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Exploration of millet models for developing nutrient rich graminaceous crops

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ABSTRACT

Protein-energy malnutrition and micronutrient deficiencies contribute to high mortality among considerable proportion of the current 7.2 billion global populations, especially children. Although poverty and diets poor in nutrition are prime reasons for prevalence of malnutrition, nutritionally dense crops offer an inexpensive and sustainable solution to the problem of malnutrition. Remarkably, millets are nutritionally superior to major non-millet cereals. They especially are rich in dietary fibers, antioxidants, phytochemicals and polyphenols, which contribute broad-spectrum positive impacts to human health. However, millets have received lesser research attention universally, and considering this, the present review was planned to summarize the reports available on nutrition profile of millets and non-millet cereals to provide a comparative insight on importance of millets. It also emphasizes the need for research on deciphering nutritional traits present in millets and to develop strategies for introgressing these traits into other conventional staple crops using germplasm and 'omics' technologies. In some millet species, excellent 'omics' and germplasm panels have started to get available which can act as a starting point for understanding as well as of introgressing healthful traits across millets and non-millet cereals.

1. Introduction

Malnutrition is detrimental to human development, and irrespective of several preventive measures to ensure proper nutrition and diet, the human race, especially children are suffering from severe malnourishment. Stunting and underweight are the two prominent outcomes of malnutrition. Noteworthy, globally 161 million and 99 million children under the age of five are estimated to be stunted and underweight, respectively [1]. The data also indicates that about half of these stunted and two-third of underweight children live in Asia, whereas one third of stunted and underweight survive in Africa (Supplementary figure 1) [1]. According to Black et al. [2], 50% mortality among children under five is due to malnutrition and a recent study on stuntedness shows that child malnutrition rate in India is the highest in the world [3,4]. The poor nutritional content of the major non-millet cereals consumed is one of the major contributors to higher child malnutrition in India [5]. However, the case of undernourishment pertains not only in India but also in other countries that consumes major non-millet cereals (like rice and wheat) as their staple food. In addition to being nutritionally poor, these non-millet cereals have higher glycemic index (GI) which rapidly increases blood glucose levels resulting in hyperglycemia upon consumption. WHO has predicted that 347 million of global population contract diabetes and of the two major forms, type 2 diabetes accounts for around 90% of all diabetes worldwide [6]. The recent reports, revealing the occurrence of type 2 diabetes in children and projection of WHO that the death due to diabetes would increase one-fold by 2030, demand an immediate requirement of nutritional as well as low GI foods. Though preventive measures have been taken to circumvent malnutrition and diabetes by providing supplementary foods, promoting immunization, and monitoring feeding and caring practices, equal importance should be given to introduce nutritious and low GI foods as well as to improve the nutrient content of existing staple crops. Thus the need for alternative food crops which adequately caters the nutritional requirements and lower GI to prevent diabetes emphasizes the necessity of millets.

'Millets' is the generic term denoting an extraneous group of forage grasses known for their small-sized grains. Millets are mostly cultivated in the semi-arid areas of Asia and Africa, and being C_4 photosynthetic crops, millets are known to be climate-change

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Table 1
Proximate nutrient composition of millets and non-millet cereals.

Grain	Composition (per 100 g grain) [17–19]							
	Protein (g)	Fat (g)	Ash (g)	Crude fiber (g)	Carbohydrate (g)	Energy (kcal)	Thiamin (mg)	Riboflavin (mg)
Pearl millet	11.8	4.8	2.2	2.3	67.0	363	0.38	0.21
Finger millet	7.3	1.3	2.7	3.6	72.0	336	0.38	0.21
Foxtail millet	12.3	4.3	3.3	8.0	60.9	351	0.42	0.19
Proso millet	12.5	3.1	1.9	7.2	70.4	364	0.59	0.11
Little millet	7.7	4.7	1.5	7.6	67.0	329	0.41	0.28
Barnyard millet	6.2	2.2	4.4	9.8	65.5	300	0.30	0.09
Kodo millet	8.3	1.4	2.6	9.0	65.9	353	0.33	0.10
Rice	6.8	0.5	0.6	0.2	78.2	362	0.41	0.04
Wheat	11.8	1.5	1.5	1.2	71.2	348	0.41	0.10
Sorghum	10.4	3.1	1.6	2.0	70.7	329	0.38	0.15

resilient crops as they could grow efficiently in minimal conditions of moisture, high temperature and soils with poor nutrients [7,8]. In addition, millets possess several salient features such as high nutritive properties, minimum vulnerability to pathogens and tolerance to drought and salinity [7]. Being the crops of shorter life-cycle, millets therefore are ideal staple crop for growing population. Millets are the members of grass family Gramineae, and are considered to comprise ten genera and at least fourteen species [9]. Of these, most important millets such as pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), proso millet (*Panicum miliaceum*), and foxtail millet (*Setaria italica*) belong to Eragrostideae tribe, whereas other minor millets namely fonio (*Digitaria exilis*), kodo millet (*Paspalum scrobiculatum*) and tef (*Eragrostis tef*) belong Paniceae tribe. In addition to the differences in tribe, genus and species, these millets differ in genome size, ploidy and chromosome number (Supplementary Table 1). Among the studied millets, foxtail millet has the smallest genome (~405.7 Mb; 2n = 2x = 18), whereas finger millet, 2509 Mb and pearl millet (~2450 Mb; 2n = 2x = 14) have the largest genomes [10,11]. The grain size and mass are also variable among the millets. Grains of pearl millet are relatively larger with an average thousand-seed weight ranging from 8 to 12 among germplasm accessions followed by proso millet (average thousand-seed weight ranging from 3 to 10 g), while foxtail millet has relatively small grains with an average thousand-seed weight ranging from 1.9 to 3.6 g [11].

Interestingly, genomes of these millets share a considerable synteny with non-millet cereals and bioenergy grasses since all these crops have evolved from a common Poaceae ancestor around 70 million years ago. Among these millets, foxtail millet and its wild relative green foxtail (*S. viridis*) were considered to be the model crops for studying the genetics and genomics of other millets, non-millet cereals and biofuel crops [12]. Considering this, the genomes of both the crops have been sequenced [13,14] and the availability of draft genome sequences has facilitated the large-scale development of genetic and genomic resources and demonstration of their utility in crop improvement [15].

Except foxtail millet and pearl millet, no other millets have been extensively studied and of note, the nutritional traits in these millets have not been systematically investigated till date. In this context, the present review summarizes the reports available on nutrition profile of millets and non-millet cereals to provide a comparative insight on the importance of millets. Further, the article also emphasizes the need for research on deciphering the nutritional traits of millets and to develop strategies for introgressing these traits in to conventional staple crops. In millets, which are genetically closest to non-millet cereals, the feasibility of transferring these nutritional traits through integrated 'omic' approaches is higher and the resultant nutritionally enhanced graminaceous crops would cater the nutritional requirements of humans.

2. Nutrient profile of millets

Millets in general offer highly nutritious, non-glutinous and non-acid forming diets, although foxtail millet and proso millet have both glutenous and non-glutenous type of grains [16]. They possess high levels of proteins, minerals, vitamins and antioxidants, which imparts nutritional superiority of millets over non-millet cereals, and for such reasons millets are called 'nutritious millets' or 'nutricereals' (Table 1).

In addition to their high micro- and macro-nutrient contents, millets also encompass enhanced levels of low GI non-starchy polysaccharides and dietary fibers. Among different starches, high amount of slowly digestible starch and resistant starch accentuates millets as ideal diet for type 2 diabetics [20]. The forthcoming sections describe the composition of important nutrients and minerals in millets.

2.1. Proteins

Proteins are polymers of amino acids linked together by peptide bonds. As a nutrient, proteins serve as the source of amino acids, especially the essential amino acids which the human body cannot synthesize. Grains of millets and non-millet cereals contain large amounts of storage proteins which are utilized after germination as a source of nitrogen during the initial stages of embryo development. These storage proteins are fit for human consumption and so, the levels of seed storage proteins (SSP) are nutritionally important. SSPs are broadly classified into four categories according to their solubility characteristics, namely albumin (water soluble), globulin (soluble in dilute salt solution), prolamin (soluble in alcohol) and glutelin (extractable in dilute alkali or acid solutions) [21]. Albumin and globulin constitute major SSPs in dicots, whereas higher amount of prolamin and glutelin are found in monocots [22]. In millets, about half of the total grain proteins is prolamin and these are of four types, namely alpha-, beta-, gamma- and delta-prolamins. Alpha-prolamins appear to be the major components in all millet species except fonio (*D. exilis*).

Comparison of proteins among millets and non-millet cereals showed that proso millet has highest levels of proteins (12.5 g/100 g), followed by foxtail millet (12.3 g/100 g) (Table 1). As of other non-millet cereals, wheat has a comparable level of protein (11.8 g/100 g) but rice comprised a much lower level of about 6.8 g/100 g. Further, wheat proteins are deficient in essential amino acids while almost all the millet proteins are reported to possess essential amino acids which are necessary for the prevention of protein-energy malnutrition (Table 2). A recent study on grain nutrient content in Indian cultivars of barnyard millet, little millet, finger millet, kodo millet and foxtail millet revealed that foxtail millet (cultivar 'RAU-8') had maximum protein (13.1%) in the seeds than other millets [24]. The analysis also showed that the levels of lysine (2.42 g/16 g N) and tryptophan (0.31 g/16 g N) were