973) and located in endosperm while germ is rich in albumins and globulins.

The sorghum carbohydrate content is composed of starch, soluble sugar and fiber. Carbohydrates in sorghum are classified into non-structural (sugars, starch and fructosans) and structural (cellulose, hemicelluloses and pectin substances). Sorghum contains slow digestible starch (SDS) in good amounts, which has functional property, prolongs digestion and absorption of carbohydrates in intestine. This SDS is favorable for dietary management and also for metabolic disorders such as diabetes and hyperlipidemia (Asp, 1994; Wursch, 1997). Sorghum also contains good amount of dietary fiber that is 9.7-14.3g and plays the role of bulking agent, binding agent of cholesterol, increases transit time and retards carbohydrates absorption (Narasinga Rao, 2003), which has a significant positive effect on preventing and managing the diseases like constipation, irritable bowel syndrome and obesity.

Lipid content of Sorghum grain is minor and located in the scutellar area of the germ. Sorghum lipid has potential to lower the cholesterol. A study was done on effect of cholesterol absorption and plasma non-HDL cholesterol concentration in hamsters fed with grain sorghum lipid extract. In this study, hamsters were fed with grain sorghum lipid extract (GSL) comprising different proportions of the diet and compare with control. Liver cholesterol ester concentration was also significantly reduced in hamsters fed with GSL. GSL diet lowers non-HDL cholesterol, at least in part, by inhibiting cholesterol absorption; GSL extract consist plant sterols that reduce cholesterol absorption efficiency significantly and policosano is that inhibit endogenous cholesterol synthesis. Research findings further indicate that grain sorghum contains components that could be used as food ingredients or dietary supplements to manage cholesterol levels in humans (Carr *et al., 2005*).

Sorghum is a good source of minerals and vitamins and mostly located in aleurone layer and germ. Sorghum is an important source of B vitamins except for vitamin B12 (Gazzaz*et al.,* 1989).Yellow coloured sorghum grain is rich in beta carotene, leutin and zeaxanthin. However, it varies due to environment and genes. It is poor in vitamin-C, but can be synthesized with soaking and germination process. Detectable amounts of other vitamins E, K and D are found to be present in sorghum grain. Decortications and degermination reduces water and fat soluble vitamins since the micro nutrients are located primarily in aleurone and germ portions of caryopsis. Grain sorghum is good source of potassium and adequate source of Mg, Fe, Zn and Cu but a poor source of calcium and sodium.

Rajendra Prasad *et al.* (2015) studied 160 boys and 160 girls aged between 9 to 12 y to receive 60% sorghum diet and 40% rice diet resulted that the growth rate was significantly higher ($p < 0.01$) in girls. Hemoglobin, serum ferritin, albumin, retinol binding protein and iron levels were significantly improved ($p < 0.05$) in both genders, with an increase in serum folic acid and calcium levels in boys when the meal was replaced with 60% sorghum.

Sorghum is excellent source of polyphenols, flavonoids and condensed tannins which are antioxidant potent in nature. The phenolic acids such as hydroxyl benzoic acids (galliac, vanillic, syringic, p-hydroxyl benzoic and protocatechic acids), hydroxycinnamic acids (coumaric, caffeic, ferulic and sinapinic acids) are located in sorghum pericarp, endosperm and aleurone layer (McDonough *et al.,* 1986). The anthocyanins are the major class of flavonoids present in sorghum. Sorghum anthocyanins do not contain the hydroxyl group in the 3-position of the C-ring and called as 3-deoxyanthocyanins. These anthocyanins are responsible for stability of grain at higher pH and natural color.

Sorghum 3-deoxyanthocyanins are apigeninidin (yellow), luteolinidin (orange) (Awika *et al.,* 2004). Sorghum pericarp contains highest amounts of 3-deoxyanthocyanins and flavonoids such as luteoforol and apiforol. These flavan-4-ols play an important role in mould resistance. Other identified flavonoids in sorghum grains are flavones (apigenin and luteolin), Flavanones (riodictyol and eriodictyol 5-glucoside), flavonol (kaempferol and taxifolin). Condensed tannins, also known as proanthocyanidins or procyanidins, are high-molecular weight polyphenols which are also present in sorghum (Dykes and Rooney, 2006)

3.2 Health Benefits of Sorghum

3.2.1 Celiac disease

Celiac disease (CD) is one of the most common genetic diseases, by which genetically predisposed people suffer a reaction to gluten proteins found in wheat and other cereals. This disease is caused by an adverse reaction of the immune system to gluten and it may lead to severe abdominal pains. Sorghum can be a healthy diet for those who are ailing from celiac disease as it is gluten free. Sorghum products could not modify the level of anti-transglutaminase antibodies after prolonged consumption (Carolina *et al.,* 2007).

3.2.2 Obesity

Obesity is an emerging problem in India and it is positively associated with several chronic diseases including diabetes and CVD. Empirical evidences suggest that intake of highdietary fibre decreases the 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)*.* Sorghum is rich in dietary fibre and has unique chemical and physical characteristics (bulk to the diet, viscosity, water holding and absorption capacity) which determine the subsequent physiological behaviour. It aids to the hunger satisfaction, increases satiety and thereby reducing the risk of development of obesity.

3.2.3 Diabetes

Diabetes Mellitus - complex metabolic diseases a major health concern in many countries. The prevalence of diabetes type 2 is on the rise across the globe at an alarming rate, especially in India where the prevalence of diabetes has reached 14.3%. Prevention of type 2 diabetes will require measures to promote healthy dietary pattern and life style which includes balanced diet and physical activity. People who eat three or more servings of whole grains in a day, especially from high-fiber cereals, are less likely to develop insulin resistance and the metabolic syndrome, common precursors of both T2D and Coronary Heart Disease (CHD) (Mckeown *et al.,* 2004). Diets rich in whole grain foods tend to decrease LDL cholesterol, triglycerides, blood pressure, and increase HDL cholesterol (Anderson, 2003). Sorghum is rich in dietary fibre and low glycemic index, which could help in prevention and control of T2D in Indians. The fibre, 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*).

National Institute of Nutrition (ICMR) in 2010 assessed Glycemic Index (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 sorghum based foods have low GI and reduces the postprandial blood glucose level, glycosilated 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 jowar varieties showed that boiled Yellow Jowar flour (coarse) had lower glycemic index compared to flour prepared from the same. Similarly chapatti prepared from white Jowar flour showed low glycemic index over yellow Jowar flour. These changes in glycemic index due to processing and cooking play an important role in diets followed in dietary management of diabetes. (Vahini and Bhaskarachary, 2013)

3.2.4 Coronary Heart Disease

Empirical evidences (Slavin*,* 2003; Slavin and Salvin*,* 2004) suggest that regular consumption of whole grains reduces the risk of CVD (Anderson *et al.,* 1999). A long term prospective study by Heidemann *et al.* (2008) showed that regular consumption of balanced diet which includes whole grains, vegetable, fruit, fish and poultry diet 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 40-75 years for a period of 14 years and found intake of whole grains 40g/ per day reduces the risk of CHD by 20%.

3.2.5 Cancer

Anti-carcinogenic properties of sorghum have been well documented. *In Vivo* and *In Vitro* studies have shown 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 6 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.

3.2.6 Oxidative Stress

Free radicals are atoms or molecules with an unpaired number of electrons and can be formed with interaction of other molecules. These free radicals are responsible for oxidative stress related pathogenesis of various diseases such as Alzheimer's disease, myocardial infarction, atherosclerosis, Parkinson disease, auto-immune diseases etc. Antioxidants play an important role in preventing oxidation process, thereby reducing cellular damage. Sorghum has potential antioxidant capacity which can act against reactive oxidative species.

Chapter-4

Pearl Millet

4.1 Nutritional Importance of Pearl Millet

Pearl millet is the most widely grown type of millet. It has been grown in Africa and the Indian subcontinent since prehistoric times. In different pearl millet genotypes the starch content of the grain varied about 62.8 to 70.5%, soluble sugar 1.2 to 2.6% and amylose 21.9 to 28.8% (Jambunathan and Subramanian*, 1988).* Lower values for starch (56.3 to 63.7%) and amylose (18.3 to 24.6%) have been found in some high-yielding Indian pearl millet varieties (Singh and Popli*,* 1973). Jambunathan and Subramanian found that the predominant component of total soluble sugar (2.16 to 2.78%) was sucrose (66%), followed by raffinose (28%). Other sugars detected in measurable amounts were stachyose, glucose and fructose. The proportion of sucrose in total sugar was lower in pearl millet than in sorghum.

Pearl millet, like sorghum, is generally 9 to 13% protein, but large variations in protein content, from 6 to 21%, have been observed (Serna-Saldivar *et al.,* 1991). Lysine is the first limiting amino acid of pearl millet protein. A significant inverse correlation has been reported between the level of protein in the grain and the Lysine content of the protein (Deosthale *et al.,* 1971). In high-protein varieties of pearl millet with protein content ranging from 14.4 to 27.1%, significant inverse correlations have also been observed between protein and threonine, methionine and tryptophan. The essential amino acid profile shows more lysine, threonine, methionine and cystine in pearl millet protein than in proteins of sorghum and other millets. Its tryptophan content is also higher.

Differences in lipid extraction procedures as well as genetic variability were shown to contribute differences in the fatty acid content of pearl millet (Jellum and Powell, 1971). The principal fatty acids in both free and bound were found to be linoleic, oleic and palmitic acids. Distinct differences in fatty acid composition were noted in the neutral lipid, phospholipid and glycolipid fractions (Osagie and Kates, 1984). Neutral lipid was highest in linoleic acid and lowest in palmitic acid; phospholipid was lowest in oleic acid and highest in palmitic acid; and glycolipid was highest in linolenic acid.

The total dietary fibre in pearl millet (20.4%) and finger millet (18.6%) was higher than that in sorghum (14.2%), wheat (17.2%) and rice (8.3%) also found that the total dietary fibre content of pearl millet was 17% (Kamath and Belavady, 1980).

4.2 Nutritional Facts of Pearl Millet

Due to its rich composition of minerals and proteins, Pearl Millet has many health benefits. Pearl Millet has the highest protein content. It contains many essential minerals like magnesium, phosphorus, zinc etc. It contains essential amino acids and vitamins also which contribute to its therapeutic properties.

- ***Beneficial in treating stomach ulcers:*** Pearl millet is recommended for curing stomach ulcers. The most common cause for stomach ulcers is excess acidity in the stomach after food intake. Pearl millet is one of the very few foods that turns the stomach alkaline and prevents formation of stomach ulcers or reduces the effect of ulcers
- ***Beneficial for Heart health:*** The lignin and phytonutrients in millet act as strong antioxidants thus preventing heart related diseases. This is why, pearl millet is considered good for heart health. High amounts of magnesium present in pearl millet have been shown to control blood pressure and relieve heart stress
- ***Beneficial due to high amount of magnesium:*** Pearl millet contains high concentration of magnesium which helps reduce severity of respiratory problems for asthma patients and is also effective in reducing migraine attacks

- ***Helps in bone growth development and repair:*** Pearl millet has a large amount of phosphorus. Phosphorus is very essential for bone growth and development as well as for development of ATP which is the energy currency of our body
- ***Reduces cancer risk:*** All millets are known to reduce the risk of cancer occurrence and pearl millet is no exception. Though scientists are not sure how this is, they believe it has something to do with the high amount of magnesium and the compound phytate
- ***Helps in weight loss:*** The biggest challenge faced by people trying to lose weight is controlling their food intake. Pearl millet can aid the process of weight loss as it is high in fibre content. Owing to its fibre content it takes longer for the grain to move from the stomach to the intestines. This way, pearl millet satiates hunger for a long period of time and thus helps in lowering the overall consumption of food
- ***Beneficial for diabetes:*** Pearl millet is very effective for controlling diabetes. Because of its high fibre content, it digests slowly and releases glucose into the blood at a slower rate as compared to other foods. This effectively helps in maintaining the blood sugar level constant in diabetes patients for a long period of time
- ***Beneficial for Celiac Disease:*** Celiac disease is a condition in which a person cannot tolerate even a small amount of gluten in his/her diet. Unfortunately, most of the common grains like rice, wheat, etc have gluten present in them. Millets are the only type of grains which do not have any gluten present. Thus this is suitable for people with celiac disease
- Reduces Cholesterol: It is common knowledge that Pearl Millet is suggested for people suffering from high cholesterol levels. Pearl millet contains a type of phytochemical called phytic acid which is believed to increase cholesterol metabolism and stabilise the levels of cholesterol in the body
- ***Contains all the essential amino acids:*** Amino acids are essential for smooth functioning of our body. Pearl millet is one of the few foods which have all the essential amino acids required in it. Unfortunately, most of these amino

acids are lost in the process of cooking because these amino acids cannot stand high temperatures. Thus it is better to consume in a low cooked form so as to preserve as many of these amino acids as possible

- ***Beneficial in Preventing Gall stones:*** The high fibre content in pearl millet is also known to reduce the risk of gall stone occurrence. The insoluble fibre content in pearl millet reduces the production of excessive bile in our system. Excessive amount of bile secretion in our intestine often leads to aggravate the condition of gall stones
- ***Anti-allergic properties:*** Pearl millet is a treasure trove of beneficial properties. The grain is very digestible as such and has a very low probability of causing allergic reactions. Due to its hypo allergic property, it can be safely included in the diets of infants, lactating mothers, elderlyand convalescents

Chapter-5

Finger Millet

5.1 Nutritional Importance of Finger Millet

Finger millet is an annual plant widely grown as a cereal in the arid areas of Africa and Asia. It remains one of the main ingredients of the staple diet in Karnataka. Nutritionally, finger millet is good source of nutrients especially of calcium, other minerals and fibre. Total carbohydrate content of finger millet has been reported to be in the range of 72 to 79.5% (Bhatt *et al.,* 2003). The carbohydrates include starch as the main constituent being 59.4 to 70.2% (Mittal, 2002).

Finger millet starch granules exhibit polygonal rhombic shape. About 80 to 85% of the finger millet starch is amylopectin and remaining 15 to 20% is amylose. The non-starch polysaccharide accounts for 20 to 30% of the total carbohydrates in finger millets. It contains around 1.5% reducing sugar and 0.03% non-reducing sugar (Bhatt *et al.,* 2003). The white varieties have higher protein content than the brown varieties of the finger millet. Finger millet contains 44.7% essential amino acids (Mbithi *et al.,* 2000) of the total amino acids, which is higher than the 33.9 % essential amino acids. Since *ragi* does not contain gluten, it is a wonderful grain alternative for people who are gluten-sensitive.

The total dietary fibre (TDF), insoluble dietary fibre (IDF), and soluble dietary fibre (SDF) con tent in finger millet was found to be 12, 11 and 2%, respectively (Ramulu and Rao, 1997). It was reported that 18.6% dietary fibre and 3.6% crude fibre in finger millet (Kamath and Belavady, 1980). The health benefits associated with high fibre foods are delayed nutrient absorption, increased faecal bulk, lowering of blood lipids, prevention of colon cancer, barrier to digestion, mobility of intestinal contents, increased faecal transit time and fermentability characteristics (Tharanathan and Mahadevamma, 2003). Finger millet is a good source of energy for weight watchers, as it contains the amino acid tryptophan that reduces the appetite.

Total antioxidant capacity of finger, little, foxtail and proso millets were found to be higher and their total carotenoids content varied from 78–366 mg/100 g in the millet varieties (Mathanghi and Sudha, 2012). Finger millet has the higher amount of calcium (344 mg) and potassium (408 mg). Calcium helps in keeping your bones and teeth healthy. It has higher dietary fiber, minerals, and sulphur containing amino acids compared to white rice, the current major staple in India (Shobana *et al.,* 2013).

However, the finger millet also contains phytates (0.48%), polyphenols, tannins (0.61%), trypsin inhibitory factors, and dietary fiber, which were once considered as "anti-nutrients" due to their metal chelating and enzyme inhibition activities (Thompson, 1993) but nowadays they are termed as nutraceuticals. It is now established that phytates, polyphenols and tannins can contribute to antioxidant activity of the millet foods, which is an important factor in health, aging and metabolic diseases. It functions as an amazing common relaxant and serves to battle fidgetiness, a sleeping disorder and discouragement. Additionally assists in treating headache cerebral pains. Antioxidant effects of finger millet on the dermal wound healing process in diabetes induced rats with oxidative stress-mediated modulation of inflammation were studied by Rajasekaran *et al.* (2004). They reported that the role of finger millet feeding on skin antioxidant status, nerve growth factor (NGF) production and wound healing parameters in healing the impaired early diabetic rats.

5.2 Health Benefits of Finger Millet (Mathanghi and Sudha, 2012)

- Finger millet also is known to have several potential health benefits. Some of the health benefits are attributed to its polyphenol contents. The phenolic acid content of brown finger millet 96% higher compared to white variety
- It contains more lysine, threonine, and valine than other millets. In addition, black finger millet contains 8.71 mg/g dry weight fatty acid and 8.47 g/g dry weight protein
- Finger millet is reported to have anti-ulcerative properties and finger millet diets lowered blood glucose and cholesterol in diabetic rat models (36% reduction in blood glucose levels)

- Finger millet seed coat matter which is a rich source of dietary fibre and phenolic compounds were found to exhibit blood glucose and cholesterol lowering, nephron-protective and anti-cataractogenic properties in streptozotocin induced diabetic rat models
- Supplementing infants with the germinated finger millet-based food showed a general improvement on hemoglobin status
- Lower serum cholesterol and triacylglycerol levels (43% and 62%, respectively) compared to diabetic controls
- Finger millet extracts were also reported to possess free radical scavenging, anti-protein glycation, anti-cataractogenic and antimicrobial properties in 'in vitro'. Inhibition of snake venom phospholipases by finger millet phenolics in '*in vitro*'
- High reducing power for seed coat polyphenol extract compared to the polyphenol extract from finger millet whole flour. Higher antioxidant activity for finger millet seed coat polyphenol extract (86%) compared to polyphenol extract from finger millet whole flour (27%)
- Offered protection against mucosal ulceration, epithelialization, increased synthesis of collagen, activation of fibroblasts, and mast cells

5.3 Nutritional Facts of Finger Millet

Finger millet is highly nutrious and renders various health benefits. The nutritional facts of finger millet are listed below.

- ***Finger millet/ Ragi for losing weight:*** *Ragi* contains an amino acid called Tryptophan which lowers appetite and helps in keeping weight in control. *Ragi* gets digested at a slower rate thus keeps one away from intake of excessive calories. Also, fibres present in *ragi* give a feeling of fullness thus controls excessive food consumption
- ***Finger millet/ Ragi for bone health:*** *Ragi* is rich in Calcium which helps in strengthening bones. It is an excellent source of natural calcium for growing children and aging people. *Ragi* consumption helps in development of bones in growing children and in maintenance of bone health in adults. *Ragi* keeps diseases such as osteoporosis at bay and could reduce risk of fracture

- ***Finger millet/ Ragi for diabetes:*** Finger millet's phytochemicals help in slowing digestion process. This helps in controlling blood sugar level in condition of diabetes. In a study conducted in 2000, it was found that Finger Millet based diet helps diabetic as it contains higher fibre than rice and wheat. Also, the study found that diet based on whole finger millet has lower glycemic response *i.e.* lower ability to increase blood sugar level. This is due to presence of factors in *ragi* flour which lower digestibility and absorption of starch.
- ***Finger millet/ Ragi for lowering blood cholesterol:*** Finger millet contains amino acids Lecithin and Methionine which help in bringing down cholesterol level by eliminating excess fat from Liver. Finger Millet also contains Threonine amino acid which hinders fat formation in the liver, which brings cholesterol level of the body down.
- ***Finger millet/ Ragi for anaemia:*** *Ragi* is a very good source of natural Iron. *Ragi* consumption helps in condition of Anaemia.
- **Finger millet/ *Ragi* for relaxation:** *Ragi* consumption helps in relaxing body naturally. It is beneficial in conditions of anxiety, depression and insomnia (sleepless nights). *Ragi* is also useful for migraines.
- ***Finger Millet/ Ragi for Protein/ Amino Acids:*** *Ragi* 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 formation contributes to bone formation and improves skin health. Valine is 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.
- ***Finger Millet for other health conditions:*** If consumed regularly, *Ragi* could help in keeping malnutrition, degenerative diseases and premature aging at bay. Green *Ragi* is recommended for conditions of blood pressure, liver disorders, *asthma* and heart weakness. Green *Ragi* is also recommended to lactating mothers in condition of lack of milk production.
- *Ragi* is an extremely nutritious cereal and is very beneficial for maintaining a good health. However, its high intake could increase quantity oxalic acid in the body. Therefore, it is not advised to patients having kidney stones (Urinary Calculi). *Ragi* could be enjoyed in different forms and preparations. *Ragi Roti*, *Ragi Dosa, Ragi* Porridge, *Ragi Upma*, *Ragi* Cakes, *Ragi* Biscuits are few popular dishes of *Ragi.*

Chapter-6

Small Millets

6.1 Nutritional Importance of Small Millets

Small millets have myriad of health benefits and due to high levels of insoluble dietary fibre, phytates, phytochemicals catechins, flavonoids etc., They are rich source of minerals like copper and iron. Unlike rice, they releases glucose steadily without affecting the metabolism of the body. The incidence of diabetes is rare among the population which consumes small millet diet. The millet protein characterization showed that its protein concentrate is a potential functional food ingredient and the essential amino acid pattern suggests possible use as a supplementary protein source to most cereals because it is rich in lysine (Ravindran, 1992). Small millets are minor millets and major studies are done for foxtail millet, barnyard and proso millet.

The foxtail millet is also known as Italian millet. It is one of the world's oldest cultivated crops. In the northern area of China it has been widely used as a nourishing gruel or soup for pregnant and nursing women and has been applied to food therapy. It has been recorded that millet has many nutritious and medical functions (Prashant et al., 2005). Foxtail yellow seeded cultivars, medicinally used as astringent, digestive, emollient and stomachic. It is also used in the treatment of dyspepsia, poor digestion and food stagnancy in abdomen (Yeung, 1985).White seeds are refrigerant and used in the treatment of cholera and fever while the green seeds are diuretic and strengthening to virility (Duke and Ayensu, 1985). This millet contains 12.3% crude protein and 3.3% minerals (Vithal and Machewad, 2006).

Barnyard millet showed comparable amounts of crude protein with foxtail millet which was highest among all the millets studied. The work of Liang et al. (2010) presented the general properties of millet oil and its fatty acid profile. It is apparent that millet oil could be a good source of natural oil rich in linoleic acid and tocopherols (Liang et al., 2010). Millets are good sources of magnesium and phosphorus. Magnesium has the ability to help reduce the effects of migraine and heart attacks, while, phosphorus is an essential component of adenosine triphosphate (ATP) a precursor to energy in the body (Devi et al., 2011).

Proso millet is the best alternative crop for diversifying and intensifying winter wheat-based dryland production systems. Proso Millet is calculated to be 356 Kcal per 100 gm. The protein content is similar to that of wheat, but it contains no gluten and by itself is not suitable for yeast-leavened bread. The protein content was found to be (11.6% of dry matter) and was significantly rich in essential amino acids (leucine, isoleucine, and methionine) than wheat protein (Kalinova and Moudry, 2006). It is rich in vitamins and minerals such as copper and magnesium. Proso millet also improved glycemic responses and plasma levels (Park et al., 2008). In addition, proso millet protein concentrate has protective effects against D-galactosamin-induced liver injury in rats (Ito et al., 2008). Choi et al. (2005) and Park et al. (2008) concluded that proso millet protein could be a potential therapeutic intervention in type-2 diabetes. Devi et al. (2011) review the nature of polyphenols and dietary fiber of finger millet and their role with respect to the health benefits associated with millet. The composition of free and bound lipids in proso millet flours and brans were analysed and found that, in the free lipids, hydrocarbons, sterol esters, triacylglycerols, diacylglycerols, and free fatty acids were present. Proso millet is rich source of B vitamins, especially vitamin-B6 and folic acid.

6.2 Health Benefits of Small Millets

Small millets are highly nutrious and renders various health benefits. The nutritional facts of small millet are listed below.

Helps control Blood sugar levels when consumed on regular basis. It showed lowered triglyceride levels, LDL/VLDL Cholesterol and increase in HDL Cholesterol.

It is known for its Low Glycemic index- gradual increase in blood sugar after food intake when compared to rice.

Ideal food for people suffering from Diabetes & Gastric problems.

Reduces risk of Heart Attack.

Helps in the development of Body Tissue & Energy Metabolism.

Rich in Anti-oxidants.

Chapter-7

Nutritional Evaluation of Sorghum/Millets Food Products - Findings from NIN & IIMR Joint Colloboration

Special nutritional and technological features of the millet grains has been adequately documented but still a lot has to be done for widening the scope of their food and allied utilization. Under the NAIP (National Agricultural Innovation Project) in order to increase sorghum production and its benefits towards the farmers, the farmers are directly linked up with the markets (processors) through ITC (ABD) Ltd, and their market surpluses are aggregated by the ITC through village *sanchalaks*. This created sustainable linkage of farmers with the value chain on sorghum foods. Commercializing sorghum products (detailed description of the food products is given in chapter 4) at pilot scale was necessitated at IIMR to identify the feasibility and sustainability of value addition in sorghum.

With a view to promote and initiate commercialization of sorghum as health foods, interventions were made on processing by developing novel sorghum ready to eat/cook (RTE/RTC) such as Multigrain *atta*, flakes, *rawa*, pasta etc. with a brand name "*eatrite*". Nutritional evaluation and certification of sorghum food products was done at National Institute of Nutrition (ICMR), Hyderabad. National Institute of Nutrition, Hyderabad has worked on the below mentioned areas:

1. Nutritional composition of sorghum processed foods
2. Evaluation of organoleptic properties of sorghum based Indian traditional breakfast and snack recipes
3. Glycemic index and glycemic load of sorghum foods
4. Effect of sorghum diet on glycosilated hemoglobin and lipid profile in people suffering from diabetes

5. Effect of sorghum diet on nutritional status of school going children
6. Amino acid profile of sorghum processed foods
7. Determination of protein efficiency of sorghum

7.1 Nutritional Composition of Sorghum Processed Foods

Sorghum products such as flour, multigrain flour, coarse, medium and fine semolina, flakes, pasta, vermicelli and biscuits were evaluated for its nutritional composition under NAIP project. Nutrients such as energy, carbohydrates, protein, fat, fibre, ash, moisture, total carotenoids, β-carotene, B-vitamins, C-vitamin, calcium, iron, zinc, copper, manganese, magnesium, phosphorus and molybdenum were estimated with standard methods. All the sorghum based foods are rich in energy (330 Kcal to 481 Kcal). The available carbohydrate content was found to be highest in sorghum rawa followed by pasta, flour, flakes, multigrain flour and biscuits. Protein, total dietary fibre, soluble fibre and insoluble fibre content were high in sorghum soya blend whereas, fat content was found to be high in Sorghum biscuits due to the incorporation of trans-free fat in the recipe formulation.

Table 12: 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)	Carbohy drates (g)	Energy (Kcal)
Sorghum Flour	13.8	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	1.2	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	74.9	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*

The carbohydrate content observations made in sorghum processed products are the total available carbohydrates after deducting the total fibre present (NVIF, ICMR, 1989). The methods used for detection of various nutrients are highly sensitive than those previously undertaken. The sorghum soya blend was found to be relatively low in availability of carbohydrates when compared with sorghum flour. All products were further analyzed for the mineral composition (per 100g) which is tabulated in Table 13 Among the minerals, highest amount of calcium, iron, zinc and copper was found to be in flakes, highest amount of manganese in multigrain flour, highest amount of phosphorus and magnesium in pure sorghum flour.

It is to be mentioned that calcium, zinc and iron are deficient in the majority of Indian population which could be curbed by consumption of mineral rich millets. As the bioavailability of minerals in whole millets is poor, they are to be converted into processed foods. Calcium, copper, iron, zinc was found to be high in sorghum flakes when compared with other sorghum processed products (Table 13). Magnesium and phosphorus was found to be high in sorghum flour when compared with the other processed products. Manganese was found to be high in sorghum soya blend. The vitamin compositions of the sorghum processed products were analyzed (100 g) and tabulated in (Table 14).

Table 13: Mineral Composition of sorghum processed products (per 100 g)

Name of product	Calcium (mg)	Magnesium (mg)	Copper (mg)	Manganese (mg)	Iron (mg)	Zinc (mg)	Phosphorus (mg)
Sorghum Flour	10.03	171	0.46	0.78	8.4	1.3	222
Sorghum-Soya blend	25.41	62.90	0.22	1.44	3.03	1.06	85.14
Sorghum Rawa	5.75	86.02	21.11	0.91	5.1	1.3	150.0
Sorghum Pasta	64.51	67.48	1.407	0.66	64.51	5.7	110.0
Sorghum Flakes	93.15	80.51	27.7	0.53	87.78	8.78	110.0
Sorghum Biscuits	68.80	56.10	0.25	0.57	2.2	BDL	107.7

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

Thiamine vitamin is found to be rich in sorghum flour which is followed by *rawa*, sorghum soya blend, biscuits and flakes. Niacin is rich in sorghum flour followed by sorghum soya blend, biscuits, *rawa,* flakes and pasta. Riboflavin is rich in sorghum biscuits followed by pasta, *rawa*, flour, sorghum soya blend and flakes. The B-Vitamin profile of the selected sorghum based products is given in Table 14.

Among all the sorghum based products the amino acid lysine is the limiting factor. People subsisting purely on sorghum foods carry the risk of lysine deficiency and thereby result in less absorption of niacin. Niacin deficiency leads to the pellagra disease. Sorghum as staple food consumed in the range of 50% of whole cereal intake is safe and helps to avoid pellagra. By combining sorghum with lentils and legumes, the deficiency of lysine could be avoided. Thus, the drawbacks of the limiting amino acid could be removed and sorghum can be consumed at a stretch for months.

Table 14: Vitamin Composition of Sorghum food product (per 100 g)

Name of product	Thiamine (mg)	Niacin (mg)	Riboflavin (mg)	Total Carotenoids (mg)	β-Carotene (mg)	Vitamin C (mg)
Sorghum Flour	2.31	3.1	0.38	ND	ND	ND
Sorghum-Soya blend	0.45	1.93	0.15	ND	ND	ND
Sorghum *Rawa*	0.615	1.58	1.093	ND	ND	ND
Sorghum Pasta	BDL	1.15	1.28	ND	ND	ND
Sorghum Flakes	0.07	1.28	0.02	ND	ND	ND
Sorghum Biscuits	0.23	1.9	2.26	ND	ND	ND

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

7.2 Assessment of Glycemic index (GI) and Glycemic load (GL) of sorghum foods

Sorghum based foods such as multigrain flour, coarse semolina, fine semolina, flakes, pasta and biscuits were evaluated for its Glycemic index (GI) and Glycemic load (GL) and were compared with wheat/ rice based foods using standardized methodology. For this study, ten non-diabetic healthy volunteers, in the age group of 20-40 years were recruited for evaluating each food item. The study was conducted according to the guidelines laid down in the declaration of Helsinki, and all procedures involving human subjects were also approved by the Institutional Ethics Committee of the National Institute of Nutrition, Hyderabad.

Raw materials used for the preparation of test foods were prepared at the Indian Institute of Millets Research (erst while DSR), Hyderabad and recipes were prepared in the Metabolic Kitchen, National Institute of Nutrition, Hyderabad. 50 g of available carbohydrate portion of a reference food and test food (sorghum, wheat or rice based recipes) was given in a random order after 8-10 hr overnight fast, (at least one week apart was considered between the tests (Fasting and 0 min)) and postprandial blood samples were taken from finger prick at 15, 30, 45, 60, 90 and 120 minutes after the reference or test food is feed to determine the GI and GL of test foods. Calculation of Glycemic index of test food was measured by positive incremental area under curve (+i AUC).

$$\text{GI (\%)} = \frac{\text{(Area under 2 h glucose response curve of test food))}}{\text{(Area under 2 h glucose response curve of reference food))}} \times 100$$

Table 15: Glycemic Index (GI) and Glycemic Load (GL) of Test Foods and + i AUC

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)*

The protocol used to measure GI was adapted as described by Wolever *et al*. (1991) and is in line with the procedure recommended by the FAO/WHO (1998). GL of a specific serving of each food was calculated by the formula.

$$GI\ (\%) = \frac{(GI \times \text{serving size of food} \times 50)}{(100 \times \text{serving size of food containing 50g of available Carbhohydrate})} \times 100$$

Difference between the test foods was tested by paired 't' test. Among the sorghum based foods, the GI of coarse *rawa upma* ($p < 0.05$), fine *rawa upma* ($p < 0.05$), pasta ($p < 0.01$) and *poha* ($p < 0.01$) were significantly lower than their respective control food (wheat/rice) and no significant difference was found for multigrain *roti* and biscuits (Rajendra Prasad *et al*., 2014). The GL of all sorghum based foods was lower than that of wheat/ rice based foods (Table 15). This information is useful in labeling of sorghum based products for commercialization as anti-diabetic foods and claiming evidence of the same to project them for their suitability.

7.3 Effect of Sorghum Diet on Glycosilated Hemoglobin and Lipid Profile in People Suffering from Diabetes

Effect of sorghum diet on glycosilated hemoglobin and lipid profile in diabetic patients was assessed with supplementation of sorghum diet for a period of 60 days. Volunteers (n=150) in the age of 30-60 years, suffering from type-2 diabetes were recruited for the study. The study was approved by the Institutional Ethics Committee of the National Institute of Nutrition, Hyderabad. The control group was given regular rice diet and experimental group was given 50% sorghum diet and 50% rice diet for a period of two months.

The anthropometric indices such as height, weight and BMI were measured and the biochemical indices such as glycosilated hemoglobin, fasting blood glucose, hemoglobin, insulin, creatinine, triglycerides, and LDL and HDL cholesterol were assessed before and after supplementation of sorghum diet using standard methods. The biochemical indices showed that there was a significant decrease in glycosilated hemoglobin and fasting glucose levels (Table 16).

Table 16: Mean glycosilated hemoglobin and lipid profile of diabetic patients before and after supplementation of sorghum

Parameter	Before	After
Glycosilated 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*

7.4 Amino Acid Profile of Sorghum Foods

Sorghum multi grain flour has better availability of total proteins and the individual amino acids especially methionine, an essential amino acid, is found to be in twice the levels than that found in sorghum flour. The total amino acids present in all sorghum foods were almost similar. However, the total essential amino acid present were higher in sorghum flour than other foods; and amino acid score was found to be high in multigrain flour. This could be due to inclusion of soybean in the flour formulation. In all sorghum based products the amino acid lysine is the limiting factor which is same as in case of most cereal based products; and is thus, the cause of poor quality protein. This could be overcome by inclusion of lentils and legumes in the sorghum diet.

7.5 Effect of Sorghum Diet on Nutritional Status of School Going Children

To assess the effect of sorghum diet on nutritional status of school going children, girls (n=137) and boys (n=125) aged between 9-12 years, residing at social welfare hostel, *Wanaparthy*, Mahabubnagar district, erst while Andhra

Pradesh were recruited for the study. The study was approved by the Institutional Ethics Committee of the National Institute of Nutrition, Hyderabad. School going children were divided into control and experimental groups. The control group was given regular rice diet and experimental group was given 50% sorghum diet and 50% rice diet for a period of 8 months. The anthropometric indices such as height, weight and BMI were measured and biochemical indices such as hemoglobin, total protein, albumin, ferritin, folic acid, and vitamin B-12, Retinol binding protein (RBP), iron and calcium were assessed before and after supplementation of sorghum diet using standard methods.

The biochemical indices showed that there was a significant increase in height, folic acid, RBP, Iron, hemoglobin, ferritinand vitamin B-12 levels with the supplementation of sorghum diet. There was significant decrease in total protein, albumin in both experimental and control group of girls. (Table 17a and 17b). There was a significant decrease of height in experimental group of boys than the control group. There was a significant increase of hemoglobin, ferritin, albumin, calcium, iron and folic acid is seen in experimental group than the control group. No significant difference was observed in total protein levels. Significant increase of RBP is observed which is found to be high in control group than the experimental group of boys. This study states that the sorghum rich diet will improve the growth, serum ferritin, folic acid, hemoglobin, calcium, iron and retinol binding protein among school going children (Rajendra Prasad *et al*., 2015).

Table 17a: 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±12.23NS
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
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 17b: Nutritional status of school going children (boys) before and after sorghum supplementation

Group Intervention	Experimental	Control	Experimental	Control
	Before		After	
BMI (kg/m²)	14.9±1.330 **	14.9±1.57 **	14.7±2.02 **	15.6±2.17 **
Hemoglobin (g/dl)	11.8±1.650 **	12.2±1.31 **	12.6±1.15 **	11.4±1.73 **
Total Protein (g/dl)	8.80±0.830 **	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±1.450 **	5.20±4.19 **	5.20±2.52 NS	5.20±4.19 NS
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)*

7.6 Determination of Protein Efficiency of Sorghum

Six Weanling male NIN-Wistar rats of similar weight were taken in three groups to assess the protein efficiency of sorghum. Animal Ethics committee approval was obtained, P20/7-2011/GBR to conduct the study. One group was fed with control-casein starch diet, the second group received sorghum diet and the third group protein free diet for two weeks. The total amount of diet intake and feces excreted were measured during the last 4 days of experiment. The feces were lyophilized weighed and ground to measure the protein digestibility of sorghum.

Table 18: Total amino acids, amino acid score, total essential amino acids and limiting amino acids of sorghum foods (g/100g)

Nutrient (g/100g of protein)	Sorghum Flour	Multigrain Flour	Sorghum *Rawa*	Sorghum Pasta	Sorghum Flakes	Sorghum Biscuits
Total amino acid	99.65	97.4	99.81	99.42	99.6	98.44
Total essential amino acids	40.12	36.38	40.43	36.83	39.84	41.35
Amino acid score	42.74	61.71	32.64	35.09	34.97	41.75
Limiting amino acid	Lysine	Lysine	Lysine	Lysine	Lysine	Lysine

Source: *Ravindran (1992)*

The following formula was used to calculate the true protein digestibility. True protein digestibility of casein starch diet was found to be 96.7 and true digestibility of sorghum was found to be 89.9. The amino acid score of casein was found to be 93 and the amino acid score of sorghum was found to be 42.74 (Ravindran, 1992).

$$\text{True protein Digestibility} = \frac{PI - (FP - MFP)}{PI} \quad X\ 100$$

Where PI = Protein Intake, FP = Fecal Protein, MFP = Metabolic fecal Protein

The Protein Digestibility Corrected Amino Acid Score (PDCAAS) of casein starch diet was 89.9% and PDCAAS of sorghum diet was 38.4% (Table 19). This PDCAAS value of sorghum diet was compared with that the casein starch diet and semi-synthetic wheat starch-based diets (Rutherfurd *et al.,* 2015) and found that the values were far superior.

Table 19: AAS and PDCAAS values for sorghum calculated using 2002 WHO/FAO/UNU Expert Consultation recommendation

Age group preference	Lysine scoring pattern	AAS	Threonine scoring pattern	AAS	Tryptophan scoring pattern	AAS	PDCAAS (based on lysine)
0-5 years	57	0.35	31	1.00	8.5	1.29	0.26
1-2 years	52	0.38	27	1.15	7.4	1.49	0.28
4-18 years	48	0.42	25	1.24	6.5	1.69	0.31
>18 years	45	0.44	23	1.35	6.0	1.83	0.33

Source: *Ravindran (1992)*

Chapter-8

Processing and Impact of Sorghum on Nutritional Composition

8.1 Processing of Millets

Whole grains provide a wide range of nutrients and phytochemicals that optimize health. Epidemiologic studies support the protectiveness of whole grain consumption for cardiovascular disease and cancer. Dietary guidance endorses increased whole grains in our diet. A crucial question remaining is the effect of processing of whole grains on their content of nutrients and phytochemicals. Although processing is often considered to be a negative attribute in nutrition, and some forms of processing reduce nutritional value, many factors support the importance of processing of grains to enhance grain consumption. First, whole grains as harvested are generally not consumed directly by humans but require some processing prior to consumption. While refining, that is, removal of the bran and the germ, reduces the nutrient content of grain, milling of grains otherwise concentrates desirable grain components and removes poorly digested compounds and contaminants. Cooking of grains generally increases digestibility of nutrients and phytochemical

Plausible Reasons for Less Popularity of Millets

- Lack of technical-know-how among the farmers and processors about the processing methods with respect to their own old methods of processing

- Associated cultural issues in adoption and diversification of food.
- Lack of awareness among people about nutritive value of millets and a general opinion that millets are poor men crop
- Reluctance among consumers to buy and consumer

Processing

Processing involves the partial separation and / or modification of the three major constituents of the cereal grain-the germ, the starch-containing endosperm and the protective pericarp. Various traditional methods of processing are still widely used, particularly in those parts of the semiarid tropics where small millets are grown primarily for human consumption. Most traditional processing techniques are laborious, monotonous and carried out by hand. These are almost entirely left for women to do. To some extent, the methods that are used have been developed to make traditional foods to suit local tastes and are appropriate for these purposes. Traditional techniques that are commonly used include decorticating (usually by pounding followed by winnowing or sometimes sifting), malting, fermentation, roasting, flaking and grinding.

In general, industrial methods of processing small millets are not as well developed as the methods used for processing wheat and rice. The potential for industrial processing of small millets is good. Custom milling may have significant impact in our country is custom millet like Nigeria, where about 80 per cent of sorghum and millets are now custom milled into whole flour.

- Mechanical Processing Technologies
  Decortication
  Milling and sieving

- **Dry Milling:** Grinding of the whole grain stone or roller mill to produce flour or meal is a simple method processing used worldwide when the ground products are to be consumed shortly after processing. The stability of such products is limited owing to the presence of crushed germ in the flour oil from broken germ cells is oxidized to produce rancid odour and flavor.

The large as well as small grits are used in the production of breakfast cereals. Dry milled germ can be pressed or solvent extracted to recover the valuable oil. The major advantage of dry milling are the lower capital costs as compared to wet milling

- **Wet milling:** in developed countries like USA, the major utilization has been wet milling. The two most important product of wet milling are high fructose corn syrup and ethanol
- **Alkali processing:** in this, the cereal with water and lime and cooked at 900C is mixed with water and lime and cooked at 900 c for 50 minutes. The cooked cereals is the steeped for 14 hours before being washed with fresh water to remove residual alkali and other waste materials from cereals. The washed cereals is milled to grits
- **Traditional and Bioprocess Technologies**
  Germination or malting
- **Fermentation and enzymatic hydrolyzation**
  Popping or puffing
  Soaking and cooking
- **Other Processing Technology**
  Application of high hydrostatic pressure (HHP)

8.2 Effect of Grain Processing on Nutrient Composition of Sorghum Products

Sorghum grain used for human consumption is mainly subjected to primary and secondary processing. The grain consists of the pericarp, corneous endosperm, flouryendosperm and the germ unit of the embryo. The pericarp consists of stone cells and contributes to dietary fiber, sorghum wax and some anti-nutritional factors like infectious agents, external contaminations and microscopic artifacts. During the primary processing the grain will be subjected to cleaning, purifying and refining to remove the undesirable and anti- nutritional factors. The primary processing involves dehulling (pearling), and milling the grain into flour and semolina (fine and medium semolina). Secondary processing involves use of the primary processed raw material to process ready-to-cook and ready-to-eat products for processing such as flaking, extrusion, popping, baking and blending with other cereals etc.

The objective undertaken under NAIP is to examine the effect of these processing techniques on the nutritional quality of the processed end products. The nutrient composition of the sorghum whole and dehulled grain is given in Table 20. It is observed that, there was decrease in the macro nutrients (protein and fat) and micronutrients (iron, calcium, chromium, zinc and riboflavin) which occurs on dehulling. Similarly, the nutrient composition of the primary processed products is given in Table 21 and the effect of milling on the end product is tabulated. In general, there was observed decrease of both macro and micro nutrients, except in carbohydrate content which showed marginal increase. The decrease in nutrients is minimal during milling. There was observed decrease in fat composition and this is useful especially for those suffering from obesity.

Table 20: Nutrient composition of whole sorghum grain and dehulled sorghum grain (Per 100g)

S. No	Parameters	Whole grain	Dehulled 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

S. No	Parameters	Whole grain	Dehulled grain
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

Table 21: Chemical, Mineral and Vitamin composition during milling process of sorghum (per 100 g)

Parameters	Whole grain	Flour	Fine semolina (*idli rawa*)	Medium semolina (*upma rawa*)
Moisture (%)	11.9	13.8	10.17	08.97
Ash (%)	1.6	1.6	00.73	02.03
Protein (%)	10.4	06.2	06.65	07.15
Fat (%)	1.9	02.8	01.70	01.20
Carbohydrates (%)	72.6	76.15	77.75	77.74
Iron (mg)	4.1	8.4	10.57	5.102
Calcium (mg)	25	10.03	7.552	5.750
Chromium (mg)	0.008	0.008	01.27	1.476
Zinc (mg)	1.6	1.3	1.209	1.382
Riboflavin (mg)	0.13	0.38	0.110	01.09
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*

The primary processed products raw materials are subjected to secondary processing for preparation of final products like flakes, pasta, vermicelli, pops, biscuits, multigrain flour and multigrain *roti*/*dosa* etc. There was decline in macro nutrients like protein and micronutrient like iron, zinc and vitamin (riboflavin) during processing, this decline varied with product and was found to variably distributed or sharp when compared to the rest of nutrients. The change in the carbohydrate composition of processed products when compared to raw material used is not very significant, this indicates that the calorific value was intact in the processed ready- to- eat foods as well. Products like biscuits showed much increase in fat content due to incorporation of fat in the recipe formulation (Table 22)

Table 22: Macro and micro nutrient changes during sorghum processing (per 100g)

Parameters	Grain	Flour	Fine rawa	Medium rawa	Flakes	Vermi-celli	Pasta	Pops	Biscuits
Moisture (%)	11.9	13.8	10.17	08.97	13.80	8.430	11.47	5.870	5.670
Ash (%)	1.6	1.6	00.73	02.03	0.630	0.770	0.770	0.630	2.000
Protein (%)	10.4	06.2	06.65	07.15	05.09	8.39	8.39	5.040	4.590
Fat (%)	1.9	02.8	01.70	01.20	02.40	1.38	1.38	2.600	24.50
Carbohydrates (%)	72.6	76.15	77.75	77.74	74.99	76.21	76.21	83.06	60.29
Iron (mg)	4.1	8.4	10.57	5.102	87.78	64.51	64.51	2.402	2.254
Calcium (mg)	25	10.03	7.552	5.750	93.15	54.51	64.51	10.26	68.8
Chromium (mg)	0.008	0.008	01.27	1.476	00.90	0.200	0.215	1.400	0.510
Zinc (mg)	1.6	1.3	1.209	1.382	08.78	7.49	5.740	4.510	BDL
Magnesium (mg)	171	171	76.48	86.02	80.51	67.48	67.48	86.77	56.10
Riboflavin (mg)	0.13	0.38	0.11	01.09	0.020	1.28	1.28	0.150	2.260
Energy (Kcal/100 g)	349	355	350	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*

Multigrain flour was prepared by blending five different flours from sorghum, wheat, finger millet, black gram *dhal* and fenugreek and nutrient analysis was done. Significant decrease was observed in zinc, iron and riboflavin in multigrain flour while, most of the other nutrients remained unaltered. Much of the nutrient loss is replaced by blending of different grains in multigrain flour. Multigrain flour is one among the secondary processed products which can be recommended for all age groups. The nutrient composition of the multigrain flour by blending with 3 and 5 different grains is given in Table 23.

From the study it is observed that nutritional losses occur during processing which is unavoidable. However, attention should be given to select products and processing of the semi-finished products to avoid further loss in nutrition and calorific values of the end product. Various genotypes of millets may differ in their original composition and which should be subjected to primary and secondary processing to identify those with minimal loss.

Table 23: Nutrient composition after blending with other cereal grains with sorghum flour (per 100 g)

Parameters	Sorghum Flour	Multi grain Flour (3 grain)	Multi grain flour (5 grain)
Moisture (%)	13.8	10.17	8.570
Ash (%)	1.600	1.530	1.500
Protein (%)	6.2	7.100	5.960
Fat (%)	2.8	2.400	2.600
Carbohydrates (%)	76.15	75.61	77.42
Iron (mg)	8.4	4.588	2.984
Calcium (mg)	10.03	10.61	15.94
Chromium (mg)	0.008	0.1460	0.300
Zinc (mg)	1.3	0.550	0.810
Magnesium (mg)	171	76.25	-
Riboflavin (mg)	0.38	0.140	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*

Chapter-9

Summary and conclusions

Millet as an Industry

Millets have good grain qualities suitable for processing. Processing of the grain for many enduses involves primary (wetting, dehulling and milling) and secondary (fermentation, malting, extrusion, flaking, popping and roasting) operations. Being a staple and consumed at household levels, processing must be considered at both traditional and industrial levels, involving small, medium and large-scale entrepreneurs (Obilana and Manyasa, 2002; Hamad, 2012). Dehulling is not favourable to millets due to their small grains sizes. In addition, dehulling causes nutrients loss. All the Millets can be milled by hand grinding (household level) or machine milling (cottage, small-to-medium scale service and large scale industrial).

Millet and sorghum malt production is a traditional practice in Africa, where malt is used in lactic acid- and alcoholic-fermented beverages and infant food production (Adekunle, 2012). Traditional malting processes in many developing countries involve three main operations: soaking, germination, and drying. The duration and conditions of each operation are highly variable, resulting in highly variable malt and derived product quality (Vidya *et al*., 2012). *Burukutu* and *Pito* are traditional African beers differ from Western beer types in several ways: they are often sour less carbonated and have no hops; these beer are products of both at traditional and industrial level (Anukam and Reid, 2009; Amadou*et al.,* 2011a).

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 such as millet, sorghum, and corn are now common items in the 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, showing encouraging results (Akeredolu *et al*., 2005; Laminu *et al.,* 2011; Vidya *et al.,* 2012).

In the infant weaning food sector, in spite of unlimited potential, progress has been slow, as the installed capacity for industrial malting is limited. Many brands of beer in the underdeveloped countries market have substantial content of local cereal such as millet to reduce the cost of imported barley. The industries are confronted with a number of problems which tend to diminish product qualities and affect overall utilization. For instance, in the nonalcoholic beverage and weaning food sectors, storage quality of the grain, nutritional losses after processing, high cost of imported equipment and variation among cultivars are some of the problems militating against improved utilization of millet in the developing countries (Akeredolu *et al*., 2005; Laminu *et al.,* 2011; Adekunle, 2012).

In a weaning process there is always the need to introduce soft, easily swallowed foods to supplement the infant's feeding early in life. A process weaning diet from pearl millet conophornut flour was found to promote growth in a clinical experiment (Akeredolu *et al.,* 2005); whereas, weaning food blends prepared from fermented pearl millet/roasted cowpea in 70:30 and 60:40 ratios were reported to have resulted in lower levels of phytic acid and higher in vitro protein digestibility of the weaning food blends (Laminu *et al*., 2011).

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