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STATE-OF-THE-ART OF KNOWLEDGE ON UNDERUTILIZED MILLETS: KODO AND KUTKI, GROWN IN TRIBAL AREAS OF INDIA

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ABSTRACT

This review of literature aims to arrive at the state-of-the-art-of-knowledge on millets, starting from their farming to processing. Though research done on all types of millet is reviewed, here emphasis has been given to two varieties of millet i.e. Paspalum scrobiculatum(Kodo) and Panicum sumatrense (Kutki), widely grown in tribal areas in different regions of India. Why farmers over the years have shifted from growing millets and what technology-interventions need to be provided to them so that they start growing them again are the key points of focus, here. What all approaches and methodologies tried and tested by researchers to resolve challenges to meet desired results, would also be examined. The future course of actions and a path forward to facilitate farmers so that they adopt cultivation of Kodo and Kutki again has been prepared. This review has revealed certain specific gap areas, both technological as well as commercial, which would be necessary to bridge in order to make Kodo and Kutki to be preferred crops again. Designing new products based on Kodo and Kutki and making post-harvest management practices of these crops easier for their growers have been the key findings of this study. Once a number of products, of mass consumption, based on these millets, are introduced in the market and the consumers are convinced about their nutritional benefits, the demand for these millets will rise and as a result, farmers will find Kodo and Kutki as cash crops.

KEYWORDS: Kodo, Kutki, Nutrition, Processing; Shelf-life & Value-Addition

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Original Article

INTRODUCTION

In the developing world, hunger and poverty are the most challenging problems that remain unsolved despite the fact that there have been advancements in science and technology leading to multi-fold increase in the production of food grains. It is due to: a) urbanisation and industrialisation making population shift from villages to cities and b) land available for agriculture has reduced with time[1]. All these are interrelated and depend on each other. Unless problems associated with the so-called development and growth is resolved, sustainability of humans on earth will remain an issue of concern for policy makers, all over the world. Already, there is an excessive load on traditional agriculture products and hence, there is an urgent need of identifying the alternate source, mainly of staple food. FAO document,2017on trends of agriculture [2] in the world has clearly highlighted the urgent need for solving this. Countries like India which are dependent on agriculture to sustain their economic growth will have to make extra efforts towards that. Till the other day, 80% of the population in India lived in villages. Just in a matter of a century, the situation has changed for the worse because all that has been done in the name of development and growth has resulted little as far as the sustainable supply of quality food to all is concerned. Thus, policy makers in India will have to adopt novel approaches, never tried before and find alternative ways to deal with them.

India is known for its agro-biodiversity thanks to its climatic zones, availability of river water and fertile land [3]. Traditionally, millets were the crops grown across the country but with time, all that has changed, for worse! Millets belong to grass family (Poaceae) [4]. It may be noted that millets were never given as much importance as given to rice in spite of the fact that growing millets had several advantages such as: a) millets can be grown in regions that are of stressed-climate where soil is not so fertile, b) millets are a rich source of nutrients fibre and minerals, c) comparison to wheat which contains gluten, millets are gluten-free and d) millets are considered, traditionally, in different parts of India as superior to all other crops like rice and wheat [5]. This fact about the superiority of millets can is in fact a traditional knowledge passed from one generation to the other in different parts of India. In fact, for several health-related problems, millets are consumed in combination with certain select vegetables and other functional ingredients in different parts of India. For example, in the state of Rajasthan in India, there is not a single patient with diabetes and that is often ascribed to the fact that people in those regions consume food based on millets, throughout their lives, along with camel milk. This is something that cannot go unnoticed because of the reason that India has the highest population of patients of diabetics in the world. But, in spite of the fact that millets are climate-resilient as well as superior in terms of nutrition, there has been a trend of millets being replaced by other crops. This trend needs to be reversed, in order to achieve a sustainable supply of food for all and to address the challenges of malnutrition. [3]But it must be noted here that farmers will opt to grow millets as a cash crop, only if the latter becomes a major staple food accepted by masses. Efforts will have to be made to address all those challenges due to which farmers shifted away from growing millets [4].

Taking note of the FAO report of 2017 [2] where millets were stated to be vital for sustainable agriculture, the Indian government raised the minimum support price for millets by 50% and declared the year 2018 as the national year of millets [6]. Further, India took initiatives towards making other countries encourage farmers to grow millets; India got millets included in the program for adaptation of technologies for African agriculture transformation so that farmers of Africa preferred growing millets [1]. Accepting the proposal of the government of India, FAO declared the year 2023, as the international year of millets [6]. India is the largest producer of millets in the world but its cultivation has shrunk to only certain regions of Andhra Pradesh, Bihar, Chattisgarh, Gujarat, Haryana, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, Uttar Pradesh etc. This is so, in spite of the fact that millets need just 2-3 months' time span and required a minimum of effort for their cultivation. It is mainly because farmers don't find millets as a cash crop on the one hand and there are difficulties associated with harvest as well as the post-harvest management of millets [7-8]. In times to come, however, millets would have to be a preferred crop for farmers and staple food for masses [9]. Once that happens, the goal of making agriculture sustainable as well as eliminating malnutrition will be easily achieved. Therefore, the rise of multi-crop agriculture and settled farming societies will be the driving factors for millets to be in demand [5, 7]. The fact that millets are gluten-free grains besides being the power house of fibre, proteins, polyphenols and minerals important for enhancement of immunity [10,11]. It is known that certain specific millet crops are rich in vital nutrients making them a preferred choice for nutrient-related preparations [12].

Gluten-tolerance has been the major concern for health across the globe. Wheat, a staple crop preferred across the globe for almost all types of food of mass consumption is known to contain gluten, a type of protein which a significant part of the population is found allergic to! On the other hand, millets don't contain gluten and hence, nutritionists across the world recommend consumption of millets for those who suffer from gluten-intolerance. Recent trends in this regard indicate that the global demand for millets will rise. Countries which grow millets at large scale stand to gain from this trend as this will provide export possibilities especially to the developed world [13].

Since millets are C4 carbon sequestering crops,[3, 14-15]schemes such as PES (payment for environmental services) must be applicable to such crops because they give an immense advantage of reduction of carbon dioxide in the atmosphere, besides being saving water. In other words, millets have a very efficient photosynthetic system for capturing carbon dioxide. Benefits of growing millets are: a) improved carbon fixation in crops, b) concentration of heavier isotopes of carbon compared with C3 plants, c) more efficient carbon accumulation, d) improved water utilization efficiency (WUE), and e) higher yields. Moreover, all these benefits are derived from millet crops within a period of 4 to 6 months, in comparison to what most of the C3 plants are not able to do this even over a whole year. Therefore, millets will not only serve the purpose of attaining food security but they will also be helpful in eliminating malnutrition [15-18].

Production of millets in 2019 in India was ~10 million tons which was ~ 40% of the global share. Of this, the production of small millet is as high as ~50% of total millets produced [13, 19, 20]. Millets in India are cultivated as a dual-purpose crop providing both staple food for humans and fodder for animals. Kodo and Kutki are grown largely in Madhya Pradesh covering an area of ~1 million hectares, producing ~ 0.35 million tonnes. But why consumers shifted from millets to other crops overtime must be understood and kept in mind while targeting to exploit millets? What are the hurdles on the way in realising the value-addition in growing millets must be envisaged? This review, therefore, focuses on literature in following areas:

A) Varieties of millet and their nutritional composition, B) comparison of millets with other grains, mainly to understand the virtues of millets in comparison to crops like rice and wheat, C) reasons for the trend of shift from millets and ways to reverse this trend, D) technology-interventions for millet crops, so that farmers find it easy to be able to process them post-harvest, E) best agricultural practices for millets, F) value-added millet-based foods for masses G) export-potential of Millets, and H) path forward for millets.

A) Varieties of Millet and their Nutritional Composition

The leading types of millets cultivated are: *Eleusine coracana* (finger millet), *Echinochloafrumentacea*(barnyard millet), *Panicum miliaceum* (proso millet), *Pennisetum glaucum* (pearl millet), *Paspalum Scrobiculatum*(Kodo millet), *Panicum sumatrense*(little Millet) [20, 21, 22]. Different varieties (their common and scientific names) and regions where they are grown are presented in Table 1. Millets are divided into two main categories: major and minor based on their grain size. Kodo and kutki are the two largely grown varieties of minor millets, mainly in tribal areas of Madhya Pradesh and Chhattisgarh. Kodo millet is also known by other names: cow grass, rice grass, ditch millet, Native Paspalum, Indian cow grass, Kodra, Kodon, Harka Kodua, Varagu, Arikelu etc. Kutki (*Panicum sumatrense*) is also called as Samai and Mutaki [20, 21, 22].Kutki is an important crop of tribal agriculture also in Sri Lanka, Nepal, and Burma [16, 17].

Millet grains are composed of: a) an outer layer: "pericarp", b) inner layer: storage tissue and c) inner most part called as "germ" or "embryo". Based on their structural differences, grains are divided into two categories: a) utricles and b) caryopsis. In the utricle type of seeds e.g. in the case of finger millet, proso millet and foxtail millet, the pericarp is attached only at one point and that is why it breaks away from the seed coat or testa and as a result, it forms a strong barrier over the endosperm. The second category of seeds i.e. caryopsis type, pericarp is completely fused into inner parts of seeds e.g. in case of: pearl millet, fonio millet and Teff millet, Kodo millet and Kutki millet. In the latter type, it was reported that majority of the kernel weight comprised by endosperm. Grains of kodo are enclosed in hard, corneous, persistent husks and that is why, they are not easy to de-husk [20,21].

Table 1: Names (Scientific and Common) of Millets and Regions where They are Grown

Common Names	Scientific Names	Growing Areas
Pearl millet	*Pennisetum glaucum* *P. americanum* *P. typhoiides* *Panicum milaceum*	Africa, India
Finger millet	*Eleusine coracana*	Africa, India, China
Foxtail millet	*Setaria italic*	China, Near East, Europe
Fonio	*Digitaria exilis* *D. iburua*	West and North Africa
Little millet	*Panicum sumatrense* *P. psilopdium*	India, Nepal, Burma
Teff	*Eragrostis tef* *E. abyssinica*	East Africa, Ethiopia
Kodo millet	*Paspalum Scrobiculatum* *P. commersoni*	Southern Asia
Japanese millet	*Echinochloa crusgalli* *E. utilis* *E.frumentacea* *E. colona*	Asia

Kodo and kutki were reported [20-27] to contain:apigenin, kempherol, vitexin, isovitexin, leutolin, quercetin which were useful in preventing chronic disorders like cancer, diabetes etc. kutki millet was found to contain the maximum content (73.40%) of carbohydrates amongst all millets including kodo[18, 22, 23, 27]. Kodomillet was found to contain majorly glutelins as a storage protein, [27] which makes it completely different from other millets as far as proteins are concerned. Kodo millet was found to be having high amount of essential amino acids: lysine, threonine, valine and those containing sulphur such as cysteine and methionine [20-23]. Lysine content of kodo was found to be similar to foxtail millet and barnyard millet but it was higher than kutki and finger millet [27-30].

All millets were found to contain essential fatty acids like linoleic, oleic and palmitic acids in free form and some fatty acids in the bound form [22, 24]. Whole grain and decorticated forms are found to have similar trends in the ratio of oleic to linoleic in both forms. In kodo and finger millet varieties, eicosonic acid was found higher than lignoceric acid. In kutki millet, fat content ranged from 3.10% to 3.70% whereas in kodo millet, it ranged from 1.10% to 3.30%. Kodo millet was reported to contain fibre content (9.95 g/100 g) highest amongst all millets [29-31] and even higher than pulses like horse gram. Due to its high fibre(37-38%) content, products based on Kodo flour could be considered as functional foods as they exhibited lower Glycemic Index (55 to 60) than wheat (70) [9, 30-32]. Millets could meet the nutritional requirements of vitamins as they contain vitamin E and vitamin B-complex [30-32]but care must be taken as during the processing of grains, the vitamins could be lost. A study related to mineral content (Table 2) of millets revealed that even though all millets were rich in minerals(Na, K, Mg, Ca, P, Fe, Cu, Zn, Mn), certain millet types were found to be rich in specific mineralse. g. kutki and barnyard in iron (9-18 mg/100 g) and kodo in copper content (1.6 mg/100 g)[20, 29, 31]essential for sustaining healthy life. Because of high mineral content, millets exhibited higher ash content than most commonly consumed cereal grains including sorghum. Millets were also found to contain high content of phosphorus required in smooth functioning of the nervous system and cell membranes [21, 27, 28].

Table 2: Mineral Composition of (mg/100 g) of Different Crops

Minerals	Kutki Millet	Kodo Millet	Foxtail Millet	Barnyard Millet	Pearl Millet	Finger Millet	Wheat	Rice
Potassium(mg)	160	144	250	120	307	490	284	490
Sodium(mg)	8.1	4.6	4.6	5.7	10.9	49	17.1	5.7
Magnesium(mg)	139	160	81	82	137	201	138	64
Calcium(mg)	30	32	31	22	42	398	43	7.49
Phosphorus(mg)	260	188	300	280	296	250	357	160
Manganese(mg)	0.7	2.9	0.60	0.96	1.15	17.6	138	0.58
Zinc(mg)	3.7	0.7	2.4	3.0	3.1	2.3	2.9	1.3
Copper(mg)	1.0	1.6	2.4	0.60	1.06	0.47	0.68	0.23
Iron(mg)	9.3	3.2	2.8	18	8	15	5.2	1.25
Sources: Devi et al; 2014; Kumar et al; 2018, Saleh et al; 2013								

It is evident from this discussion that the nutritional composition of millets is good enough to qualify them as functional foods. The fact that constituents of millets vary from one variety to the other, consumers get a lot of choices to select the right variety of millet for preparation of foods with desired nutritional composition.

B) Comparison of Millets with other Grains

Indians, had knowledge, which they passed through generations, about functional and nutraceutical benefits of millet-based foods [29, 32-36]. Based on the experience of consuming millets, they believed that millets made them strong and healthy with high immune system. It is evident from an old Kannada saying which means: "Those who eat rice will grow as a light weight; their body being just like that of a bird; those who eat Jowar will become as strong as a wolf but those who eat Ragi (millet) will be the strongest of them all, plus they would remain free from any illness: remain 'nirogi' in Sanskrit!" Consumption of millets was the best; ancient Indians knew it well.

In a study, kutki, foxtail and barnyard varieties of millet were found to be rich in crude fibre (6.7% to 13.6%) and iron content (9.3 to 18.6 mg per 100g) as compared to cereals like rice, wheat and sorghum [24, 29-30, 36-37]. Large-scale prospective studies demonstrated the positive effect of dietary fibre on chronic diseases such as type II diabetes [24, 25, 38]cardio vascular disease and gastrointestinal cancer [37, 38, 39, 40]. Further, the presence of lecithin in millets was found to help in invigorating the nervous system [22]. Nutrients like niacin, B6 and folic acid, and minerals like calcium, iron, potassium, magnesium and zinc were reported to be present in significant amount in millets as compared to other cereals [20, 30-32].

Kodo millet was found to have the highest amount of bound polyphenols amongst all types of millet [11, 21-23]. Bound phenolic content of Kodo millet was reported to be higher than that of rice. This bound form of phenolic compounds was attributed to nutraceutical properties like antioxidant, anti-diabetes, anti-mutagenic and anti-carcinogenic [21-24,38]. Further, millets were found to exhibit antimicrobial, and antiviral properties with a potential to inhibit the growth of variety of disease-inducing organisms including HIV and influenza virus [38, 41-42]. The poly phenolics in millets inhibited amylase and hence, consumers could manage type 2 diabetes mellitus by adopting foods based on millets [38-42]. Behaviour of inhibiting amylase and glucosidase was just like that of medicines like acarbose, miglitol, and voglibose was ascribed to the presence of polyphenols in millets [41]. Further, due to high content of polyphenols (antioxidants), millets were considered as beneficial in protecting against oxidative stress while maintaining glucose levels in type-2 diabetes [41-45]. Kodo millet was found to have the highest activity of free-radical (DPPH) quenching amongst all millets. (91.67%) [43]. Studies on five healthy persons of the age group of 45–50 years proved that glycemic index of those consuming Kutki millets ranged from 35.20 to 57.20 whereas those who consumed rice it ranged from 65.2–75.25. This confirmed that because of the slow release of glucose from Kutki millet as compared to rice could benefit in controlling diabetes [38, 41, 45-48]. Subbulakshmi, [26] based on animal studies revealed that diet based on millets and leafy vegetables could control diabetes in subjects induced with alloxan, showing anti-diabetic potential of millets. Similarly, Rizkalla and Loromiguiere [49] observed that when fed with millet-based food, rich in fibre, the occurrence of diabetes mellitus in young adults decreased.

Consumption of millets resulted in low glycemic index as compared to rice [50, 51]. Daniel [52] isolated five anti-diabetic and anti-obesity compounds: quercetin (the major one), ferulic acid, p-hydroxybenzoic acid, vanillic acid and syringic acid from kodo successfully. Ferulic acid exhibited strong antioxidant, free-radical scavenging, and anti-inflammatory activity [43] and exhibited anti-cancerous and anti-tumor behaviour [43, 45]. Kodo millet was also found responsible for inhibiting diabetes-induced cataract (cataractogenesis).

A significant level of antioxidant and antimicrobial activity of kodo millet was reported [46-47]to be due to the presence of ferulic acid and cinnamic acid. Here it must be noted that the important aspect about nutrients in millets was not their presence but infact, it was about their bioavailability so that the potential of millets being functional foods could be exploited.

Presence of anti-nutrients like phytates and tannins were considered as undesirable for bioavailability of nutrients in millets [53]. Even high fiber content of millets was also assumed to be responsible for lower bioavailability of nutrients [26, 39, 48]. In order to derive maximum benefit from millets, as a potential source of nutrients, appropriate methods of processing including cooking were to be adopted [53]. It was found that germination could be one of the ways to achieve this; it increased bioavailability of micronutrients such as copper, zinc and manganese while reducing total phenols as well as other anti-nutrients [16]. Fermentation was reported as another method to increase bioavailability of calcium, phosphorous and iron while also reducing phytates [34, 36, 47 54-59]. After adopting appropriate processing technology, millets being gluten-free, could be made easy-to-digest and become the suitable replacement for wheat in different foods of mass consumption including beverages [60, 61].

C) Reasons for Shift from Millets and Ways to Reverse this Trend

Even though India is the largest grower of millets in the world, its production has been steadily declining over the years. Mainly because of their low yield and declining demand, millets were not considered as a cash crop. Farmers started growing wheat and rice instead of millets, while the consumers started preferring wheat or rice in foods of mass consumption [8]. Unless this trend is reversed, it will be difficult to ensure food security as well as sustainable supply of food with high nutrients for ever-growing population. FAO in its report of 2019, [1]highlighted the need to adopt climate resilient crops to address this challenge. It must be noted here that unless all reasons due to which farmers shifted from millets are understood and measures are taken to reverse this trend, desired outcome of all this will remain as a far-fetched dream.

Kodo millet was reported [62] to be prone to attack from mycotoxins leading to possibility of exposure to cyclopiazonic acid [63] which caused the grains to darken in colour and making them not fit for human consumption. Head smuts and Udbatta, common diseases that affect millets especially, kodo millet, transforming the entire panicle into a long sorus causing yield loss. In addition to these problems, non-availability of processing units in villages was another major reason due to which farmers lost interest in cultivating millets. Technology interventions for different levels of processing: primary, secondary and tertiary would have to be provided to farmers to motivate them to grow millets. For example, Kodo millet being the toughest to process, de-husking by conventional methods was not only tedious but it also required time; several rounds to de-hull it completely. Availability of state-of-the-art of equipment near farm level would be a must for this. It must be mentioned here that millets are grass-cereals just like rice and hence, infrastructure to process them must be put in place, on similar lines like that for rice.

In order to increase yield as well as to save them from diseases, research-interventions including molecular characterization (genome sequences and DNA markers) of different millets would be imminent. Availability of superior variety of seeds and rendering technical support related to selection of farm, crop pattern, crop sequence etc. would help inspire farmers to cultivate millets instead of other crops having high water foot print [64-66]. Millets could reacquire the status of a preferred crop [53], provided all types of technology and research interventions were rendered at farm level [66].

In an era of industrialisation, nothing would happen unless there will exist a market for it. Thus, efforts would have to be made to establish products based on millets like Kodo and Kutki replacing wheat and rice in almost all of the processed foods for masses. For this, actions would have to be taken on two fronts: a) designing new products incorporating millet flour or composite flour having millets in the recipe and establishing their consumer acceptability and b) setting up processing units to manufacture ready-to-use or ready-to-cook products based on millets [67-70].

From the discussion above, the reasons why growing millets is not beneficial for farmers can be listed as: a) diseases, b) difficulties faced during post-harvest processing, c) non-availability of infrastructure, in villages for processing d)fungal attack resulting due to contamination of mycotoxins e) non-availability of good quality seeds and f) poor demand for millets because consumers opted for foods based on wheat and rice.

It is evident that scientists must work on quality of production of seeds with good yield and those seeds should be supplied at the minimal cost to the farmers. Regular guidance on aspects such as line-sowing, space requirements and the depth of sowing seeds required for getting good yield etc. must be provided to the farmers. Identifying preferred varieties that are well-suited to the local conditions will be the key. Further, ways to value-add millets would provide a gateway of resource and revenue generation for growers. Imparting training on good agricultural practices to farmers for cultivation as well as for post-harvest management practices, particularly to the women, will help in raising production. Rendering post-harvest processing technologies along with support-based systems for their facilitation would motivate farmers for adopting millet crops. If tribal women are trained and involved in this process, it would also help in getting consumer acceptance for different types of foods based on millets.

Now a days, consumers have become aware of their health and they prefer to eat food that helps build immunity to fight against diseases [21, 71-72]. Hence, it will be easy to introduce foods, having high content of nutrients, based on millets. Another virtue of Kodo or Kutki due to which farmers would be keen to grow them pertains to the fact that these millets can be harvested during spare months in between the two major crops. Already, these crops are widely grown in tribal areas due to their tolerance for stressed conditions and there is no reason why they would not be crops of choice across the country once the essential post-harvest processing facilities are provided [72-74]. All this will ensure making millets as a profitable crop for farmers [68]on the one hand and virtues of millets for the well-being of humans would be exploited for the sake of eradicating malnutrition, on the other hand.

D) Technology-Interventions for Millet Crops

Millets are more like rice and hence, post-harvest processing techniques would have to be similar to that of paddy. Compared with wheat, processing of millets is not easy because of smaller grain size with tough coatings over them compared with former. Appropriate mechanised technologies will have to be selected and made available at farm level, for millets. For designing of suitable equipment for processing, not only for post-harvest but also for manufacture of food products, knowledge about physicochemical properties of millets will be the key for engineers as well as for food scientists and processors for exploiting nutrition potential of millets [72-77]. Details such as composition and basic structure must be known for deriving desired benefits of their functional properties from processes like parboiling, germination, fermentation or an enzymatic treatment etc. [50]. For example, fermentation of kutki millets was found to be useful for reducing anti-nutritional components and increasing bioavailability of minerals [52]. Hassan [59] inferred that among various processing treatments, germination followed by natural fermentation proved to be more effective.

De-cortication was found to affect content of various nutrients; decreasing some while increasing others e.g. increasing bio-accessibility of calcium, iron and zinc and decreasing anti nutrients [77]. De-hulling of grains (small size) of millets could be done with ease if prior to decortication, hydrothermal treatment was done; this hardened the grains, facilitating removal of husk of grains [75-76, 80]. Hydrothermal treatment of millets was reported to register better milling yield, if conditions of pressure and temperature were controlled well [78-79]. An increase in shelf-life of millets was observed when after thermal processing grains were kept in suitable packaging material under controlled conditions so that there was little loss of thermal-sensitive nutrients [78-80].

Blanching, malting, dry heating, acid treatment, popping, etc., as reported by Duodua [79], were found to be beneficial in reducing anti-nutritional contents and improving digestibility of millets. Roasting or popping for a short time period with hot sand, as a heat transfer media, caused: a) gelatinization of starch, b) elimination of anti-nutrients and c) burst-opening of endosperm rendering highly desirable flavour and aroma and that was the reason as to why it was considered as an important technique for value-addition of millets [77, 80-82]., For ready-to-eat food at commercial level could be easily adopted for utilizing millet grains [21, 26, 83-88].

Different technologies have different implications and depending on requirement a suitable technology can be adopted. During malting process enzymes got activated and this in turn led to conversion of starch to fermentable sugars and also partial hydrolysis of proteins, thereby increasing the bioavailability of minerals like vitamins B, C, while improving sensory attributes too [81]. Germination caused reduction of anti-nutrients such as phytic acid, tannins, and polyphenols, thereby improving protein digestibility [54]. Reduction in content of protein and fats, on germination, was due to the fact that nutrients of the grain were consumed for sprouting and for enzymatic effects like hydrolysis of lipids and oxidation of fatty acids Availability of minerals was also found to increase, thanks to the rising phytase-activity, during germination [56-57].

One of the technologies that has come to prominence, in recent times, is radiation processing. On irradiation of grains of Kodo and Kutki, at the radiation dose of 5kGy to 10kGy, using gamma radiations from Co-60, as the radioactive source, it was established[89] that the de-husking of these millets became much easier. On irradiation, the husk could be easily removed and that means there was no need of any tedious and time consuming manual process followed traditionally by farmers. Moreover, the shelf-life of irradiated flour was enhanced significantly. Since gamma irradiation technology does not employ any electricity etc. it is also termed as a green process technology [90]. By this research, it is established that this green process could make life much simpler and easier for farmers if rendered at near their farm level. Furthermore, on gamma irradiation, it was also shown[91], that the germination of grains also improved besides the de-husking becoming easier. Hence, irradiation of millets can also be considered as one of the options of technology-intervention that policy makers could provide to growers of these crops.

Similar notable studies in this regard include that of Mustapha [92]who reported that by gamma irradiation, shelf-life of food products could be enhanced. Gamma irradiation could be used therefore, as a safe post-harvest method for shelf-life enhancement, as also revealed by Mahmoud and other researchers [92-95]. Food irradiation has two main benefits to the health and well-being of humans: i) destruction of certain food borne pathogens, thus making the food safer; and ii) prolongation of the shelf-life of food by killing pests and delaying the deterioration process [95], thereby, saving food from losses due to insect infestation etc.

Foods with desired functional properties, for mass consumption, based on millets could be designed using extrusion technology as it helped breakdown of high molecular weight of secondary compounds into their lower homologues having higher bio-accessibility [77, 81, 83, 84]. Of late, in southern regions grains are parboiled prior to de-husking and this has helped in the removal of husk easier. But there is no full information available related to pre-treatments required before de-husking for different millets like kodo and kutki as it is quite tougher to remove their husk easily. Hence, different treatments need to be optimized and standardised for de-hulling of kodo and kutki with ease, as traditional methods involved laborious processing operations. By popping, ready-to-eat food, of high nutrition, with improved taste, flavour and protein digestibility can be rendered to consumers [86, 88].

E) Best Agricultural Practices for Millets

Grains of kodo millet are the hardest amongst all small millets and that is why they could survive in harsh conditions; shallow as well as in deep soils and water-logged soils. Kodoseeds could remain dormant for years until they are brought under conditions favourable for germination. Because both kodo and kutki are known to have shallow root system they would be ideal for intercropping as a subsidiary crop besides being grown as a main crop. Moreover, due to their short-cropping period, they could fit well in the intercropping pattern.

In Madhya Pradesh, several combinations of crop sequencing were popular as a sustainable system of agriculture e.g.kodo millet–soybean and kodo millet-niger-kodo millet in rotation with horse gram every two years [64, 65].In several other places, crop sequences such as kutki millet-niger or kutki millet-mustard were also considered productive as it helped in retaining soil fertility by holding nutrients.

Soil pH plays a key role in agriculture; depending upon the pH of soil, which crop can be grown there is decided. It’s not common that crops can tolerate stresses due to pH variations in soils. Wheat and rice, grown the most in the country are quite sensitive to soil pH; high acidity ($<$pH 5.5) and high alkalinity (pH $>$8) soils would not be suitable for them. Even though the ideal pH to grow millets is 5.5 to 7.5, certain millets can tolerate pH as low as 4.5 and as high as pH 9.5. Thus, millets were described as those rare crops which could tolerate stresses due to wide variation (4.5 to 9.5) in pH of the sandy soil [65]. Millets therefore can be grown in soils which are considered not suitable for wheat or rice. It directly means that the land considered useless for growing rice and wheat could be utilised to produce millets; food of high nutrition. Will it not be a big boost to efforts towards attaining food security? Similarly, tolerance to drought conditions including high temperature is low in case of other food grains but millets can be grown in such climates [15, 96]. The examples of Madhya Pradesh and Andhra Pradesh can be a useful reference, in this regard. In both these states, area under cultivation of small millet registers the highest production in India in spite of the fact that there was inadequate irrigation and not enough fertiliser was used. What is required the least for desired results is: an improved variety of seeds, timely tillage, sowing, weeding and inter culturing etc. But if that is also not available then it would be the waste of resources and efforts. An improved crop management practice is another concern that must be addressed so that farmers feel motivated to adopt cultivating millets. What can be concluded from this discussion is that since millets can tolerate acidic as well as basic soils, they will help have potential to balance pH of soil; convert acidic as well as alkaline soil into near neutral so that other crops can be grown later. In fact, this has been the common practice in different regions of India. This means that it will be an advantage from the point of view of recovery of soil fertility by way of pH correction done by growing millets in between the other crops.

F) Value-Added Millet-Based Foods for Masses

Millets are not only known for balancing pH of soils but they are also known to balance the pH of human body; diets of alkaline pH are recommended to achieve optimal health. Millets were reported to be conducive to enzymes, due to their alkaline nature and hence, considered good for maintaining healthy pH balance in the body; crucial for prevention of illnesses. [11, 21].Different types of foods are being designed incorporating sufficient quantity of millets along with other grains to introduce alkaline-forming foods recommended for well-being of consumers. Millets are also referred as soothing food mainly due to their alkaline nature [84, 85, 87]. This means millets are not just staple food of high nutrition but they can also value-add foods based on other grains when used in combination [97-99].

A large number of foods of mass consumption were designed [32]incorporating composite flour based on kodo and kutki millets. All these products were subjected to large scale consumer acceptance tests especially using sensory evaluation methodologies. It has been encouraging to see the overwhelming response of consumers asking for different types of foods based on kodo and kutki. Besides the sensory preferences that they showed for these products, once the consumers were told about the nutritional aspects of these foods based on kodo and kutki, they got inspired to adopt them.

Blends of different flours, based on the requirements of the food products to be made, for example to improve nutrition level as well as taste are called composite flours. Blends of different flours having millet flour were studied for nutritional enhancement characteristics [26 86-87]. Incorporation of millet flour was found to raise nutrient density and thus, improved the resistant starch content of composite flours [100-106]. For Bakery products, gluten is very important as it renders elastic and extensible properties to dough. Because millets don't contain gluten, their dough is not easy-to-handle and hence, manufacturing bakery products based on millets alone is a challenge; addition of wheat flour is essential for that purpose. Blends of flours of millets and wheat will prove to be synergistic; deficiencies of millets e.g. low specific volume, height to width ratio and sensory quality of bread will be taken care of. Studies showed that bakery products made by incorporating millet flour were found to have consumer acceptance [53, 95, 105]. Biscuits made with composite flour of soy and millet (Kodo and Kutki) having as high as 90% fraction of the latter could be easily prepared but biscuits made with 70% of Kutki were found to be the best during sensory evaluation [76, 88]. Mamata [78]showed that incorporation of 30% of Kutki flour bread of acceptable quality and functional properties could be prepared. Recent studies [100, 105-106] showed that different type of biscuits could be prepared from composite flours. Thus, a variety of bakery products, prepared by using kodo and kutki would not only render high nutritional products to consumers but it would also be a perfect option of value-addition.

Blending millets with grains of wheat, rice, corn etc. to modify existing foods to increase the functional properties and nutraceutical aspects would be a real value-addition for the former [106-109]. For example, foods based on millets were found to minimise oxidative stress while keeping sugar level of consumers with Type II diabetes mellitus under check [97]. Due to lack of knowledge and pre-processing facilities, millets are being utilized for feeding birds, as animal fodder rather than to be adopted them fully as human feed. Wasn't it strange that millets, in spite of being rich in nutritional properties like minerals, phytochemicals, polyphenols, dietary fibre content and which could prevent lifestyle disorders were not exploited to their fullest potential [21]. Amutha [58] reported that composite flour consisting of soy and millet (kodo as well as kutki) registered increased characteristics: spread ratio, percent spread factor, weight, density and moisture content, as compared to soy flour and hence, were found suitable for making biscuits. It was also observed that content of millet in composite flour affected colour of biscuits; raising kodo, decreased yellowness index and increased whiteness index whereas in case of kutki yellowness index increased and whiteness index decreased. Chakraborty [76]prepared composite flour blends of refined wheat flour with varying content of millet starting from 3.2% to 36.8% to make biscuits by baking for varying: time (3.3-6.7 min) and temperature (166.6–183.4°C), following observations were recorded: a) with increase in millet content, hardness of biscuits increased b) for desired hardness and cutting strength, optimisation of baking time was a must and c) for desired crispiness, optimisation of baking temperature was required. Bread made with composite flour having kodo in it was found to be superior in terms of contents of fibre and antioxidants as compared to commercial wheat bread [58]. Chandrasekara [23-24] reported high phenolic content in millets and Amutha [58]developed breads of superior quality in terms of nutritional value and anti-oxidant property, using composite flours having millet (kodo millet and kutki) upto 20 % level. Karuppasamy [108]reported breads made from composite flour with incorporation of millet to the level of 20% were found to be highly acceptable in terms of sensory characteristics. Breads made with millet contained higher content of fibre and minerals than the breads made with refined wheat [18]. Composite mixes containing: 80% millet (Foxtail or Kutki), 10% black gram and 8% spices with hypoglycemic character were designed for diabetics and when evaluated for their shelf-life, mixes stored in sealed packages were okay up to 165 days; even better than unsealed aluminium container. Therefore, the sealed package offered better suitability for storage of millet. Composite flours were found to be better than their individual components e.g.wheat and millets, and therefore, they are considered as perfect options for value-added preparations. By adopting popping techniques that brought desired changes in starch-protein matrix of millets, several products could be designed, with, unique textural attributes, acceptable to consumers [86-88].

In recent in-vivo studies on wistar rats [38]it was established that the rats, induced with diabetes, when fed with diet based on Kodo and Kutki, their metabolic system underwent significant changes. Infact, the effect of diet based on these millets was so pronounced that the rats fed with that diet got rid of their diabetes and behaved better than even the rats treated with anti-diabetic medicine.

By cold extrusion, [76-77, 99] products like pasta could easily be prepared within a few minutes. Several products like jaggery laddoo with good sensory characteristics are already in use in certain regions of India. Similarly, fortified-khichdi made of millet grains plus green gram was found to be the best from aspects of nutrition and sensory [68]. Application of shearing by the rotating screw, under high temperature for a small period of time could make convert millets into superior quality product in terms of, increase in *in vitro* protein digestibility etc.[79, 90]. Using the same technology of extrusion cooking, weaning food with increased bioavailability of minerals such as iron, calcium etc. could also be prepared [69]. Millet-based extruded snack foods prepared from blends of Kodo millet and chickpea flour blend (70:30) [80, 99] were found to be acceptable when evaluated for sensory characteristics.

Fermented products are known to be good for the gut and are easily digestible. They are consumed during breakfast time like Dosa and Idli in several regions of India. Fermentation process enhanced protein value as well as minerals in addition to enhancement of taste for millet-based products [36, 48, 56, 57, 59]. Infant foods based on millets could be designed by adopting the process of malting which resulted in enrichment of nutrient composition [77]. Composite flours containing ~30% of Italian millet in combination with different other grains were found to be appropriate for designing weaning foods meeting sensory requirements, adopting malting and roasting techniques for preparation [69, 98-99].

Fermented form of Kodo, called with a local name ‘Kosna’ is considered as a value-added product consumed by masses. A recent study on optimisation of process parameters for open and closed fermentation of millets in order to minimize anti nutrients [98]will be useful in designing fermented products based on millets. Process optimization for the development of a synbiotic beverage based on lactic acid fermentation of nutricereals and milk-based beverage was made [109-110].

Other value-added products such as laddoo and pudding made with Kodo and Kutki are also popular in tribal areas. With 100% millets, making bakery products may be a challenge, but products, such as peer and porridge can be easily made. Amongst different type of products of Kodo and Kutki, the most liked ones were malted health drink of Kodo and sweet ball of puffed Kutki [94]. Being rich in phyto-chemicals, millets were described as having huge potential to serve as functional foods for enhancing immunity besides being safe for gluten-allergic consumers [60-61]. As millets are rich in fibre content and support healthy gut micro-flora imparting prebiotic properties, they could also be used to design products for preventing constipation and other digestive disorders [57, 98, 102, 109-110]. Millets were considered as an important constituent for fortification of various foods designed to serve the purpose of eliminating nutrient deficiencies, especially for vitamins and minerals [100, 103, 104].

Kodo millet was consumed by tribes, as a staple food, in the form of a popular preparation called "paye",a product similar to cooked rice. That is why, it is also known as Kodorice. Popular products e.g. noodles, rusk, dosa and chapatti could be designed using composite flour having millet flour as one of the major components [33, 88]. It was found that pressure-cooked products of Kutki millet were reported to exhibit greater oil absorption capacity and swelling power; indicating larger α-amylase activity. Similar results were reported for Finger millet [80=81, 103]. All types of products of mass consumption: baked, fermented, germinated, extruded etc. could be made with composite flours starting from 30% to as high as ~100% of Kodo flour [86]. For realizing the potential of Kodo millet, the future agenda would be to have all such products made available to consumers at commercial scale leading to rising demand for Kodo millet; a reason for farmers to adopt cultivation of resilient crops [80].

Kutki millet is known for its longer shelf-life with little damage due to pests etc., during storage because of its grain texture and hard seed coat. Even though hard seed coat is a virtue, from the point of view of their longer shelf-life, it presents the challenge to farmers as processing millets is a challenge. Moreover, shelf-life of flour of millets is poor in comparison to that of wheat. Devi [46]conducted shelf-life study on ready-to-eat pasta and recommended that for ready-to-cook pasta product, low density polyethylene (LDPE) is suitable packaging; pasta (made from blend of kodo and wheat in 60:40% ratio) could be stored on shelf for 3 months without appreciable quality deterioration when packaged in LDPE. Kavita [50] reported that kutki millet could be processed into flakes with good shelf-life and several benefits such as medium glycemicindex, convenience while cooking and free from trans fats.

G) Export-Potential for Millets

Amongst the developing countries, India has taken lead also in identifying the export potential of millets. It is evident[111] from the fact that an agency(Agricultural and Processed Food Products Export Development Authority)of Government of India has collaborated with agencies i.e. Uttarakhand Agriculture Produce Marketing Board and Just Organic of the state of Uttarakhand in India mainly to put focus on exploiting the opportunity of exporting millets from this Himalayan region to different countries of the developed world. It was considered as a major boost to exports of organic millets from the Himalayan region of India to Denmark when recently, a consignment was dispatched to that country. Infact, APEDA has been preparing an action plan for increasing export of millet as well as various products based on millets for a period of five years (2021-2026). APEDA has been working very closely with all concerned stakeholders for taking necessary action in a time bound manner for achieving the target as per the statement from the commerce ministry of Government of India [111-112].

In order to be able to succeed in their mission, APEDA would involve: a) National Institute of Nutrition for getting the necessary technical support for the purpose and b) Farmer Producer Organizations (FPOs) so that they get involved in the process of ensuring that the products of desired quality are produced as per the targeted time lines. In order to achieve its objectives, APEDA would identify “millet clusters’ and create a platform to consolidate farmers, FPOs, exporters, associations and other stakeholders, required to make success of their plans.

This is just one case to demonstrate that there exists export-potential for millets and the importing countries would be largely from the developed world. But looking at the list of top ten exporting countries of millets, one would find that the USA is on the top followed by India. Here, it must be noted that India is the largest producer of millets in the world but it stands behind USA when sees the export of millets. The advantage with India is that there exists ancient knowledge base about different types of products made out of different varieties of millets. Moreover, almost all types of millets are grown here in India. If India can succeed in making their farmers to adopt growing millets again, it would be a boon to sustainable agriculture at global level because one fifth of world’s population lives here. Further, with the experience and knowledge-base on millets, India could play an impactful role in ensuring a sustainable supply of nutritious food for masses also in other developing countries, especially in the African region.

What is notable from the data about the top ten importing countries is that most of them are from the developed world, except Indonesia which is the largest importer of millets in the world. All other countries importing millets are majorly from the developed world. Hence, there exists an opportunity for developing countries to export millets to the developed world.

Looking at the report on Export-Import of millets [13, 111], it is evident that India dominates global production. As per this report, the global millet production was estimated at 27.8 million ton. India is the largest global producer with a 41.04% global market share. In the last two decades, even though the awareness about the importance of millet as food staples has risen, particularly in India, its consumption has yet to register a steady growth. More than 50% of millet production is currently finding its way into alternative uses as opposed to its consumption only as a staple. This is what has to change. As far as the consumption of millets is concerned, as per this report, countries from the African region lead in global consumption. More than 40% of global millet consumption is held by African countries mainly Niger, Mali, Nigeria, Burkina, and Sudan. Millets are popular in developing regions, like India and Africa, where food and nutritional security are the major challenges. The high drought tolerance capacity of the crop allows it to be cultivated in the adverse environmental conditions of the regions. India is the world's leading producer of millet and if India and African countries cooperate in the area of Millets, it would benefit the mankind.

H) Path Forward for Millets

Focus on indigenous plant resources [102]would be the need of the hour for food security. Instead of wheat and rice, climate resilient crops like millets would have to be the crop of choice. Millets have nutraceutical properties as they are rich in antioxidants, polyphenols, phytochemicals, dietary fibre etc. which may prevent from several health disorders. Studies reported in literature that consumption of millet grains and their products helped in reducing risk of chronic diseases like diabetes, cardiovascular disease, cancer etc. Small millets have the potential to improve food security, health, income, livestock production, diversifying agriculture, supporting traditional farming systems and overall support for farmers having marginal land holdings. Small millets are environmental-friendly crops and are much more tolerant to biotic and abiotic stresses compared to major crops such as maize, wheat and rice. Adopting millets is the need of the hour for sustaining future of agriculture and for eliminating malnutrition.

Keeping in view of all the benefits rendered by kodo and kutki millets, consumers are made aware about benefits of incorporating millet in their daily diet. Nutritive potential of millets in terms of protein, carbohydrates, and energy values are much more than the popular cereals such as rice, wheat, and barley. Dietary modification by increasing the consumption of millet grains daily would be a must for consumers in order to reduce the risk of chronic diseases. It is necessary to provide technological support to increase production and reduce the cost of production. Processing techniques, machinery and standardization of products etc. should be the areas where farmers would need support. Many processed products need to be optimized to give proper benefits to the consumer. Millets must be the part of subsidized public distribution system (PDS) with minimum support price in regions of their availability. Such a policy would also strategically address the food and nutrition security of the poor. Government policies need to be reframed in this very sense, so that farmers become keener on these crops to work upon. Additionally, mid-day meals and other initiatives will boost them to glow all the nations with healthy peoples that contribute more significantly in their nation's development.

CONCLUSIONS

This article presents a fairly up-to-date account of the research carried out on various aspects of millets. Based on the results of studies carried out, following conclusions can be drawn: i) millets contain many health-promoting components such as dietary fiber, minerals, vitamins, and phytochemicals that include phenolic compounds, and they are better than major grains; ii) millets have potential to be functional food, thanks to presence of nutraceuticals; iii) novel processing and preparation methods are needed to enhance the bioavailability of the micronutrients and to improve the quality of millet diets; iv) research is also needed to determine the bioavailability, metabolism, and health contribution of millet grains and their different fractions in humans; v) making food products based on millets that deliver convenience, taste, texture, color, and shelf-stability at economical cost for poor people needs to be the priority, vi) promoting millet grains to markets in urban areas will drive farmers to grow millet for better income; vii) cultivation and consumption of these crops will have to be promoted to benefit climate resilience, nutrition, food security and income of farmers; viii) millets must be exploited as source of micronutrients like B-complex vitamins and minerals to address malnutrition; ix) efforts should be made to make processing of millets easy by rendering technological support to farmers; x) while the under developed and developing countries see millets as a cheap source of nutrients, countries in developed world see millets having great potential in production of biofilms and bioethanol. This is a perfect case where food versus fuel or food versus packaging conflict will come into play. It will be better if further value-addition possibility is searched through research and innovation to avoid this conflict of food versus other materials!

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The authors declare no conflict of interest.

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