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A commentary on millets for enhancing agri-economy, nutrition, environmental, and sustainable development goals

Roger Clemens[a*], Paruchuri Gangadhar Rao[b], Ismahane Elouafi[c], Ruth Oniang'o[d], Anoma Chandrasekara[e], Peter Pressman[f] and Jay Yadav[g]

[a]Department of Regulatory and Quality Sciences, University of Southern California, United States
[b]Council of Scientific and Industrial Research Development Group, New Delhi, India
[c]FAO Chief Scientist, Rome, Italy
[d]Rural Outreach Africa, Nairobi, Kenya
[e]Department of Applied Nutrition, Wayamba University of Sri Lanka, Sri Lanka
[f]Department of Sociology, University of Maine, United States
[g]Department of Biotechnology, Central University of Rajasthan, India
[*]**Corresponding author:** Roger Clemens, University of Southern California, United States. Tel: +1 818.624.2616; E-mail: clemens@usc.edu
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Abstract

The IUFoST Scientific Roundtable celebrated the International Year of Millets 2023 by convening an international team of experts to discuss the value of millets relative to agri-economy, nutrition, bioactives, environmental and our delivery on the global development agenda and its sustainable development goals (SDGs). The experts advanced critical analyses that suggested this semi-arid crop, grown primarily in the tropics of Asia and Africa can be an important contributor to improving food and nutrition security. Importantly, millets are a major source of energy and protein for about 130 million people in sub-Saharan Africa. Many in vitro and in vivo (mouse) studies plus a few meta-analyses and systematic reviews suggest millets and their respective components may contribute to the reduction of an array of non-communicable diseases, especially in marginal and harsh environments. Yet these kinds of evidence need to be substantiated by rigorous, well-designed clinical studies such that there is stronger support for millets contributing to global health. In addition, improvements and adoption of technologies that provide a low carbon and water footprint may contribute to consumer acceptance of millets.

Keywords: Millets; Nutritional quality; Food security; Health benefits; Agricultural sustainability; Bioactives.

1. Introduction

In 2021, the United Nations (UN) declared 2023 the International Year of Millets. The intent of this declaration was to raise awareness of their nutritional value, potential health benefits, and agricultural and climate resilience of this ancient grain crop. In addition, the 2018 FAO State of Food Security and Nutrition in the World Report noted a worsening global trend that is affecting people's food security and nutrition, climate variability, and conflict (FAO, 2018). The report emphasizes, among other things, that there are 821 million people suffering from hunger, up by 150 million since before the COVID-19 pandemic. These statistics were accentuated in a 2023 global crises report that estimated that over a quarter of a billion people were acutely food-insecure and required urgent food assistance in 58 food-crisis countries/territories in 2022 (FSIN and Global Network Against Food Crises, 2023). These findings support the importance of grains, such as millets, may have in reducing the staggering statistics associated with world hunger.

Millets are known as the first cereals, domesticated thousands of years ago with the commencement of early human civilization. Evidence from archaeobotanical studies in Northern China sug-

Table 1. Nutrient composition of Sorghum and Millet grains (per 100g of edible grains at 12% moisture content)*

Millet	Energy(kcal)	CHO (g)	Protein (g)**	Fat (g)	CF (g)	Calcium (mg)	Iron (mg)	Niacin (mg)
Sorghum	329	70.7	10.4	3.1	2.0	25	5.4	4.3
Pearl millet	363	67.0	11.8	4.8	2.3	42	11.0	2.8
Finger millet	336	72.6	7.7	1.5	3.6	350	3.9	1.1
Foxtail millet	351	63.2	11.2	4.0	6.7	31	2.8	3.2
Proso millet	364	63.8	12.5	3.5	5.2	8	2.9	4.5
Little millet	329	60.9	9.7	5.2	7.6	17	9.3	3.2
Kodo millet	353	66.6	9.8	3.6	5.2	35	1.7	2.0
Barnyard millet	300	55.0	11.0	3.9	13.6	22	18.6	4.2

*Abbreviations are CHO-carbohydrates; CF-crude fiber, (Source: Data adapted from reference FAO, 1995); **Composition differs among varieties. Protein based on percent nitrogen ×6.25. True protein digestibility ~80%; Estimated nitrogen to protein conversion factor is approximately 5.7, as for typical cereal grains.

gested the use of proso millet was a staple food many centuries ago (Lu et al., 2009) and that the manufacturing of noodles using proso and foxtail millets was common several millennia ago (Lu et al., 2005). This gluten-free cereal grain is grown primarily in developing countries, particularly in semi-arid regions of Sub-Saharan Africa and Asia. The most recent data from FAOSTAT suggest that the global millet production was about 31 million tonnes in 2021 (FAOSTAT, 2023). Currently, millets rank sixth place among other cereals in terms of global production and contribute by 1% to the world cereal grain yield. However, their pivotal role is significant as food crops in the agroecosystems in African and Asian regions to ensure the food security of millions of people. Interestingly, millet cultivation in the United States continues to expand, producing about 350 thousand metric tonnes from 600,000 planted acres in 2021. Despite the global average production yield of about 1,300 kg/ha (approximately 1,100 lbs/acre) for millets, and for sorghum of about 1,500 kg/ha (approximately 1,300 lbs/acre), the global supply of millets is marginalized with crop alternatives that promise better profits and agricultural incentives. In addition, Western consumers and markets seem to prefer classic wheat, corn, and rice cereals which typically have a good shelf life and are easy to process into a variety of food products (OECD/FAO, 2021).

During this era of increasing attention to environmental challenges and the need to adapt to climatic dynamics, millets typically use less water than other cereal plants and economically valuable crops, such as wheat, maize, cotton, rice, and sugarcane. Millets are champion subsistence crops to grow in low fertile soils while under drought conditions other crops, including cereal grains, the yield is markedly reduced. For example, wheat, a low-humidity crop, typically relies on rainfall for water. Maize, most of which is used for livestock in many countries, requires about 6 mm of water for transpiration plus evaporation, which varies depending on climate conditions, cultivar type, and growth stage. By contrast, pearl millet has the lowest water requirement of all the major cereals, only some 250 mm, and sorghum is the most high-temperature and drought-tolerant.

2. World's grocery basket

The increase of food insecurity and malnutrition in the world are of significant global concerns. A 2021 FAO world hunger map indicates about 10% of the populations in Central and South America suffer from food insecurity (FAO, 2020). This number increases to more than 40% in various regions of Africa. Interestingly, there is information that indicates rainfall in these regions may be suitable for growing pearl millet as well as wheat while sustaining productivity in a semi-arid ecosystem (Kumar et al., 2022).

Harvesting and processing technologies, including fermentation and extrusion cooking, translate to consumer-acceptable food products derived from millet and sorghum. These considerations are supported by several key messages associated with millets as advanced by FAO. Millets represent a climate-resilient crop and due to its promising nutritional values, especially as whole grains, they can be important in curbing hunger while supporting healthful dietary options (Table 1). Millets also provide opportunities for smallholder farmers to improve their livelihoods, and quality of living standards while improving the diversity of the global food supply ensuring food and nutrition security.

3. Millet bioactives

There is a spectrum of main millet types, including pearl (*Pennisetum glaucum*), foxtail (*Setaria italica*), proso (*Panicum milliaceum*), and finger (*Elusine coracana*), with the pearl millet being the most popular. In addition, other minor millets include kodo (*Paspalum scrobiculatum*), little (*Panicum sumatrense),* barnyard (*Echinochola crus-galli*), fonio (*Digitaria exilis)* and teff *(Eragrostis tef)* that are popular in some agro-ecosystems. Millets contain a constellation of minerals, including calcium, phosphorus, magnesium, zinc, and iron, the concentrations of which may be greater than typically found in rice, wheat, and maize (Sabuz et al., 2023). At the same time, the innate phytate, oxalate, and polyphenol content of millets, as with other cereals and pulses, can decrease the absorption of these minerals (Arora et al., 2003; Suma and Urooj, 2014; Hassan et al., 2021).

Like all cereal grains, millets provide an array of nutrients and potential bioactives, the concentration of which depends on plant cultivars, growing conditions and ultimately processing settings. Millets are potentially important sources of several health-promoting bioactives that may reduce risks associated with non-communicable diseases (NCDs). For example, in addition to classic nutrients such as proteins, minerals, vitamins, an array of unsaturated fatty acids and dietary fiber, millets provide substances such as inulin, tocopherols, tocotrienols, oryzanols, phytosterols, phytates and phenolic compounds (Balli et al., 2022; Banerjee et al., 2017; Bhandari and Lee, 2013; Chandrasekara and Shahidi, 2011; Narumi and Takatsuto, 1999).

Phenolics from millet grains exist as free and conjugated forms

Table 2. Bioactive Phenolics and Flavonoids in Millets

Millet Types	Bioactives	References
Finger	caffeic acid, cinnamic acid derivatives, *p*-coumaric acid, gallic acid, *p*-hydroxybenzoic acid, *trans*-ferulic acid, proanthocyanidins, protocatechuic acid, quercetin, sinapic acid, syringic acid, vanillic acid	Devi et al, 2014; Pradeep and Sreerama, 2015; Chandrasekara and Shahidi, 2011; Shahidi and Chandraeskara, 2013
Foxtail	apigenin, chlorogenic acid, caffeic acid, cinnamic acid derivatives, *p*-coumaric acid, *trans*-ferulic acid, gallic acid, gentisic acid, *p*-hydroxybenzoic acid, kaempferol, myricetin, naringenin, protocatechuic acid, rutin, sinapic acid, syringic acid, vanillic acid	Pradeep and Sreerama, 2015; Zhang and Liu, 2015; Chandrasekara and Shahidi, 2011; Shahidi and Chandraeskara, 2013
Kodo	chlorogenic acid, cinnamic acid derivatives, *p*-coumaric acid, *trans*-ferulic acid, *p*-hydroxybenzoic acid, protocatechuic acid, syringic acid, sinapic acid, vanillic acid,	Chandrasekara and Shahidi, 2011; Shahidi and Chandreskara, 2013
Pearl	apigenin, caffeic acid, cinnamic acid derivatives, *p*-coumaric acid, *trans*-ferulic acid, gallic acid, *p*-hydroxybenzoic acid, protocatechuic acid, sinapic acid, syringic acid, vanillic acid	Chandrasekara and Shahidi, 2011; Shahidi and Chandraeskara, 2013
Proso	apigenin, chlorogenic acid, cinnamic acid derivatives, *p*-coumaric acid, *trans*-ferulic acid, gallic acid, gentisic acid, *p*-hydroxybenzoic acid, kaempferol, myricetin, naringenin, protocatechuic acid, rutin, sinapic acid, syringic acid, vanillic acid	Chandrasekara and Shahidi, 2011; Shahidi and Chandrasekara, 2013

of phenolic acids, which are derivatives of hydroxybenzoic and hydroxycinnamic acids (Table 2). Conjugated hydroxycinnamic acids mainly exist in insoluble bound form in millet grains (Shahidi and Chandrasekara, 2013). Phenolic acids and flavonoids are found in different parts of the grain and the content and composition vary depending on the type of millet grain (Chandrasekara and Shahidi, 2011). Several flavonoids, such as anthocyanidins, flavanols, flavones, and flavanones, are also found in millets (Table 2).

A recent report indicated pearl millet contains phenolics and flavonoids (Slama et al., 2020). Based on the classic *in vitro* DPPH (2,2-diphenyl-1-picrylhydrazyl) inhibition assay, this ecotype of millet had nearly 80% antioxidant activity relative to the control. While these observations are interesting, the physiological importance and clinical significance of these findings remain uncertain.

Some investigators suggest pearl millet presents anti-carcinogenic properties based on several cell-line models, including the human HepG2 liver cancer and MDA human breast cancer cell line (Zhang et al., 2014). The majority of anticancer studies examined potential mechanisms associated with the introduction of phenolics, gallic acid, and select peptides from millet extracts (Shahidi and Yeo, 2018). While some of the studies with an array of cell lines and among mice are intriguing and suggestive of mechanisms by which millet phytochemicals may provide anti-cancer effects, none of these kinds of studies has translated to human clinical trials. It is important to remember that cancer *per se* represents a multitude of metabolic and genomic disorders, each presenting dramatically different clinical features, responses to therapy, and course. Even acknowledging the high percentage of gene homology among mammals, the long history of dramatically different pharmacological responses between mice and humans, tells a perilous story. No matter how many apparently exciting experiments are replicated in murine models, the rate of corresponding outcomes when transitioning from mouse to human trials is incredibly high (Berry et al., 2019; Adli et al., 2018; Lithgow et al., 2017; Begley and Ellis, 2012).

Upon examination of the literature at the interface of millets and a spectrum of noncommunicable diseases, the number of clinical investigations relative to diabetes, obesity, and hypertension is limited. A recent systematic review and meta-analysis of 19 clinical studies suggest millet consumption twice a day over 28 days to 4 months may be beneficial in reducing hyperlipidemia, hypertension and possibly body weight (Anitha, et al., 2021). Unfortunately, the dietary patterns, health status, and other critical demographic information of the intervention subjects were not reported. The same group of investigators examined the interface of dietary millets and the risk of developing diabetes (Anitha, et al., 2021). The authors evaluated 65 studies relative to the glycemic index, fasting and post-prandial glucose, and HbA1C. The dietary histories and health status of study subjects and quantitative information as to millet intake were not presented. Regardless, forest plots of the data suggest millets may be an effective dietary component in managing diabetes via an unknown mechanism.

4. Examination of potential health claims

Numerous publications have touted the health benefits of millets. Because of the potential of health claims on foods to change food consumption patterns and exposure to potentially bioactive substances, the evaluation of foods with health claims must be based upon a high standard of evidence. The validity of a health claim depends upon rigorously establishing an etiologic link between the desired effect and consumption of the food in question at the recommended level of intake in the target populations.

The strength or weight of evidence, which in turn depends on criteria for validating surrogate disease endpoints and biomarkers of food intake is requisite for health claims. Claim validity asks whether the food can produce the effect as marketed and whether the food actually produces the effect as alleged.

The scientific understanding of the relationships between diet and disease risk reduction is arguably one of the most daunting challenges in clinical research. If we are to be taken seriously in the global community, we must be certain that standards of evidence supporting health claims are well substantiated.

5. Summary

There is no question that millets are resilient crops, require less water than other cereal crops, thrive in marginal soils, and are nutritionally comparable to other widely used grains. Millets generally have a high dietary fiber content, particularly in the whole grain form, which together with its micronutrient and bioactive co-components, represents an array of possible health benefits. As the global community struggles to assist the 350 million undernourished people in this world who are also stressed by conflict, climate instability, COVID-19, and widespread inflation, the potential impact of popularizing millets is both appealing and potentially of real consequence (Global Network Against Food Crises, 2023). Millets provide readily available and sustainable sources of meaningful calories and nutrients that are of critical importance in achieving and maintaining health.

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