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Yellow pericarp sorghum: An overview

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Abstract
Sorghum is an important staple food and feed crop in the semi arid regions of the world where it is grown under rainfed and irrigated conditions. Globally, sorghum is one of the most important but least utilized and neglected staple crops. Sorghum grain is a rich source of nutrients and health-beneficial phenolic compounds with pigmented and non pigmented pericarp. Sorghum grains with yellow pericarp is characterized by high carbohydrate, carotenoids, manganese, flavanones and has slightly higher total phenolic contents than white sorghum which could thus serve as a prominent nutricereal addressing the people below the poverty line and contributing for combating food security concerns in India. Yellow pericarp sorghum has gained a lot of priority nowadays owing to the nutritional benefits, preference for good roti making and keeping quality, therapeutic use though they are low yielders. The objective of this review paper is to provide a comprehensive overview of yellow pericarp sorghum with reference to its nutritional benefits over other cereals and to popularize the yellow pericarp sorghum in sustainable agriculture systems.

Keywords: Yellow pericarp sorghum, nutritional, phenolics, therapeutic use

Introduction
Sorghum *Sorghum bicolor* (L.) Moench is the third most important cereal crop after wheat and rice cultivated extensively in India. Sorghum is a cereal of Poaceae grass family native to Northeastern Africa and was first cultivated from 3700 to 4000 years ago (Rooney and Waniska, 2000) [28]. Sorghum is a self-pollinated, diploid (2n=2x=20) plant with a genome measuring 25% that of maize or sugarcane. It is a C4 plant with good photosynthetic efficiency and abiotic stress tolerance (Kumar *et al.*, 2011) [17]. Their tolerance to the dry season and high temperatures, as well as their adjustment to problematic soils, make them progressively critical for food and nutrient security in the confront of climate change. It is additionally the cheapest source of micronutrients; for this reason, Sorghum biofortification has of high significance (Kumar *et al.*, 2017) [18]. Normally sorghum is consumed in the form of roti, but now days it is also consumed as hurda (roasted grains separated from sorghum panicles at dough stage) in Maharashtra region. Due to the low consumption of vegetables and animal foods, sorghum and other millets also are the major suppliers of micronutrients especially for low income groups (FAO, 2005) [12].
Yield improvement in sorghum is essential to have multiple benefits of the crop. (Prasad BVV and Sridhar V, 2019i) [23]. In India sorghum is grown in areas receiving 500 to 1000 mm annual rainfall with temperature ranging between 26 to 32 °C. It is grown in two seasons, *viz*., *kharif* as rainfed crop and rabi with protective irrigation thereby constituting 60 and 40 percent cultivation, respectively. Sorghum grown in *rabi* season is characterized by its excellent grain quality, exclusively utilized for human consumption and hence fetches higher market price as compared to *kharif*. Normally sorghum is consumed in the form of Roti and in India it is grown as a dual purpose crop serving both grain and fodder requirements of the farming community and its regional importance as a major food crop is as much as that of wheat and rice. (Prasad BVV and Sridhar V, 2019 ii) [24].
The crop is cultivated over an area of 4.89 m ha with a production of 4.40 M t and productivity of 900 kg ha^{-1} (Agricultural Statistics at a Glance, 2022). In Telangana, it is cultivated in 90,000 ha with production of 1.60 lakh tonnes and productivity of 1711 kg ha^{-1}. Out of the total cultivated area under sorghum in Telangana, 60% accounted is under rainfed condition. India's sorghum production is dominated by high-yielding white sorghum hybrids, and new production technology have resulted in an increase in output from a gradually

shrinking cultivation area. Recent market demand has increased for sorghum grains with yellow pericarp due to their nutritional value, good roti-making and preserving qualities.

Yellow sorghums are typically tall (≥2.5 m) statured as against the white sorghum (2.0 m) and are susceptible to lodging, when raised under improved management practices during rabi and summer. Hence, they are invariably cultivated during kharif season. Currently cultivated sorghum cultivars with yellow pericarp are low-yielding local land races. Yellow pericarp sorghums are generally raised in patches in tribal areas of Telangana during kharif for subsistence with minimum management practices resulting in low yields and susceptibility to pests and diseases. However, keeping in view the consumer's preference recently high yielding sorghum (both grain and fodder) cultures with yellow pericarp were developed by RARS, Palem, Telangana, India.

Sorghum is well known for its outstanding agronomic performance, that is, adaptability to grow in a variety of environments. It is drought tolerant, heat tolerant, and can grow in high altitudes and saline-alkaline and barren soil. This is because sorghum has a well-developed root system with a high root to leaf ratio, and the leaves are protected by wax and can also roll themselves in response to external threat/stimulus (Rooney & Waniska, 2000) [28]. In addition to its agronomic advantages, sorghum grain is gluten free, high in resistant starch and is a rich source of nutrients, and most importantly, contains a diverse range of bioactive phenolic compounds (Awika & Rooney, 2004; Dykes & Rooney, 2007) [7, 10]. Sorghum contains more abundant and diverse phenolic compounds compared to other major cereal crops; it contains nearly all classes of phenolic compounds, with simple phenolic acids, flavonoids, and tannins being the dominant groups (Dykes & Rooney, 2007; Shen, *et al*., 2018) [10, 29].

Grain yield is a complex and quantitative character and is polygenically controlled by many genes. Selection on the basis of grain yield per se alone is not effective and efficient. Selection for grain yield has to be coupled with selection for other component traits for higher response and efficiency to selection for improving yield. Knowledge on association of component traits among themselves and with yield can improve the selection efficiency and response to selection in plant breeding. (Prasad BVV and Sridhar V, 2020) [26].

Sorghum is well adapted to the range of environmental conditions with high variability and is the single most important cereal in the lowland areas because of its extreme resistance to water stress. Sorghum bicolor contains both cultivated and wild relative races, and it provides a substantial amount of genetic diversity for traits of agronomic importance so as to develop the crop's different variety of interest for plant breeders. (Prasad BVV and Sridhar V, 2019 iii) [25].

Structure and composition of grain Sorghum

The composition of Sorghum grain and its parts is generally similar to that of corn, except for lower oil content. The grain contains 8 to 12% protein, 65 to 76% starch with approximately 2% fiber. The germ, a rich source of oil (28% of the germ) also has high levels of protein (19%) and ash (10%). It is a gluten free and safe food for celiac patients or people with known gluten allergies. The slow digestibility of Sorghum starch makes it a food option for diabetics. The different varieties of Sorghum grains are defined by color, including red, orange, bronze, brown, white, and black.

In addition to these botanical varieties, Sorghum can be processed into many different formats. Sorghum flour can be used in bread and pastries, liquefied Sorghum as a syrup, pearled Sorghum as a hot grain, and popped Sorghum as a popcorn like snack. Although almost all the bran is cellulose and hemicellulose, appreciable quantities of starch are deposited in the mesocarp tissue of this fraction. Bran lipid consists mostly of wax rather than oil. The composition of Sorghum grain from different sources may vary because of many factors, including the nature of the hybrid, soil and climatic conditions, and manner of crop management. Older grain Sorghum varieties differed considerably in kernel size and relative amounts of grain parts. With the newer hybrids and wider use of irrigation, the grains are larger and are better filled with starch, and have lower protein content (Lu *et al.*, 2009) [19].

Sorghum crop has health benefits acting as an antioxidants, combating cell damage, reducing inflammation, slow digestibility of starch makes it a good food option for diabetic patients, Gluten free and makes it suitable for celiac patients, allergy free, controls blood pressure and promotes weight loss.

Sorghum grain is composed of three main components, the pericarp, endosperm, and germ (Earp *et al.*, 2004) [11]. Naturally, the amounts of these components will vary, but a general composition of a Sorghum grain has been reported to be 3 to 6% pericarp, 84 to 90% endosperm, and 5 to 10% germ (Hubbard JH, 1950). The composition of these tissues varies substantially, the pericarp consists of multiple layers, including the epicarp, mesocarp, and endocarp (Rooney and Waniska, 2000) [28]. Sorghum is unique in that it is the only cereal to have starch granules present in the pericarp. Pericarp thickness is variable, is not of uniform thickness within a single grain, and is related to the amount of starch in the mesocarp. The outer layer of the pericarp is covered with wax. The endosperm in cereal grains is composed of the aleurone layer and "starchy endosperm".

In Sorghum, the starchy endosperm has been divided into the peripheral, vitreous (or corneous), and opaque (or floury) endosperm. The aleurone layer contains both protein and lipid bodies along with inclusion bodies possibly containing phytic. The peripheral endosperm lies beneath the aleurone layer and is characterized by a dense cell layer with high protein concentration and small starch granules (Zeleznak, 1982) [32]. Mature seeds of Sorghum are composed of a seed coat or pericarp (8% of dry weight), embryo or germ (10%), and endosperm (80%). The pericarp consists of the epidermis, subcutaneous tissue, starchy mesocarp, and underlying intersecting and tubular cells. Pericarp thickness is controlled by a single gene (z), which under homozygous recessive conditions results in a thicker pericarp associated with mild dissection. If a seed coat is present, it is located below the pericarp and is controlled by two co-dominant (b1 and b2) genes (Waniska, 2020) [31]. The aleurone layer just below the pericarp forms part of the endosperm but is removed along with the pericarp as bran when the grain is peeled. The highest concentrations of Fe and Zn are found in the aleurone layer and embryo (particularly in the scutellum), with low concentrations in the starchy endosperm (Chavan, 2010) [8]. Therefore, dehulling of Sorghum grains, which is common practice in West and Central Africa, dramatically reduces Fe and Zn concentrations (Hama, 2011) [14]. The embryo contains a scutellum, hypocotyl, germ and radicle (small root) and is

rich in structural proteins, lipids and minerals.

Nutritional Benefits of Yellow Pericarp Sorghum

Sorghum has a significant amount of slowly digested starch (SDS), which has a functional quality and delays the digestion and absorption of carbs in the colon. This component is extremely advantageous for diabetics. Grain starches are relatively more difficult to digest than cereal grains. According to reports, sorghum grain has the lowest raw starch digestibility because endosperm proteins hinder starch accessibility. However, yellow sorghum has less fiber content and higher starch digestibility as compared to white sorghum (Arun *et al*., 2009) [6]. Foods with a low Glycemic index help slow absorption of carbohydrates and prevent extreme blood glucose fluctuation. White jowar (flour) has a lower glycemic index (49.85) than yellow jowar (flour) (52.56), according to Vahini and Bhaskarachary (2013) [30].

The second significant component of sorghum grains is proteins. It is known that the protein concentration of sorghum fluctuates along with its amino acid profile. In addition to genetic considerations, environmental variables may contribute to the considerable variance in protein content among organisms (Geleta *et al*., 2005) [13]. Sorghum's protein content is comparable to that of wheat and corn. Significant proportion of sorghum protein is prolamin (kaffirin), which has the unique property of being less digestible than other grain proteins after boiling, which may be advantageous for the health of specific dietary groups. Compared to white sorghum, yellow sorghum has a greater protein level (12 13%) than white sorghum (10-11%). Mohammed *et al*. (2019) [20] reported higher protein content in yellow sorghum (11.57%) as compared to white sorghum (9.57%).

Sorghum also contains between 9.7 and 14.3 grammes of dietary fibre, which acts as a bulking agent, cholesterol-binding agent, increases transit time, and retards carbohydrate absorption (Narasinga Rao, 2003) [21], which has a significant positive effect on preventing and managing diseases such as constipation, irritable bowel syndrome, and obesity. Anerao *et al*. (2022) [4] reported that crude fibre content did not differ significantly between yellow and white pericarp sorghum. These results were in agreement with Mohammed *et al*. (2019) [20] who also noticed no significant differences in crude fibre content of white and yellow pericarp sorghum.

Total soluble sugars are largely responsible for the good taste of roti prepared from sorghum (Nirmal *et al*., 2017) [22]. Anerao *et al*. (2022) [4] noticed higher total soluble sugars of 1.65% in white sorghum which was followed by yellow pericarp sorghum which recorded a lower amount of total soluble sugar. Nirmal *et al*. (2017) [22] also reported similar results.

Studies performed on processing and cooking of white and yellow jowar varieties showed that boiled Yellow Jowar flour (coarse) had lower glycemic index compared to flour prepared from the same. Similarly chapatti prepared from white Jowar flour showed low glycemic index over yellow Jowar flour. These changes in glycemic index due to processing and cooking play an important role in diets followed in dietary management of diabetes. (Vahini and Bhaskarachary, 2013) [30].

Yellow pericarp sorghum is usually recommended for patients suffering from jaundice. It is hypothesized that the plant materials having higher antioxidant activity could be effectively used as hepatoprotective functional foods against radical induced toxicity to the liver. The hepatoprotective role of some selected yellow pericarp sorghum lines is assessed *in vitro* using cell culture studies with Human hepatoma HepG2 cells under Carbon tetrachloride (CCl4) treatment which is one of the most potent hepatotoxins causing oxi dative damage by free radical generation. The cells are procured from National Center for Cell Sciences (NCCS), Pune and cultured in 25 cm3 dishes and maintained in Dulbecco's modified Eagle's medium (DMEM) supplemented with 10% Fetal bovine serum (FBS) penicillin (100 U/mL) and streptomycin (100 mg/mL) under 5% CO_2 in air at 370C. Overnight extraction of four yellow sorghum ('PYPS-5', 'PYPS-16', 'PYPS-17' and 'PYPS-19') lines (0. 1 g in 10 mL PBS pH 7.4) was done. The cells are treated with CCl4 and sorghum extract for 24 h and the cell viability is quantified using MTT assay. It is interesting to note that all the four yellow sorghum lines reduced the toxicity due to CCl4 significantly indicating hepatoprotective activity mostly due to polyphenols.'PYPS-5' exhibited the highest hepatoprotective potential among the four lines tested. Further, in the absence of CCl4, i.e. Under normal conditions also, 'PYPS-5' and 'PYPS-19' promoted growth of the HepG2 cells indicating growth promoting principles in these genotypes.(Agte, *et al*., 2015) [3].

Role of Breeding in harnessing nutritional quality

Micronutrient malnutrition is primarily due to low bioavailability of minerals and vitamins, leading to diseases that interfere with healthy living. Increasing micronutrient concentrations through biofortification of common food crops such as Sorghum is a cost effective and sustainable solution to combat micronutrient deficiencies, especially in developing countries. Evidence of QTLs controlling Fe and Zn concentrations in Sorghum has enabled the development of robust plant breeding strategies through marker assisted breeding.

Plant breeding as a tool in has to follow an integrated approach to solving malnutrition problems. It requires that the inherent focus of most breeding programs on crops and varieties be broadened toward people and their needs. In addition, there's should be coordination between breeding programs and cross the partition between technology oriented and framework or agent oriented approaches (Christinck and Weltzien, 2013) [9]. In the modern era of agriculture supply of calory foods to meet the energy needs of poor people in developing countries has been possible. In the past 50 years research on agriculture has increased the productivity of cereals. But now agriculture has to score a paradigm shift to improve nutrient availability in staple food crops as well. The main goal of biofortification is to biofortify Sorghum and use genetic approaches to improve its nutritional quality to significantly increase the concentration of iron and zinc in the grain. Genetic variation is important to any plant breeding program. Genetic and environmental factors in Sorghum significantly influence differences in grain Fe and Zn concentrations between red, white, pink, and yellow grains (Are *et al*., 2020) [5].

Through plant breeding, biofortification can move forward in improving nutrient compositions giving a generally cheap, cost effective, sustainable, and long term supply of more micronutrients to the poor in developing nations. This approach not as it was decreasing the number of extremely malnourished individuals requiring treatment with extra

interventions, but also will help them maintain improved nutritional status. In addition, biofortification gives a helpful way to reach undernourished country populations who may have been inhibited to get micronutrient fortified diets and supplements commercially promoted (Hawarth and Bouis, 2011) [15]. The development of breeding strategies for traits of interest in hybrid performance is important to identify the relationship between parental line and hybrid performance. Parental selection in the hybridization program needs evidence on combining ability and level of heterosis to develop improved hybrid (Abebe *et al*., 2023) [1].

The objectives for sorghum breeding had been to enhance yield and quality of grain and stover for food and livestock use, biomass and stem sugar content for biofuel purposes (Reddy *et al*., 2008) [27]. Genetic variability exists in elite Sorghum lines for grain iron and zinc concentrations and agronomic traits that can be exploited to improve these traits. The greater variability in SCA than in GCA for cereal Fe and Zn concentrations indicates the importance of non-additive gene effects in enhancing nutritional traits. The hybrids displayed heterosis not only in terms of agronomic traits, but also in grain iron concentrations, suggesting that micronutrient improvements within populations are likely to be highly effective. Although, both parents need to be improved to improve grain Zn concentration, there is plenty of room to exploit heterosis to increase grain Fe concentration in Sorghum. Experiments suggest that there is great variability in grain Fe and Zn, and traits associated with yield can be utilized in advanced breeding lines as future parents. (Abebe *et al*., 2023) [1].

Conclusion

Sorghum is an important global cereal crop with very high nu tritional and health value. Comprehensively, it can be concluded that yellow pericarp sorghum definitely possesses higher nutritive assets as compared to white sorghum and can be employed in several culinary purposes on commercial basis. A certainly wide range of variability has been observed among the yellow pericarp sorghum genotypes with respect to the contents of phytoingredients as well as hepatoprotective activity under lab conditions which inturn is supporting the way it could be used as a medicine for people suffering from liver ailments. Also, the breeder must make a pick between the many apparently related characters and spotlight on those that are most essential for grain yield like leaf area index, relative water content, seedling vigor, relative water content, SPAD chlorophyll meter reading and fodder yield per plant. Sorghum stands at the frontier of sustainable agriculture and nutrition, indicating the need for endless attention and investment from researchers, policymakers, and agro-industries. In a nutshell, sorghum is a standout choice among nutritious food crops. Finally, revisiting of the package of practices of cultivation is crucial for reaping higher yields from yellow sorghum varieties.

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Conflict of Interest

The authors declare no conflict of interest.

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