**Millets as future for food security**

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**1.1 Agriculture, Food Security and Sustainable Diets:**

Agriculture and its allied sectors are major contributors to the growth of national economy in India and many other developing countries around the world. Agricultural development has ensured economic sustainability and fulfilled the food requirement of 1.3 billion Indians so far. The Green Revolution, alongside other agricultural advancements led to a quantum leap in crop production thus enabling the nation in meeting the burgeoning requirements of the 20th century population of around 1.6 billion. During the 21st century, when the population grew to a whopping 6.1 billion people; novel traits have been applied to increase the production of conventional crops with the help of biotechnological applications. However, need of the current day is to ensure increased food supply and eradicate food insecurity by 2050, by when the population is expected to touch 9.2 billion. Increasing the food production by 70 % within the same size of the land and fewer resources to meet the impending burgeoning food requirements of the nation is the biggest challenge (Pretty *et al*., 2010; FAO 2009a; FAO 2009b; DuPont Advisory Committee, 2016).

Other than required increase in food and agriculture production, combating food security crisis is a major concern. It is pertinent that challenges lie in the availability of acceptable, nutritious, affordable food and its supplementation to the needy population. Towards this, Public-private partnerships and small-scale farmer organizations for institutional improvement, adoption of environmental practices, technology application with consideration to rural life and market opportunities, and regulatory and taxation methods for sustainable diets will lead to steady growth in agriculture and food security (Lipton, 2006; World Bank, 2006).

**1.2 Crop Yield - Use of Technology; Conflict, Climatic Conditions and Economic Downturn; Food Security Goals:**

**1.2.1 Use of Technology:**

Developing countries yield only 30 % of their agricultural potential. Hence, there is a substantial space for increase in yields and cropping intensity through technological advancement, and there is a reduced requirement of expansion of arable land with less damage to the environment through use of chemicals and fertilizers (World Bank, 2010; Deninger, 2011; FAO 2009a). Advanced technological applications such as plant breeding, nuclear techniques, GM crops have been incorporated into the agricultural sector to improve production and accessibility. Technological applications in the field of GM Crops and biotechnology are appropriated on a few focused crops (Maize, Wheat and Rice) and only in high income countries (Pingali, 2007, Adlas and Achoth, 2006). Rampant use of chemicals, pesticides and pathogen resistant crops are resulting in evolution of more resistant pathogens which may spread like fire in the current globalization period. Scarcity and/or uneven distribution of nitrogen and phosphorous, which are essential for increased yield of the nutritive agriculture produce, is caused due to increased soil erosion, which in turn resulted in rising prices of nutrient food and growth in food insecurity, thereby further widening the economic rift between developed and developing countries (SCAR, 2011).

**1.2.2 Conflict, Climatic Change and Economic Downturn:**

Rising rift between developed countries and countries rich in natural resources has struck a conflict towards gaining upper hand in acquiring energy and further stance one’s dominance in the growing world food and geological insecurity (FAO, 2017). Conflict has resulted in a 14 % global increase in undernourishment and stunting in Children (Global Nutrition Report, UNICEF, 2018). Preserving climate is important towards Sustainable Development Goal 2030. Global warming has created an unpredictable climatic condition which in turn adversely affected agricultural systems. Hence, the requirement of food crops that are sustainable to harsh climatic conditions and promote environmental balance is the need of the present situation (Jain *et al*., 2016, FAO 2018). Climate change has always been a leading concern for food security (Parry *et al*., 2009). It not only has an effect on food production, but also on its accessibility and utilization. Every year, around 65% of the cropped area is affected by high variability of monsoon in India (Chakrabarty, 2013). Climate change is also a huge threat to the groundwater level, leading to severe drought situations in several regions in India. In general, extremely high stress of water shortage is experienced by 54% of the Indian regions (Shiao *et al*., 2015). Rice and wheat, which are considered as the central crops for nutrition in India, get affected by the climate change, thermal stress and acute water shortage conditions (Lal *et al*., 2001 and Easter ling *et al*., 2007), consequently resulting in low food production and food shortage.

**1.2.3 Food Security Goals:**

“Food Security is achieved when one has the physical, social and economic reach to food with respect to quantity, safety and nutritive value to meet the bigger objectives of active and healthy life by meeting diet preferences and requirements” (World Food Summit, 1996 and 2009). Food production alone, therefore, is not sufficient to combat the food security problem. Food security depends on accessibility, availability, utilization and stability of food with an integral dimension of nutrition. Food security also depends on eradication of severe poverty and lack of food, which is the first Millennium Development Goal (United Nations, 2009). UNFCC-COP 25 was held in Madrid, Spain, in December 2019, to re-state Millennium goal of limiting global temperature to 1.5 o C rise and for continual focus on climate control with regards to natural calamities and wildfires. Primarily, designing social, economic and trade policies and secondly instilling multi-sector inequality for developing safety thresholds for food and nutrition is a step towards fighting global economy problems, food insecurity and malnutrition (FAO, 2019). Figure 1.1 displays the Severity of food insecurity.

**Mild food insecurity Severe food insecurity**

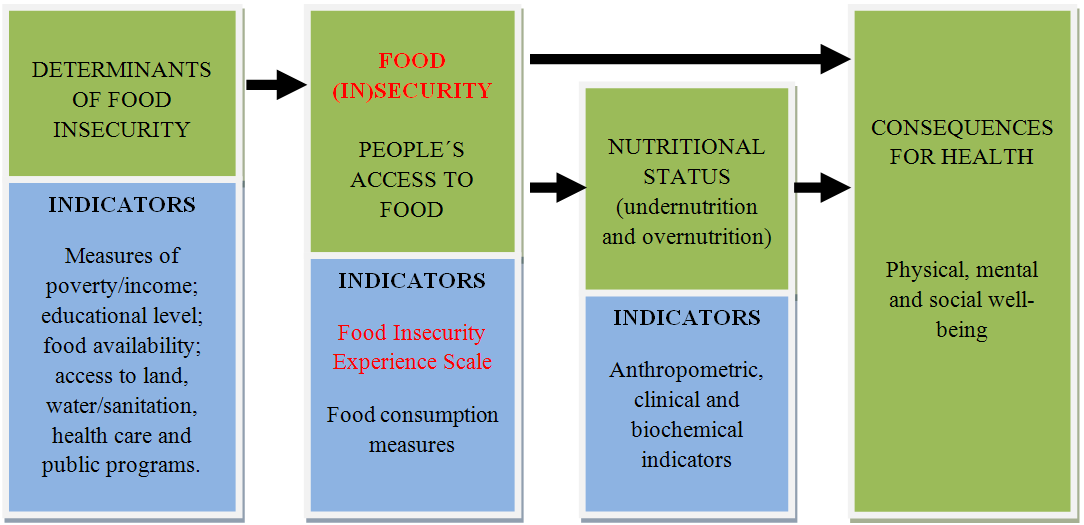
Worrying about how Compromising on quality Reducing quantities, Malnutrition,

To procure food and variety skipping meals Hunger

**Figure 1.1: Severity of Food Insecurity - Experience Scale** (Adapted from FAO– 2019)

Elimination of poverty and thereby attaining food security is possible through sustainable diets. The concept of sustainable diets includes various factors such as well being, health, food nutrients needs, food security, cultural heritage, skills, biodiversity, environment and climate change (Johnston *et al*., 2014). Promoting sustainable diets is an urgent need for measuring and understanding the role of food systems in nutrition and human health. Sustainable Diets were first defined by Gussow and Clancy in 1986, as ‘a harmony between ecology and food sustainability, for the healthy diet of an individual’. The Sustainable development agenda set up for 2030 is: ‘achieving a world without hunger and malnutrition’ (2030 agenda). Promoting agriculture, ending hunger, improving nutrition status and decreasing food insecurity are some

of the essential objectives for the 2nd Sustainable Development Goal (SDG 2) (FAO, 2019). It was aimed to uphold the integrated policy and actions for understanding the positive interrelation between hunger, insecurity, nutritional status and sustainable agriculture. Figure 1.2 displays the determinants and indicators of food insecurity.



**Figure 1.2: Food Insecurity - Determinants and Consequences**

(Adapted from Campbell (1990))

**1.3 Food Insecurity and Malnutrition:**

Malnutrition is a major obstacle in the developing and underdeveloped countries towards meeting the health goals of people (Phalkey *et al*., 2015; Global Nutrition Report, 2018). Low availability and accessibility to food nutrients has a long lasting impact on child health. Malnutrition is caused by deficiencies of either macronutrients which are carbohydrates, fats, proteins or micronutrients; vitamins and minerals. These are essential for plugging developmental delays and future cognitive impairment in infants.

The Prevalence of Undernourishment (PoU) study suggested that from 2000 to 2013, the percentage of undernourished people is decreased from 14.7 % to 10.8 %. But in 2016, FAO estimates suggested that the prevalence once again rose up to 11 %. As a result of food deprivation and insecurity, people have rampantly fallen prey to eating disorders and stress-induced metabolic responses. Thus, the diagnosis and incidence of Non-Communicable Diseases (NCD), for example diabetes and heart attack has been integral. Table 1.1 states that a total of 820 Million people were undernourished in 2018 around the world and of which, 278.5 Million were from South Asia. Urbanisation, easy access to highly-processed food, high intake of sugar and fat and decreasing importance of traditional diets explains the co-existence of multiple forms of malnourishment, specifically in Low and Middle Income Countries (LMIC) (FAO, 2017; Turner *et al*., 2019).

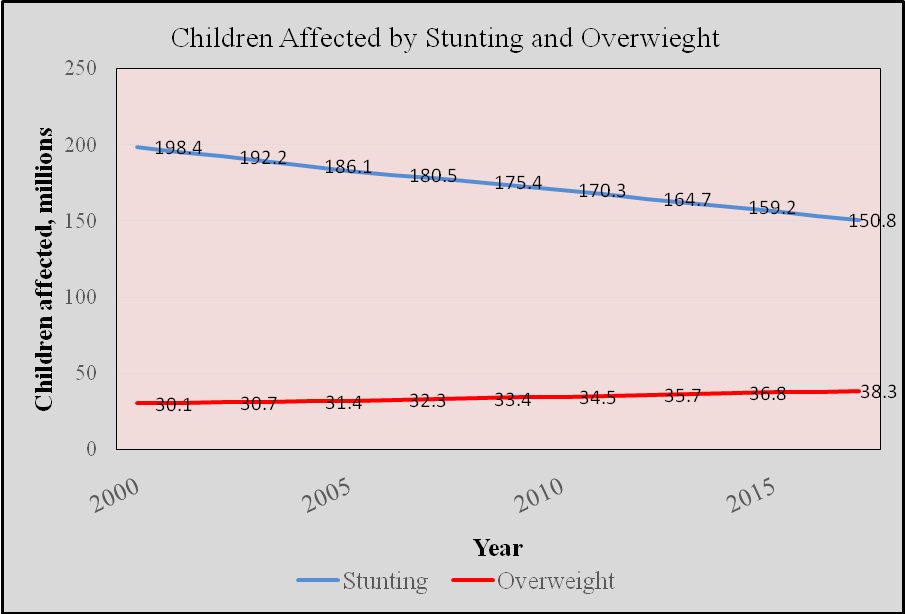
**Table 1.1: Number of Undernourished people in the World (2005-2018)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Region** | **Number of Undernourished People ( In Millions)** | | |
| **Year** → | **2005** | **2015** | **2018** |
| World | 947.2 | 785.4 | 821.6 |
| Africa | 196.0 | 217.9 | 256.1 |
| **Asia**  **(South Asia)** | **688.6**  **(339.8)** | **518.7**  **(286.1)** | **513.9**  **(278.5)** |
| Latin America and Caribbean | 51.1 | 39.1 | 42.5 |

(Source: The State of Food Security and Nutrition in the World, FAO, 2019)

In April 2016, the United Nations declared years 2016 to 2025 as ‘United Nations Decade of Action on Nutrition’ and put a stop to all forms of malnutrition by 2030. Figure 1.3 refers statistics for number of children affected by stunting and overweight during the period from 2000 to 2015. The UN adopted Sustainable Development Goals (SDG) including eradication of stunting, wasting and obesity among children, which are also the indicators of malnutrition in them. In addition, eradication of anemia among women of reproductive age and obesity among adults, improving the percentage of exclusive breastfeeding for infants less than six months of age, are the factors decided upon by the SDG for control over increasing malnutrition (FAO, 2017). FAOSTAT, 2019 defines SDG-12 as responsible consumption and production of food crops by reducing food loss and wastage to fight food insecurity, malnutrition, depleting natural resources and degrading environment.

Nutrition is not only an indicative factor for good health of people and, in turn, the community, but it also indicates the well-being of a country and its economic and social development. This can be achieved through proper nourishment. Chivenge *et al*., in 2015 stated the potential of the Neglected and Under-utilized Crop Species (NUCS) in mitigating the problems of undernourishment and food accessibility in the water-scarce dry and semi-parched regions of the world. The same was reviewed by Adhikari *et al*., in 2017 for Pakistan and Nepal and the countries in the Hindukush (HKH) region, which also includes India. These underutilized and neglected groups of crops, also called Orphan or Lost Crops belong to millets (Gupta *et al*., 2017).



(Source: 2018 Global Nutrition Report. UNICEF / WHO / World Bank Group: Joint child malnutrition estimates)

**Figure 1.3: Global Number of Children Affected by Stunting and Overweight**

In order to mitigate the multilevel concerns of climate change, food security and accessibility, undernourishment and metabolic disorders, giving attention to concurrent increase in production and utilization of millets ought to be stressed.

**1.4 Millets:**

Millets belong to the grass family of Gramineae/ Panaceae and are widespread in approximately 10 genera and 20 kinds in total are used for feed, food and forage (Lata, 2015; Singh *et al*., 2012). 'Millets' is a common name referring to number of little - seeded annual grasses in dual tribes Paniceae and Chlorideae of the family Poaceae (true grass) (Lu *et al*., 2009). Widely produced around the world, millets are small seeded grasses which are round and tiny structured and mostly used for food and fodder (Swaminaidu *et al*., 2015). Millets have shown the capability of growing on infertile land within an extremely wide range of climatic conditions. In adverse agro climatic conditions, the sustainability of millets has proved beneficial (Ushakumari *et al*., 2004). Countries like America and Europe, where millet is not a daily part of the diet, have realized importance of millets due to their high nutritional content and benefits in many metabolic disorders. However, in the parched/sub-parched regions of Asia, they are known to be a miracle food. In Africa, it is a staple food in many regions; used in many traditional preparations (Chandrasekara and Shahidi, 2011).

Millets serve as one of the best medium to fulfill today’s requirement of the organizations, world-over, striving to achieve sustainable food security. These drought resistant crops have many superseding advantages, spanning their utilization for food, feed, bio-ethanol, bio-films etc. Millets are the gluten free coarse cereals which are gaining importance in recent years, not only for their effective role in malnutrition but also in combating major health problems such as diabetes and cardiovascular diseases.

**1.4.1 Production and Consumption of Different Indian Millets:**

Encompassing 33.6 Million Hectare (M Ha), millet production worldwide was 26.7 Million Tons (MT) in 2009 (FAO statistics, 2009). According to the National Nutrition Monitoring Bureau (NNMB), in India, Gujarat (Pearl millet), Karnataka (Finger millet and Foxtail millet), Maharashtra (Sorghum) lead and Kerala, Orissa and Tamil Nadu lag in the production and consumption of millets (Sarita and Singh, 2016). From the year 2010 to 2014, Asian countries showed significant contribution to the increased production of millets from 48.72 % to 52.25 %. FAO data suggests that after maize, paddy, wheat and barley, sorghum is the fifth major crop produced all over the world.

Kulkarni, 2018, stated that, in India, area under millet production reduced from 37 M Ha in 1066 to 14.72 M Ha in 2017, when production of millets itself in 2017 was 16.14 Million Tons (MT). The reduction in Area of Production was attributed to consumption habits, low yield of millets view allotment of irrigation for rice and wheat. Surendran *et al*., 2019 reported factors affecting low consumption of fruits and vegetables in India. They included proximity to produce, availability and accessibility, occupational shift of farmers, price and affordability, vendor and product properties (Time for which product could be stocked) and desirability. Despite its adaptability and agronomic features of subsistence cereal, only 3 million tonnes of finger millet is produced each year around the world (Opole, 2019). With increased awareness and initiative in Karnataka, India, yield of small millets was increased to 8-12 Quintals per Acre overriding drought like climate and economic slowdown. With organizations such as ‘earth 360’ in Andhra Pradesh and Indian central government’s millet mission, productivity of millets was increased by generating good quality millet seed banks and farm gate decentralized model of primary processing facilities for decreasing production cost and increasing profit incentive to farmers. To increase the production of millets, IIMR, Hyderabad in 2019 released three Varieties of High Yeild (HYV) Sorghum, namely, *Jaicar Heera*, *Jaicar Sona* and *Jaicar Gold*, for production in India (Annual Report, IIMR, 2019).

In the current scenario, pearl millets cover 260000 KM2 harvested area around the world. This is half the total area used for harvesting all the types of millets. It is pertinent to mention that, above 98% of total global pearl millet market is contributed by Asia and Africa (Nutritional and Health benefits of millets, 2017).

**Table 1.2: Indian Millet Production Year on Year (1998-2018)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Year** | **Production** | **Unit of Measure** | **Growth Rate** |
| 1998 | 10235 | (1000 MT) | -1.31 % |
| 1999 | 8690 | (1000 MT) | -15.10 % |
| 2000 | 10078 | (1000 MT) | 15.97 % |
| 2001 | 11235 | (1000 MT) | 11.48 % |
| 2002 | 6494 | (1000 MT) | -42.20 % |
| 2003 | 14639 | (1000 MT) | 125.42 % |
| 2004 | 10841 | (1000 MT) | -25.94 % |
| 2005 | 10509 | (1000 MT) | -3.06 % |
| 2006 | 10347 | (1000 MT) | -1.54 % |
| 2007 | 12673 | (1000 MT) | 22.48 % |
| 2008 | 11372 | (1000 MT) | -10.27 % |
| 2009 | 8777 | (1000 MT) | -22.82 % |
| 2010 | 13005 | (1000 MT) | 48.17 % |
| 2011 | 12657 | (1000 MT) | -2.68 % |
| 2012 | 10752 | (1000 MT) | -15.05 % |
| 2013 | 11663 | (1000 MT) | 8.47 % |
| 2014 | 11630 | (1000 MT) | -0.28 % |
| 2015 | 10280 | (1000 MT) | -11.61 % |
| 2016 | 11560 | (1000 MT) | 12.45 % |
| 2017 | 11550 | (1000 MT) | -0.09 % |
| 2018 | 9400 | (1000 MT) | -18.61 % |

(Source: [United States Department of Agriculture](http://www.usda.gov/), 2019)

Table 1.2 shows the history of Indian millet production while table 1.3 estimates the vision for improvement in area of cultivation, production and yield of millets by 2050. This estimate is an important step following the UN report on the state of food security around the world in 2019 towards meeting estimated increase in global demand of food (3 Billion Tonnes) by 2050 (FAO, 2019).

**Table 1.3: Millets Cultivation and Production; Projection upto Year 2050 AD**

|  | **Scenario I** | | | **Scenario II** | | | **Scenario III** | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Millet | Area  (M Ha) | Yield  (Kg/Ha) | Production  (MT) | Area  (M Ha) | Yield  (Kg/Ha) | Production  (MT) | Area  (M Ha) | Yield  (Kg/Ha) | Production  (MT) |
| Sorghum | 1.32 | 1378 | 1.82 | 1.32 | 3000 | 3.96 | 2.00 | 3000 | 7.00 |
| Pearl Millet | 9.00 | 1214 | 10.92 | 9.00 | 2500 | 22.50 | 15.00 | 2500 | 37.50 |
| Finger Millet | 1.11 | 1428 | 1.59 | 1.11 | 2500 | 2.78 | 4.00 | 2500 | 10.00 |
| Foxtail Millet | 0.75 | 750 | 0.43 | 0.75 | 1500 | 1.13 | 2.0 | 1500 | 3.00 |

(Source: Vision Document 2050, IIMR Hyderabad, 2014)

(Scenario I: Existing situation with current levels of Area, Production and Productivity,

Scenario II: Area retained and increased Productivity due to High Yield Varieties,

Scenario III: Positive impact on area view supporting policy by government for Production, Processing and Value Addition)

**1.4.1.1 Production and consumption of Finger Millet:**

The worldwide percentage for area of cultivation of **finger millet** is 12%. The area of cultivation spreads over 25 countries in Africa and Asia. Area under production for finger millet stands sixth in India following wheat, rice, maize, sorghum and pearl millet (Chandra *et al*., 2016).

Finger millet is a principal and indispensable food variety in India as well as Eastern and Central Africa. The cultivation area for finger millets in India is 2.65 M Ha. Karnataka is the leading state producing this cereal in India, contributing 58 % of the total produce in the country (Rane *et al*., 2014; Sarita and Singh, 2016). In Tamil Nadu and Gujarat, finger millet is produced as an irrigated crop. The productivity of the crop is found to be approximately 1500 Kg per Hectare (Kg/Ha) in India (Shukla *et al*., 2015; Swami *et al*., 2013). Mandua, as it is better known in India, it can be produced in varying altitudes between Mean Sea Level (MSL) to an altitude of 1800 meters, while in the Himalayas upto 3000 meters above MSL (FAO, 2012; Dida *et al*., 2006; Bisht and Singh, 2009). The efficiency of yield is, hence, very high due its nil variation towards climatic and environmental conditions (Kumar *et al*., 2016).

**1.4.1.2 Production and consumption of Sorghum:**

The production of **Sorghum** in Africa is among the largest in the world, with a production of 22.5 (M MT) in 2005 (Rosemary *et al*., 2007). Amongst the producers and exporters of sorghum, the United States was the largest with 20% and 80% of world production and exports, respectively (USDA-FAS, 2003). Major variables affecting Sorghum production are subset of the factors defined by UN Summit on climate change (UNSCC), 2019, for food security by 2050 (Mundia *et al*., 2019). Consumption wise, sorghum is mostly identified with the African countries. With respect to the total area of production of sorghum, Africa (59%), Asia (25%), North America (11%), South America (4%) and Europe (1%) stand in that sequence. The total quantity of sorghum produced in the world is 46 % from Asia and North, Middle and South America with 27 %, 21 % and 6 % respectively (Nemeth, 2009). India was the third prominent producer of sorghum in the world with a produce of 6.30 MT in the year 2011, which now slipped to fifth rank behind US, Mexico, Ethiopia and Nigeria preceding it (World Agricultural Production, USDA, 2019).

**1.4.1.3 Production and consumption of Pearl Millet:**

**Pearl Millets** are produced on greater than 28 M Ha of ground in the dry tropical regions of Asia (USDA, 2005). The determined production of pearl millet in developing countries is found to be over 95 %. Pearl millet is a traditional cereal produced by cultivators in Maharashtra and Karnataka on the Deccan plateau and in Tamilnadu. India grows around 5 MT of pearl millet per year and contributes around half of the world pearl millet production. Rajasthan, Gujarat and Maharashtra contribute to around 70 % pearl millet production in India. However, the production has been observed to have declined from the year 2007-2011 in these regions and improving thereafter. To improve the production and consumption of this crop with high content of minerals (Iron and Zinc), Pearl Millets are being cross pollinated by fast-track breeding and biofortified breeding pipelines of derived varieties to fight malnutrition in semi-arid regions of India (Govindaraj *et al*., 2019a). Pearl Millet High Yeild (HY) Open Pollinated Varieties (OPVs) and Hybrids (03 types) were first introduced in India (Govindaraj *et al*., 2019b). Market opportunities for these crops and thereby consumption is possible by introducing them to Public Distribution System (PDS) and facilitating opportunities.

**1.4.1.4 Production and consumption of Foxtail Millet:**

Since ancient times, **Foxtail Millet,** also known as Italian millets**,** has been cultivated in Eastern Asia. Prasad *et al*., 1987 suggested that it has been part of central China since 5000 years. Domestication is responsible for spreading this crop to India, Africa and Europe (Pawar and Machewad, 2005). Raxhie, in 1975, reported that yields in China exceeded 11,000 Kg/Ha and Rawat and Tyagi, in 1998, reported that China ranked first in the production of foxtail millet. Foxtail millet was a major rain-fed crop in India, however, presently, continued cultivation is observed only in scattered locations in India. Foxtail millet is produced in different state of India mainly in Karnataka, Maharashtra, Andhra Pradesh, Tamilnadu, Rajasthan (Kusuma, 2011). Patil and Sankangoudar, 2019, studied the consumption pattern of Foxtail Millets in Dharwad amongst Growers and Non-Growers of this crop from same and different village. It was reported that Foxtail Millet is consumed less than 10 % by growers and less than 5 % by Non-Growers from both categories monthly. The percentage of consumption falls below 2% for weekly and daily analysis. However, consumption was reported to be more than 40% on occasions/ festivals. Consumption pattern was defined by difficulty in processing of these crops for food preparation.

**1.5 Nutritional Significance of Millets:**

Millets are unique among cereals, as they are calcium, dietary fiber, polyphenols and protein rich (Devi *et al*., 2014) and also contain abundant iron, magnesium, phosphorous and potassium (Stanley *et al*., 2013). Millets usually contain considerable quantity of necessary amino acids, especially sulphur containing amino acids, methionine and cysteine. They have higher fat content compared to maize, rice and sorghum (Obilana and Manyasa, 2002). Nutrient opulence of millets has earned them denotation, that is, ‘Nutra-cereals’ or ‘Neutraceuticals’ (Stanley *et al*., 2013). A comparative nutrient composition between wheat, rice, maize and different millets is tabulated in table 1.3. It is observed that, millets are superior in protein, fiber and micronutrient contents when evaluated with wheat, rice and maize.

**1.5.1 Carbohydrate content in Millets:**

Percentage of carbohydrates in **finger millet** was observed within 60.80 to 85% according to McNeill *et al*., 1975 and comprised of Pentosans (7.2%), cellulose (1.8%) (Wankhede *et al*., 1979), free sugars (1.04%), starch (65.5%), loose polysaccharides (Malleshi *et al*., 1986) and dietary fiber (Gopalan *et al*., 2009). Maximum proportion of carbohydrates was in the form of flexible polysaccharides (Swami *et al*., 2013). Finger millet is composed of both simple and compound starch sub-constituents and has a large variation in shape and size. The amylose content of starch found by Mohan *et al*., 2005, was 22%, which was found to be enhanced when compared with the one suggested by Malleshi *et al*., 1986, that is, 38.6%. The percentage of carbohydrates in **Sorghum** was found to be around 60.80% according to McNeill *et al*., 1975. Around 94% starch is contained in the endosperm of the sorghum grain kernel and 69.5% average in the grain. Less than 5% amylose is found in the waxy varieties of sorghum whereas 23 to 30% of the amylose content is found in regular endosperm varieties (Leder, 2004).

## Table 1.4: Nutrient Composition of Millets and Other Cereals

## (Per 100 g edible portion; 12% moisture)

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Food** | **Proteina (g)** | **Fat (g)** | **Ash (g)** | **Crude fibre (g)** | **Carbo- hydrate**  **(g)** | **Energy (KCal)** | **Ca (mg)** | **Fe (mg)** | **Thiamin (mg)** | **Ribo- flavin (mg)** | **Niacin (mg)** |
| Rice (brown) | 7.9 | 27 | 1.3 | 1 | 76 | 362 | 33 | 1.8 | 0.41 | 0.04 | 4.3 |
| Wheat | 11.6 | 20 | 1.6 | 2 | 71 | 348 | 30 | 3.5 | 0.41 | 0.1 | 5.1 |
| Maize | 9.2 | 4.6 | 1.2 | 2.8 | 73 | 358 | 26 | 2.7 | 0.38 | 0.2 | 3.6 |
| Sorghum | 10.4 | 3.1 | 1.6 | 2 | 70.7 | 329 | 25 | 5.4 | 0.38 | 0.15 | 4.3 |
| Pearl millet | 11.8 | 4.8 | 2.2 | 2.3 | 67 | 363 | 42 | 11 | 0.38 | 0.21 | 2.8 |
| Finger millet | 7.7 | 1.5 | 2.6 | 3.6 | 72.6 | 336 | 350 | 3.9 | 0.42 | 0.19 | 1.1 |
| Foxtail millet | 11.2 | 4 | 3.3 | 6.7 | 63.2 | 351 | 31 | 2.8 | 0.59 | 0.11 | 3.2 |
| Common millet | 12.5 | 3.5 | 3.1 | 5.2 | 63.8 | 364 | 8 | 2.9 | 0.41 | 0.28 | 4.5 |
| Little millet | 9.7 | 5.2 | 5.4 | 7.6 | 60.9 | 329 | 17 | 9.3 | 0.3 | 0.09 | 3.2 |
| Barnyard millet | 11 | 3.9 | 4.5 | 13.6 | 55 | 300 | 22 | 18.6 | 0.33 | 0.1 | 4.2 |
| Kodo millet | 9.8 | 3.6 | 3.3 | 5.2 | 66.6 | 353 | 35 | 1.7 | 0.15 | 0.09 | 2 |

(Sources: Hulse *et al*., 1980; United States National Research Council/National Academy of Sciences (1982); USDA/HNIS (1995); FAO (1995). Modified from Gopalan *et al*., 2004)

(a - All values except protein are expressed on a dry weight basis)

Starch, an essential factor of sorghum, has a very complex structure. Starch digestibility is increased with processing methods such as steaming, puffing, micronization (milling and grinding) due to its release from the protein matrix. Sade, in 2009, found the carbohydrate content in **Pearl Millet** to be around 71%. Pearl millet's amylose percentage spanned 20-21.5%. Swelling power and solubility of pearl millet starch is higher as compared with other millets. Starch in different varieties of pearl millet varies from 62.8 to 70.5%; soluble sugar between 1.2 to 2.6%. In pearl millet grain, non-starch polysaccharide fractions include glucose, arabinose, xylose and uronic acids which are monosaccharides (Hoseney, 1994; Hadimani *et al*., 2001; Taylor, 2004). Due to the absence of gluten, carbohydrate percentage is low in pearl millet and thereby, resulting in a low glycemic index (Suma and Urooj, 2014; Singh *et al*., 2010). Carbohydrate content in **Foxtail Millet** is around 61%, which is comparable to other millets (Kusuma *et al*., 2013).

**1.5.2 Protein content in Millets:**

**Finger Millet** grain has the highest percentage of proteins (10%) amongst the cereals and with a range of 5–12% as researched by Srivastava, 2006. Prolamins content found in finger millets is around 35 to 50%, whereas, albumins and globulins around 8 to 15% of total proteins. Finger millets contain high levels of methionine and other amino acids (around 3%, which is exceptionally high for a cereal grain). Amino acid content is found to be good with a total of 44.7% (Mbithi *et al*., 2000) and the distribution is 2.5% lysine, 13% tryptophan, 3% methionine, 3.1% Threonine and 4% leucine and isoleucine. Other essential amino acids present are Arginine and lecithin.

**Sorghum** proteins, the second most major nutrient of sorghum, can be classified depending on their solubility into albumins (water soluble), globulins (salt soluble), Kafirins (alcohol soluble) and glutelins (dilute–alkali soluble) (Osborne 1924; Landry and Moureanx, 1970, Abdelhalem, 2006). When compared to wheat proteins, sorghum proteins are found to be superior with regards their solubility. Sorghum is rich in amino acid leucine and has shown good digestibility and biological value (Kazanas and Fields, 1981 and Au and Fields 1981). Sorghum has shown 11 to 13% of protein and even higher values have also been reported (Dendy, 1995). **Pearl Millet** showed higher percentage of protein (9 to 13%) when compared to other cereals as stated by Desikachar, 1975. Comparison of the pearl millet to maize brought out that it is enriched with 40% Lysine and Methionine and 30% Theronine. The protein and energy in the crop is one of the highest as reported by Chikwendu *et al*., 2014. High level of necessary amino acids, amino acid balance and high *In Vitro Pepsin Digestibility* values in pearl millets proved to be a good source of protein to humans (Ejeta *et al*., 1987). **Foxtail Millet** has a higher percentage of protein content, which is around 12.3%. FAO, 1970 report presented leucine (16.7g /100g of protein) as the highest and Histidine (2.1g /100g of protein) as the lowest by weight in the amino acid composition in foxtail millet. Other amino acids were isoleucine, phenyl alanine and valine. Their fraction in foxtail millets was higher when compared to other amino acids.

**1.5.3 Fat Content in Millets:**

The percentage of fats in **Finger Millet** is reported to be around 1.2 g. Fats in finger millet include fatty acids - oleic (49 %), linoleic (25 %) and Palmitic acids (25 %) (Sridhar and Lakshminarayana, 1994). 72 % of total lipids in finger millets exist as glycolipids and phospholipids with 13 % and 6 % content, respectively (Mahadevappa *et al*., 1978). The crude fat content was superior in **Sorghum** when compared to other cereals. Major sources of fat in sorghum kernel structure are the germ and the aleurone layers. The fat content in the germ is proportionate to about 80 % of the total fats in sorghum.

Fat percentage of sorghum is higher than that of rice and wheat, i.e. 3%, with high concentrations of Palmitic acid (14%), oleic acid (31%) and linoleic acid (49%) (Leder, 2004). **Pearl Millet** fats contain linoleic acid which is just 0.9 % of the total fatty acids and therefore, pearl millets are low in n-3 fatty acid content which plays a characteristic role in undesired physiological activities like platelet gathering, LDL cholesterol increase and damage to the immune system (Kaur *et al*., 2014). **Foxtail Millet** showed fat content ranging from 3.5 to 4.75 gm/100 gm, which is higher compared to other cereals except pearl millet (Geervani and Eggum, 1989; Kusuma *et al*., 2013). Foxtail and proso millet showed higher acid value and hydroxyl value for oils where stearic and Palmitic acids were found to be highest. Linoleic and oleic acid comprise 80% of the extractable lipids in foxtail millets (Adrian and Jacqoute, 1964).

**1.5.4 Fibre content in Millets:**

The fibre in **Finger Millets** is indigestible as finger millet seeds are covered with hulls that are difficult to remove by household processes. These fibers have a lot of health benefits including enhanced digestibility and improved peristaltic movements in intestinal tract (Rane *et al*., 2014). The percentage of fibre in finger millets is around 2%. Dietary fibers found are of two types, water soluble and insoluble. The percentage of water-insoluble fibre is 13 – 15% more than the counterparts in total dietary fibre content as described by Chethan *et al*., 2007 and Shobhana *et al*., 2007. **Sorghum** constitutes different dietary fibre types viz, hemi-cellulose, cellulose and soluble dietary fibers (Ndiaye *et al*., 2008). Insoluble fibre content in sorghum is found to be 86.2% (Leder, 2004). De-pigmentation of **Pearl Millet** results in better *in vitro* digestibility of soluble dietary fibre, however, it reduces their actual content on ground (Archana *et al*., 2004). Crude fibre in **Foxtail Millet** was reported to be superior to wheat, rice, little millet and proso millet. It showed 8.0% of crude fibre (Gopalan *et al*., 2004). Kusuma *et al*., 2013 stated very high dietary fibre content in foxtail Millet, around 14 %. High fibre content in foxtail millet helps in management of diabetes.

**1.5.5 Vitamin and Mineral content in Millets:**

Mineral content in **Finger Millet** constitutes calcium at around 300-350 mg/100g, iron 3.9% and phosphorous around 283mg/100g (Gopalan *et al*., 2000). The high calcium content in finger millet has no match amongst other cereals (Gari, 2002). Finger millets are a unique source for vitamins, both water-soluble and lipo-soluble. The concentrations of vitamins in finger millet are found to be - thiamine 0.25 mg, Vitamin A 6.1 mg, Vitamin C 1.2 mg, folic acid and niacin 1.1 mg (Vidyavati *et al*., 2004; Swaminaidu *et al*., 2015).

The **Sorghum** grain kernel includes the embryo, approximately 10% of the size of the grain, bran layer (pericarp) around 8 % of the grain and the endosperm, the structure of the outermost layer of the sorghum grain, is greater than 80 % of the grain. The largest proportion of the architecture endosperm contributes around 50 to 75 % B-complex vitamins (Kulamarva *et al*., 2009). Other than the B-complex vitamins, sorghum is a source of fat-soluble vitamins like Vitamin D, Vitamin E and Vitamin K, however, does not include Vitamin A and Vitamin C. Thiamin, riboflavin and niacin are present in sorghum in equal measures when compared to other grains. Beta carotene pre-existent of vitamin A is found in traces in sorghum varieties.

**Pearl Millets** are a rich source for Phosphorous and Iron and a very good source for calcium and zinc as well (Eyzaguirre *et al*., 2006; Millet Network of India (Deccan Development Society, FIAN, India)). Calcium content in pearl millet is around 300-350 mg/100g, iron 3.9% and phosphorous 283 mg/100 g (Gopalan *et al*., 2000). Being a rich source of calcium and phosphorus (Ramanathan *et al*., 1975), **Foxtail Millet** showed a high total mineral content of 3.3 %. This accounts higher than the calcium and phosphorous contained in wheat and rice, as reported by Gopalan *et al*., 2004. The calcium and phosphorous content in foxtail millet were found to be 31 mg and 290 mg per 100 g as observed by Kusuma *et al*., 2013. Foxtail Millet is a good source of magnesium and thus referred to as a healthy heart food (Reddy, 2017).

**1.5.6 Micro-Nutrient content in Millets:**

**1.5.6.1 Iron:**

**Iron** helps in DNA and enzyme-binding oxygen consistency, bodily rate and immunity (Anderson *et al*., 2012). Classification of iron as it is found in food can be either haem or non-haem. Haem iron exists as hemoglobin and myoglobin. Lack of inclusion of haem iron resulting in low hemoglobin amongst people in progressing countries heightened outcome of Child and Women Iron Deficiency Anemia (IDA) (Young *et al*., 2018, Mann *et al*., 2012, Geissler *et al*., 2011). Haem iron absorbtion (around 35%) is independent of physiological and dietary factors, whereas, non-haem iron depends on dietary components and health status of individuals. The bioavailability of iron is better in moist heat methods as compared to dry heat methods used for studies (Mounika *et al*., 2017). Phytates, tannins are the antinutrients which inhibit formation of iron-catalysed hydroxyl radicals. Phytates have an anti-nutritional factor due to significant amounts of inositol hexaphospahtes (IP6). Therefore, phytic acid content is reduced in foods, leading to increased absorption of iron. Iron is found to be concentrated in the endosperm and the decortications treatment for a controlled duration removed it approximately 46 to 62 % from the grain (Hama *et al*., 2011).

**Pearl millet** consists of a good quantity of Fe and Zn and is a crucial grain with regards to breeding based biofortification or enhancing nutrient levels and for a fight against malnutrition in semi-arid tropical region (Kumar *et al*., 2018). Kodakany *et al*., 2013 determined the amalgamation of Fe and Zn in pearl millet (found in abundance in Karnataka) which are deficient in non-fortified plant-based foods worldwide and found it to be superior in pearl millets when compared to **Sorghum** and rice. In the decreasing order, the iron content per 100 g of grain was observed to be 9.0 mg in pearl millet, 7.0 mg in **Little Millet**, 4.0 mg in sorghum 3.65 mg in **Finger Millet**, 2.6 mg in **Foxtail Millet** and 2.6 mg in **Proso Millet**, while in wheat it was 4.5 g and in rice it was 0.5 mg (Mounika *et al*., 2017).

**1.5.6.2 Zinc:**

**Zinc** ranks sixth among top 10 risk factors for diseases in developing countries (WHO, 2002). Micronutrient malnutrition affects around 66 % of the global population as stated by Stein *et al*., 2010. The mean zinc absorption below the physiological requirements causes stunted growth in children (Brown *et al*., 2002). Absorption of Iron and Zinc amongst children who were kept on only pearl millet diet was found to be above the physiological requirement of 0.54 mg/g and 2.5 mg/g in that order as given in the Food and Nutrition Board, 2001 (Kodakany *et al*., 2013). Zinc content is found to be highest in Proso millet and lowest in finger millet (Mounika *et al*., 2017).

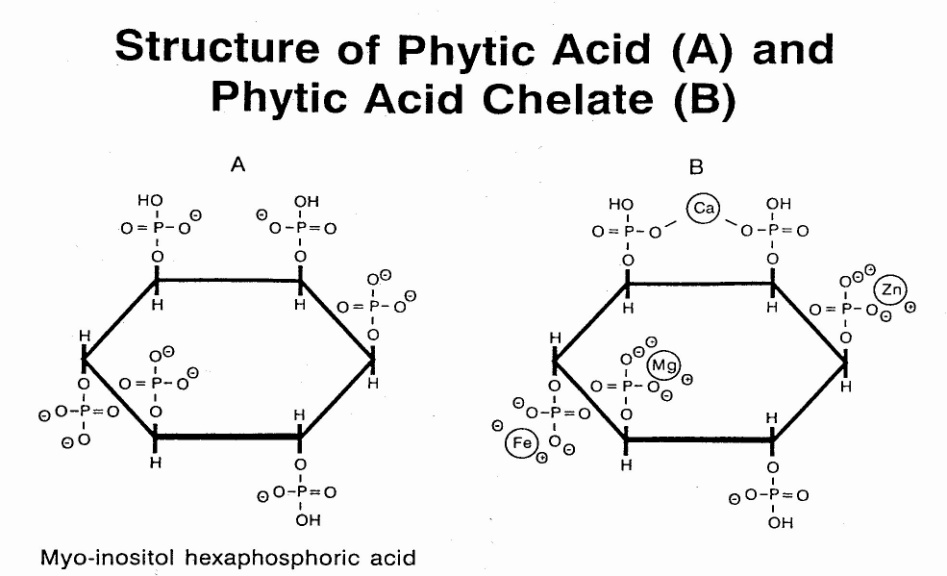
**1.5.6.3 Copper:**

As the millet grains are consumed as a whole and are only hand crushed compared to rice and wheat which are refined, the mineral content in millets is found to be high. However, the same is limited due to inhibition from inherent antinutritional factors. Soaking and germination help reduce these factors in millet grains (Jood and Khetarpaul, 2005). **Copper** exists in association with phytic acid in plant foods leading to its poor availability. Soaking and germination causes liberation of the copper ions (Hemalatha *et al*., 2007). Sorghum copper content was observed to be increased to an order of 2 from 0.19 mg/100g to 0.40 mg/100g after sprouting due to degradation in phytate, known to hold minerals into low molecules (Azhari *et al*., 2015). Bioavailable intake rather than the gross intake of minerals appropriately defines the method for assessing the food products. Agte *et al*., 1999 reported that percentage capacity of Zinc and Copper to separate by dialysis (also known as dialyzable Zinc and Copper) was found to be higher in rice (10.0 and 35.7 %) than in pearl millet (6.8 and 26.6 %) based foods, however, the total Zinc and Copper content in Pearl millet diets (3.1 and 1.06mg/100g) available for dialysis was up to 10 times higher than rice (1.4 and 0.14 mg/100g) based diets. The decrease in bioavailability of Cu in pearl millet may be due to binding with phytates and tannins whereas the gross high mineral content is due to the grain goiterogenicity (Abdel rahman *et al*., 2005). It was also found that the bioavailability of minerals including copper differs in composite meals as compared to the individual ingredients of the meal.

**1.6 Antinutrient Content in Millets:**

**Antinutrients** bring serious consequences by modifying nutrient availability (Abdel haleem, 2006). Millets consist of tannins (mostly found in finger millets (Ragi) and sorghum), flavonoids, phenolic acids (pearl millets, sorghum and finger millet) and alkyl resorcinol among the phenolic compounds and amides among others. These anti-nutrients are located mostly in the outer endotherm or the bran of the grain which gives the grain its colour. Waniska, 2000, stated that tannins help maintain the grain mould of millet and are a good source of anti-carcinogenic, anti-ulcerogenic, gastro-protective and cholesterol lowering contents. Derivatives of Benzoic (11-16) or Cinnamic (17-21) acid are majorly denoted as phenolic acids (PA) of Sorghum. Phenols maintain flavor, texture, color, oxidative stability and taste of food products as researched by Naczk and Shahidi in 2004.

Phytin or phytate is a form of phytic acid, obtained when mixed with magnesium, potassium and calcium salts in seeds. Comprising of 1-3% of legumes, cereals and oil seeds, it acts as a major storehouse for phosphorus (Graf, 1986). Phytic acid forms complex bond with calcium and protein, the latter being multivalent (Haug and Lantzsch, 1983). Protein digestibility and trace minerals availability is, however, reduced by this kind of formation. The structure of phytates is depicted in Figure 1.4 below. Finger millets consist of a considerable amount of Inositol Hexaphosphate (IP6) or phytates (contribution of 150mg/100g as given by Pragya Singh *et al*., 2011), an anti-nutritional factor affecting the assimilation of Ca, Mg, Zn, Fe, Cu and Mn. Phytates, otherwise, are responsible for chelating reactions forming iron catalysed hydroxyl radicals (Honke *et al*., 1998).



**Figure 1.4: Structure of Phytic Acid and Phytic Acid Chelate**

Out of all the phytochemical components in **Sorghum**, tannins have superlative importance as they consist of properties that generate viable and important factors in animal and human health. These viewpoints are explained by the harvest and genus of tannin sorghums. Tannins also reduce the feed value. They bind to nutrients resulting in loss of digestibility of different food/ feed kinds. They have better tolerance to pests and diseases and control the pigmented testa layers using B1 and B2 genes present in them. Tannins are structurally complex which make them hard to isolate and characterize in an effective manner. The shell of a grain, also called bran, consists of the highest percentage of sorghum PA in cereals. PA may be found bound or stuck to cell wall polymers as well (for example – extensively found bound PA in sorghum is Ferulic acid (18) (Hahn *et al*., 1983) and other grains (Nordkevist *et al*., 1984; Adam and Liu, 2002).

Phytates and phytic acids form complexes with the nutrients to decrease their bioavailability thus making their absorption difficult. Phytic acid found in **Pearl Millets** is considerably high with 825.7 mg per 100 g; bringing out a negative effect on its nutritional value (Kumar *et al*., 1993). The seed coat or endosperm demonstrate high antibacterial and anti fungal action due to the presence of high polyphenol content. Polyphenols hold the nutrients bound to them and the nutrients are, then, not bio-available. The nutrients held include minerals, for example, iron and zinc (Eyzaguirre *et al*., 2006). Antimicrobial and antioxidant activities are predominant due to the polyphenol content in pearl millet as given by Chethan and Malleshi in (2007).

**Foxtail millets** are rich in phytochemicals and antinutrients such as polyphenols (Tannins and Phenolic Acids) (0.052mg/100gm), flavonoids, flavones and phytates (1.94mg/gm). The presence of polyphenols is proved from the testa and the outer pericarp of the whole grain. These anti-nutrients cause lack of IVPD and availability of iron and zinc. The presence of phytochemicals in foxtail millets gives them the brand value of availability of natural antioxidants, thereby, enhancing their market potential.

**1.7 Processing of Millets to Reduce Antinutrient Content:**

Kayoed, 2006 and Steiner *et al*., 2007 reported that breakdown of certain nutrients such as phytate and protease inhibitors can be achieved by germination. Nayini and Markakis, 1983 discussed milling, Chang *et al*., 1977 described soaking and Vidal-Valverde *et al*., 2001 explained germination, which could lead to decreased phytate level in plant matter. Mahgoub and El Hag, 1998 reported that the natural fermentation of four sorghum cultivars namely Hageen, Fetarita Gezira, Fetarita Gadarif and Dabar, for 20 hours in Sudan, showed decrease in phytic acid content by 60 %, 58 %, 58 % and 57 % respectively. Whereas Marfo *et al*., 1990 found a 52 % loss of phytate in red sorghum variety. Malleshi and Desikachar, 1986 and Opuk *et al*., 1981 reported that phytic acid levels reduced in cereals which underwent sprouting.

Addition of malt has reduced phytate content in corn, as given by Fageer and Tinay, 2003 whereas Tangkongchitr *et al*., 1981b, described that denaturation and inhibition of phytase may occur during 48 hours of fermentation. Incubation, germination and fermentation with malt (Salunkhe *et al*., 1977), treating of sorghum grain with formaldehyde (Graf *et al*., 1982), strong alkalies (Chavan *et al*., 1979) and ammonia (Price *et al*., 1978) are a few methods which helped in reduction of tannins in sorghum. Butler, 1982 observed that major assayable tannins in sorghum were eliminated by 5 days of germination.

Dehulling of foxtail millet resulted in reduction of anti-nutrients by 41.49 %, while soaking resulted in stripping the anti-nutrients from the grain by just 3.75 %, whereas dehulling in combination with soaking and cooking resulted in reduction of polyphenols by 59.02 % and phytates from 1.94 mg/gm to 0.032 mg/gm. It also caused an increase in availability of minerals by 45 % and IVPD by 32 % (Pawar and Machewad, 2005).

**1.8 Effect of Processing on Millets:**

Millets such as sorghum and finger millets are still processed by traditional methods in dry regions of the world. The germ, protective pericarp and starch containing endosperm are three major constitutes which get affected by the processing methods (Eastman, 1980). **Malting** can be used to enhance the quality of millets. It also helps in formulation of complementary foods and infant diet. Soaking of millet and steeping process is often referred to as germination (Roohinejad *et al*., 2010). Soaking and germination brings about hydration of grains which leads to multiple accelerated chemical reactions. It helps in increasing the availability of minerals and breakdown of complex macronutrients such as carbohydrates, fats and protein (Mayer and Poljakoff, 1963). Bioavailability is increased for vitamins such as vitamin C, niacin and riboflavin (Lay and Fields, 1981).

One of the most valuable effects of germination is conversion of starch to soluble sugars. Amylase and amylopectin are the two enzymes which play a vital role in converting starch into dextrin and maltose (Seenappa, 1987). Germination of soybean and finger millet was studied by Magala-Nyago *et al*., 2005. They observed that soybean, when germinated for 72 hours at 25 oC showed increased beta carotene from 1102 % to 8316.9 % whereas finger millet showed a rise of 126.9 % for 48 hours of germination at 30 oC. Griffith and Castel-Perez (1993) studied the effects of malting and roasting on cowpea, peanut and pearl millet with respect to their physicochemical properties. They observed that malting has the most significant effect on the physiological properties. Reduction in viscosity of the flour is also brought about by malting.

Hasan *et al*., 2006, described that soaking and germination of pearl millet for different sets of hours led to improved protein digestibility and polyphenol, tannin, and phytic acid reduction. Naveeena and Bhaskarachary (2013) observed germinated millets and legumes samples, such as finger millet, sorghum, green gram dal, horse gram whole and others for 0, 12, 24, 48 and 72 hours and then analysed the samples for total polyphenolic content. They concluded that processing improved the bioavailability of proteins and minerals. Laxmi *et al*., 2015 studied the effect of malting on foxtail millet flour and concluded that malting increased the fibre, carbohydrate, moisture and protein content and availability of minerals. However, it reduced fat, ash and calcium content in foxtail millets.

**1.9 Health Benefits of Millets:**

Millets are coarse cereals, grown seasonally in India and have tremendous advantages in the health and nutritional field. Millets have an alkalizing food effect, and are a calming mood food (Sarita and Singh, 2016). Researchers have found these cereals to be giving favorable results in long term illnesses like cancer, type II diabetes, disorders of the heart and stomach. Millet flours are gluten-free, least allergenic and digest slowly and hence, are useful and highly recommended for consumption by diabetic patients in India. They are easy to absorb and do not cause any harm to the lining of the intestine.

Neutraceutical drugs benefiting human health are defined as the food components which support health and supplement dietary health benefits for prevention, treatment and cure of various cardiovascular and lifestyle diseases. Neutraceuticals are used equally in the food industry as well as in factories as pre-processors for the production of different nutrients. This proves them to be of dual benefit to the industry over and above the basic nutrition (Srivastava *et al*., 2012). Presently, finger and pearl millets are amongst the high potential neutraceuticals available in the market.

**1.9.1 Cancer:**

Frequent consumption of sorghum found low cases of esophagus cancer in Africa, India, Russia, China and Iran (Rensburg, 1981). Sorghum tannins and polyphenols (common in tannins and red wine, tea) were found to be anti-carcinogenic (Awika *et al*., 2003). Sorghum reduces the impact of cancer on human health due to its antioxidant characteristics. Finger millets are used in preventive medicinal health and have been advantageous in reducing fat content in diet and increasing dietary fibre thus preventing colon cancer as researched by Schatzkin *et al*., 2007 and Lattimer and Haub, 2010. Dietary fibre in finger millets further helps reduce constipation, prevents gallstone formation and intestinal cancer (Usha, 2004). Phytate constituents in finger millet reduce cancer risk. Pearl millets are used for curing high cholestrol and fat content, constipation, preventing diabetes, atherosclerosis and colorectal cancer (Mathangi and Sudha, 2012). Due to the unique, bound composition of phytochemicals in foxtail millets, they sustain stomach and intestinal reactions to arrive at the colon. This results in prevention of colon, prostate and other digestive system cancers (Suma and Urooj, 2012).

**1.9.2 Cardio Vascular Diseases (CVD):**

Consumption of whole grain sorghum has a positive cholesterol-lowering effect; it increases the HDL levels without increasing the overall cholesterol (helps reduce occurrence of Cardio Vascular Diseases) due to its composition of tannins, phytochemicals, phytosterols, policosanols and polyphenols. Hegde *et al*., 2002 confirmed that Vitamins A and B and phosphorous in finger millet help in lowering high cholesterol levels. According to Pradhan *et al*., 2010, patients with diabetes, heart disease or atherosclerosis benefit the most from finger millets as it lowers blood pressure and heart attack risk. The antioxidant activities in pearl millet help manage cardiovascular and geriatric diseases (Zhang and Liu, 2015). Foxtail millet has cholesterol lowering properties due to its high fibre content (Kusuma *et al*., 2013).

**1.9.3 Obesity:**

High percentage of tannins in sorghum has weight-reducing properties. This occurs when the nutritional value of the food is reduced by developing bonds with proteins and carbohydrates into insoluble composites which cannot be biodegraded into enzymes, thereby, increasing capacity of the grain to stay longer in the stomach (offer durable satiety value). Therefore, they are preferred over other cereals in certain regions of Africa by farmers, so that they don’t frequently feel hungry and thus allowing longer days at field (Rosemary *et al*., 2007). Jones *et al*., in 2000 elucidated the benefits of pearl millet in the treatment of obesity. Kusuma *et al*., 2013, stated that high dietary fibre content in foxtail millet results in smooth bowel movements, reduces constipation and complements digestion and thus is beneficial for weight-reduction.

**1.9.4 Diabetes:**

Diabetes mellitus is a non-communicable disease which is a result of excess or low insulin secretion and insulin action defects. It has multi-characters, which is, hyperglycemia, lipoprotein abnormalities, raised basal metabolic rate, defect in reactive oxygen species scavenging enzymes and damage to pancreatic cells due to high oxidative stress. As one of the threats for many nations, increasing incidence of diabetes has become major concern all over the world. Statistics suggest that by 2030 number of diabetic persons would reach to 87.0 million from 50.8 million in 2010, in India (Thilagavathi and Kanchana, 2017). Earlier this disease was considered as ‘Rich Man’s Disease’ in India but now it is predominant across all economic classes. India, which is now considered as ‘Capital of Diabetes’, finds itself second after china. By 2030, it is projected that diabetes can be sixth leading cause of death (WHO, 2017a).

Glycemic Index (GI) is a gauge of rate at which carbohydrate containing food raise blood sugar post two or more hours of food consumption (post prandial response) (Miller *et al*., 2003b). Diabetes is caused by genetic pre-dispositions, obesity and consumption of foods with high GI (Dias-Martins *et al*., 2018). Alpha glucosidase and alpha amylase are enzymes present in brush border membrane of small intestine. Alpha Amylase is responsible for hydrolyzing complex carbohydrates to oligosaccharides. Alpha glucosidase breaks down oligosaccharides, trisaccharides and disaccharides, that is, sucrose and maltose to monosaccharides which are glucose and fructose (Mclver *et al*., 2020). Controlling enzyme activity in intestine controls blood sugar levels. Reactive hypoglycemia is correlated with symptoms of weakness, nausea, perspiration, hunger, anxiety and tremor post 2 hours of meal intake. It is caused by rapid gastric emptying (Dumping Syndrome) or digestion of carbohydrates in intestine by breakdown of oligosaccharides into simple monosaccharides (sucrose and fructose) resulting in hyperglycemia and thereby having a rapid insulin secretion or response causing low plasma glucose levels (Sivakumar *et al*., 2012; Ozgen *et al*., 1998).

Use of insulin, glycemic drugs and dietary manipulation are major forms of treatment for diabetes. Primary prescription for diabetes is dietary manipulation by increased consumption of fiber, restricted carbohydrate-based diets and controlling intake of processed sugar in addition to physical exercise. Besides regulation by injection of insulin and drugs, the secondary way ahead for diabetes prevention and control is inhibition of glucose release using drugs (Tamura *et al*., 2006).

Acarbose and Miglitol are blood sugar level controlling drugs, both systemically absorbed and Miglitol has less absorption percentage per dosage (Schmeltz, 2007). Acarbose is a natural microbial complex oligosaccharide drug and an effective alpha-glucosidase enzyme inhibitor causing delay in breakdown of carbohydrates into sucrose and fructose, thereby controlling hyperglycemia or post prandial glucose levels. It also helps to control rate of insulin secretion followed by reactive hypoglycemia (Shibao, 2012). However, acarbose is not an FDA approved drug for type I diabetes mellitus. But it is a potential pharmacological choice to prevent pre-diabetes to type ii diabetes mellitus. Side effects of acarbose consumption include nausea and in the long term may cause carbohydrate malabsorption (Mclver *et al*., 2020). Acarbose does not cause hypoglycemia, however, if ingested along with sulfonylurea or insulin, blood sugar drugs, it may reduce glucose levels.

Millets are cereals with low GI (GI range<55mg/dl) and thus help control diabetes (Ugare *et al*., 2014; Vanisha *et al*., 2011). They, therefore, fall into primary mechanism of diabetes control by dietary manipulation. Low GI food has a virtue of slow rate of gastric emptying, slow digestion and intake of their carbohydrates in intestinal lumen leading to slow increase in insulin levels, slower rate of glucose absorption in portal and systemic circulation and thus, improve glucose tolerance. Therefore, satiety is increased and voluntary food intake is reduced (Bornet *et al*., 2007). Slow digestible starch in millets are attributed to their characteristics of amylose content, granular structure, amount and type of fatty acids (Oleic acid content) forming complexes with starch molecules, starch-protein-lipid interactions and high content of fibers (Annor *et al*., 2017). Millets and resistant starch apparently provide impetus to lower or delay health problems due to diabetes and also lower serum cholesterol levels (Ilamaran *et al*., 2017). Millets contain high insoluble fibers which cause gradual sugar release thus benefiting diabetic patients (Rathore *et al*., 2016). Magnesium increases efficiency of insulin and glucose receiving agents produce multiple carbohydrate digesting enzymes which control insulin levels and helps control Type II diabetes (Ambati and Sucharitha, 2019). As India is one of the major producers of millets, these traditional foods can form a good alternative source for replacing simple carbohydrates for diabetics.

**1.9.5 Antioxidants:**

Sorghum, finger millet, pearl millet and foxtail millet have high antioxidant properties naturally occurring in the grain aleurone layer, the endosperm and the bran layers. These natural antioxidant properties are attributed to the presence of polyphenols (Tannins and Phenolic acids), flavonoids and free radical scavenging activity in millets. The above reducing power assay of millets results in metal chelation, free radical termination, single-oxygen quenching and in decreasing the percentage of oxidative minerals such as iron. Antioxidants neutralize free radicals in the food, thereby, resulting in prevention of non-communicable diseases like cancer and diabetes (Hegde et al., 2005; Shobhana *et al*., 2007).

**1.9.6 Other Health Benefits of Millets:**

Sorghum consumption helps reduce Polycystic Ovarian Disorder (PCOD) in women (Klopfenstein and Hosency, 1995; Chavan *et al*., 2007). Sorghum also shows a protective effect on Red Blood Cells (RBC) by thinning of blood stimulated by tannins present in the grain and by preventing RBC hemolysis induced by hydrogen peroxide (Grinberg *et al*., 1997; Yang and Koo, 2000). Consumption of finger millets benefits in enhancing folate for child nervous channel defects as stated by Lumley *et al*., 2001 and Czeizel *et al*., 2013 and calcium for osteoporosis as given by Srivastava and Deal in 2002 and by Lanham- New in 2008.

Hadimani and Malleshi had researched in 1993 and Malleshi reported in 2005 that finger millet seeds meet the nutritional requirements and further enhance the therapeutic value of formulated foods. Its high protein content aids in building the damaged cells and tissues (Swaminaidu *et al*., 2015). Malted ragi flour is used for unaccustomed and new born foods, drinks and pharmacological preparations (Nirmala *et al*., 2000). Medicinally, finger millet is diaphoretic, diuretic and vermifuge. Hence, it is used as traditional nutritional supplement for internal treatment of leprosy, liver disease, measles, tuberculosis and pneumonia in the dry regions of India (Wyk and Gericke, 2000). Finger millets help avoid aging by decreasing the glycosylation of body proteins as per Doraiswamy *et al.,* 1969. Phosphorous, a major mineral in finger millets, is a critical component of Adenosine Triphosphate (ATP), a molecule also known as a body energy carrier. Therefore, phosphorous is critical for body cell growth, growth of bones, genetic codes (DNA and RNA). It regulates the metabolism of lipids (Fats) and Fat composition complexes like cell membrane and system of nerves. Containing high amount of magnesium, they help reduce migraine attacks and fight the severity of asthma (Dubey et al, 2013). Glew *et al*., 2008 suggested that amino acids in finger millet improve body health by formation of nitric oxide and growth hormone stimulation. Additionally, they curtail male infertility by improving sperm production and motility. Anti-inflammatory, anti-viral and platelet aggregation inhibitor benefits are add-ons with respect to finger millet. They help avoid life-altering allergies like Salmonella Tymphimurium and Eschericia Coli (Usha *et al*., 1998).

Digestive utilization in pearl millets is found to be high. It increases hemoglobin in the body by three times due to high iron content caused by iron balance and retention. Pearl millets are a rich source of iron and zinc which facilitates the growth and cognitive balance in infants (Eyzaguirre *et al*., 2006). The metabolized energy derived from pearl millets is high and approximately equals to that acquired from maize. Pearl millet is a high exothermic food with high calorific value and energy content. Thus, it is consumed during winters in the boiled form across India (Mathangi and Sudha *et al*., 2012).

**1.10 Utilization of Millets:**

Sprouts prepared out of **ragi/ finger Millet** is recommended for infants and elderly people for its calcium content which helps build bone density. Ragi is used to prepare local drink, ragi soup, in eastern state of Andhra Pradesh in India, which constitutes high calcium, vitamins and nutrient content for recovery of bones and tissues post work-outs. Sprouted finger millets are consumed as it is and, sometimes, ground into a flour to form baked items or flat breads (Bhakri).

In India, **sorghum** is used to prepare local delicacies like idli and dosa (steamed and leavened products, respectively) and thus helping in gaining brand value in the sorghum-growing central and southern states. Papads prepared from sorghum by drying in the sun may be a cheap, effective and durable (shelf life of over one year) manufacturing option for the Indian people, thus bringing in the regional strategy for food products prepared from sorghum (Chavan *et al*., 2015). Partial and/or complete substitution of other cereals by whole-grain sorghum may be considered in various baked food products including snacks and breakfast cereals. Sorghum usage improves phytonutrient content, dietary fibre and sensory properties. Pigmented sorghum (pigmented testa type of tannins in sorghum) provides a wide range of options in color and texture of sorghum products, thus making it commercially attractive (Awika *et al*., 2003). Sorghum is also used for generating animal feed. It is a component of alcoholic beverages and other secondary industrial products as well. A range of porridges, thick or soft, can be prepared from sorghum. Dibou or Oto or Oka-Baba as it is called in Bevin, Burkina Faso and Nigeria, respectively, is a concentrated sorghum porridge consumed during afternoon and night meals in the main course, served with okra or soup in a non-vegetarian dish depending on the financial capacity to spend.

**Sorghum** is used for extraction of starch by wet milling process to produce dextrose from it; later to be used in foods. It is used for cattle and poultry feed mainly in the United States. Juice extracted from the sorghum stem is an excellent source for production of sugar with 15–17% of saccharose. Sorghum can be used for production of snack foods and tortillas and noodles (Taylor *et al*., 2006). As given by NDRI news in 2011, iron and protein augmented biscuits can be prepared from lightened and germinated **pearl millet** flour, combined cereal flours and whey protein concentrate (Singh *et al*., 2006). More crunches may be added to the food when pearl millet grates and flour are used as an addition to it. Pearl millet is processed with other food items such as soya and protein rich ingredients, for example, legumes or groundnut cakes, to provide very well-balanced nutritional eatables (Malleshi *et al*., 1996). Indian traditional food-uses of pearl millet are characterized by cooking snack foods like noodles, papads, semiyan, laddoos (from popped pearl millet, as experimented by Singh and Sehgal in the year 2008) and daily meal food like chapati (Indian flat bread). Processed dried secondary food is cooked from composition of pearl millet, corn and whey – skim milk as given by NAIP, 2010.

With its hygroscopic properties upon germination, the pearl Millet grain has a contention for pasta production. Therefore, pearl millets are well-suited for bakery products (Rathi *et al*., 2004). Malting catalyses increase in Water Absorption Capacity (WAC) of pearl Millets which helps in preparation of chapatis as stated by Poongodi *et al*., 2009. Chapatis may be prepared after heat treating the pearl millet for better overall benefit and acceptability (Kaur *et al*., 2014). Iron-fortified processing increased the fat and carbohydrate content of the food by many times and the iron content found was 6.5 mg per 100g (Kaur *et al*., 2014). Laddoos and biscuits prepared using pearl millets were found to have more mineral (Calcium, Iron, Manganese and Phosphorous) content.

**Foxtail millets** are used in traditional food preparation in India. They are used in preparation of rice in North Karnataka to prevent and fight diabetes. Value-Added (VA) papad and timbittu were prepared from foxtail millets; their economical analysis for preparation and marketing was conducted by Kusuma *et al*., 2013. Due to their very low Glycemic Index and resistance to any kind of storage pests (high duration of storage –upto 60 days), they are ideally suited for preparation of VA products. Foxtail millet was used to produce biscuits and were successfully analysed for the nutritional and sensory properties (Anju and Sarita, 2010). On the other hand, constant progress is being achieved in standardizing the Ready-To-Cook (RTC), value-added food products from foxtail millet; indicated in recent studies undertaken by Prabhakar, 2006, by Manju *et al* in 2014 and by Aigal and Chimmad in 2017. RTC flakes prepared from foxtail millet had a higher water absorption capacity, low cooking time (only 32 seconds against 83 seconds for rice flakes), better consistency in cooking and a better nutritional composition when compared to rice and oat flakes.

**1.11 Gluten Free Foods:**

Gluten provides textural and processing qualities to baked foods. Gliadines and Glutenins are the two components of gluten. They provide elasticity and viscosity to the dough when mixed with water. Available gluten-based foods showed that there is difference in nutritional compositions when compared to non-gluten containing products (Miranda *et al*., 2014, Mazzeo *et al*., 2015). In recent years, gluten-free products are gaining popularity due to an increased incidence of celiac disease caused by gluten foods and awareness of gluten-free products. An increase in gluten-related disorders is also contributed by a new variety of wheat which is produced through mechanized farming and excessive use of pesticides (Volta *et al*., 2013). Low permeability of the gastric cells to proteins leads to gastric resistance thus developing celiac or non-celiac sensitivity in some individuals. Gluten ingestion is completely restricted in patients with celiac diseases. Common food products such as bakery products, biscuits, cakes etc made with wheat and wheat by-products are restricted for consumption by celiac patients (Lovis, 2003). Exclusion of gluten from diet helps celiac patients in remission of the disorder and when gluten products are reintroduced in their diets, the relapse of the condition occurs (Bernado *et al*., 2012). Celiac Disease (CD) is understood as a multisystem immunological disorder than a genetic one. Broad flat villi and intestinal cell abnormalities lead to indigestion of gluten included in the diet (Paulley, 1954, and Marsh, 1992). Research has shown that the prevalence of CD in children is 1.06 %, and in adults, it is 0.18-1.2 % (Barker, 2008, Fasano *et al*., 2003, Dube *et al*., 2005). The pathogenesis of CD exhibited the involvement of auto-antigen, interactions between intestinal epithelium and gluten peptides (Dieterich *et al*., 1997).

CD is also called Autoimmune Enteropathy. CD results in constant inflammation of the intestine and its degeneration. As cereals such as wheat, barley and rye which play a crucial role in daily diet contain gluten, it is difficult for patients with CD to go by gluten-free diet. Also, the available gluten-rich products lack important nutrients which lead to deficiency of macro and micronutrients. High level of fats in processed cereals account for other metabolic disorders. Gluten-free products often contain other ingredients which may complement the above benefits; awareness of these ingredients among patients is another important parameter to study. Hence, for a positive and healthy outcome, maintenance of a strict gluten-free diet is very essential. Use of millets has been increasingly on the rise in the development of healthy gluten-free products for a number of reasons. Sorghum has a bland taste, good starch properties and light colour. It is now being used in many-gluten free product formulations (Jonas and Dahlberg, 2004). Finger millets are not considered to be allergenic and are thus best suited for patients with CD being gluten-free. They are the most easily digestible grains due to their non-acid forming characteristics. Celiac patients, who are prescribed gluten-free diet, are helped by consuming pearl millets (Shahidi and Chandrashekara, 2013).

**1.12 Biscuits:**

Biscuits or cookies manufacturing is contributing to the fastest growing industry in the food processing sector. A turnover of around Rs. 3000 Crores is reported by Indian biscuit industries, which stands at the second place, after USA. The biscuit manufacturing industry is a part of the diverse Indian food market. Going by the production statistics in the biscuit industry, 60 % of the biscuits are produced in the unorganized sector and 40 % in the organized sector. In 1997, the equation suggested that the ratio of unorganized to organized sector was 66:34. However, in 2007, it shifted to 60:40 (NIIR, 2007). In developed countries, utlisation of biscuits is 10-50 kg per annum against mere 1-2 kg per annum in India. With the growing population and boost in the use of convenience food, a rising need for snack items has been felt. Therefore, with lifestyle changes and growing income, the biscuit industry is expected to grow by 25 % by 2020 (RNCOS – Indian food processing report 2006). Bakery industry stood third in generating revenue in the processed food sector thereby becoming one of the largest industries in the food processing sector (NIIR, 2007). Due to low cost, biscuits are treated as cheapest snack products for all socio-economic groups.

The bakery sector has also been making a mark in e-retailing. Hence, more international brands are interested in future investment in this sector. Abundant raw material supply, a larger target population and increased requirements for low capital investments are some of the advantages for investors to increase their interest in the Indian bakery sector (NPCS, 2012). Major biscuit brands in India viz Parle, ITC, Cadbury and Britannia cover around 75% of the total revenue in the biscuit sector. About 81 % of the bakery market accounts for biscuits and bread (Kumar and Kumar, 2016). Biscuit consumption was recorded at par with bread at 35%. Small scale production of bakery items has been largely accepted and adopted in India, especially in the unorganized sector. The availability of raw materials, comparatively easy manufacturing process and low investment in the production has been pivotal to the popularity of this sector. Urbanization and a booming domestic market compel new producers to invest here. Technological progress paves the way to and contributes for rapid improvement. Certain limitations still need to be addressed such as high purchase and packaging cost, taxation, national and international competition etc. Nevertheless, it has an immense scope to improve on various factors (Jegan, *et al*., 2013).

**1.13 Dough Rheology:**

Changing the original dimension by an external force is called deformation. The study of matter deformation/flow is called Rheology (Bourne, 2002). Unit for measurement of deformation in Rheometry is called Strain. The exerted force leads to deformation of the material and achieved deformation is, thus, measured. Classification of dough rheology in cereal research is divided into fundamental and empirical. Viscosity and elasticity properties are provided by fundamental tests. Fundamental properties are affected by the type of material and the type of ingredients. Hence, understanding the role of these materials and ingredients is an important part of the study of dough rheology to describe the end-product quality (Khating *et al*., 2014).

Bakery products have been successfully manufactured with the help of positive research in the field of deformation and flow behavior of dough. These studies have become central for continuous improvement of bakery products. Better understanding of factors responsible for dough rheology help in the formulation and manufacturing of new products during optimization stage and hence, result in consistent and innovative production. Bakery is an interdisciplinary field which includes many factors such as rheology, fluid mechanics, process engineering, polymer science, cereal chemistry and colloid science (Faridi and Faubion, 1990). Studying rheology is important to enhance efficiency of processes as well as quality of the food product. As the baking industry is becoming more and more automated, it is imperative that the science behind dough rheology is understood and applied.

During mixing, torque is applied on dough by the mixing blades. This torque is measured and recorded by using Farinograph. Farinograph is considered to be an important instrument in dough rheology because it estimates rheometry features such as water absorption, dough development and its stability. Farinograph results are used for determining dough consistency, processing and over-mixing. Even dough texture can be adjudged from the farinographic results (AACC, 2000).

Farinographic tests can be conducted in steps such as Absorption, Peak Time, Arrival Time, Departure Time, Stability Time and Mixing Tolerance Index (MTI).  Absorption defines water required for the dough preparation from flour so as to process end-products. Peak time, under standard conditions, is the time required for optimum mixing of dough from addition of water up till retention of dough maximum consistency. Arrival time is measured in Minutes. It expresses the rate at which the flour takes up the water. Dough consistency and beginning of the dough breakdown is measured by departure time (minutes). Dough strength equals to its consistency which the dough can maintain for a longer time. This period of consistency is expressed in minutes and is termed as stability time. During mixing, the degree of softening of the dough is indicated by mixing tolerance index.

Extensograph determines the gluten strength of the flour along with effect of additives and fermentation time on bread dough. When dough is stretched, resistance to certain dough parameters is measured and recorded by Extensograph. It is measured into various factors such as resistance to extension, extensibility, their ratio and area under the curve.  Resistance is the height of the curve and curve length describes extensibility. Ratio of resistance and extensibility indicates balance of dough strength and extensibility of dough before breaking (AACC, 2000).

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