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REVIEW

Scented Sorghum (*Sorghum bicolor* L. Moench): A Novel Avenue to Boost the Millet's Popularity

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Abstract

The current unpredictability of the climate is, directly and indirectly, affecting global food and nutritional security. In this instance, nutritional enrichment major attribute that is eventually necessary to help conventional crops become more resilient to future calamities. Sorghum is a crop widely acknowledged to be sustainable for the future due to its ability to withstand environmental variations and its crucial role in guaranteeing food and nutritional security. However, the primary obstacle to its broad appeal is the difficulty of garnering public approval. Perhaps the possible solution might lie in the scented sorghum which has enhanced flavors and distinct sensory qualities. The global population has responded most affectionately to fragrant cereals, and apparently, the same opportunity can be utilized by scented sorghum cultivars. It unveils an expanded potential for offering enhanced nutrients per portion compared to conventional alternatives, and it is quite probable that customers would choose them as a fragrant substitute based on previously observed choices. This paper briefly discusses the historical background and current advancements in scented sorghum research. Additionally, it examines the genetic makeup and molecular approaches applied to the diverse fragrant crops, potentially paving the way for sorghum to become a future defender of food and nutritional security. It further emphasizes that combining a nutrient-rich cereal like sorghum with enhanced fragrance and flavors has the potential to enhance its appeal and make it more accessible on the consumer's plate.

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Statement of Sustainability: Recognized for its vital role in ensuring food and nutritional security, along with its resilience to climate fluctuations, sorghum stands out as a sustainable crop for the future. Nevertheless, the hindrance to its widespread popularity lies primarily in the challenge of gaining public acceptance. Scented sorghum with unique sensory properties and elevated flavors might be the very answer we are seeking. This novel aspect of sorghum has not been the subject of any preceding review work. This paper explores the historical context, present advancements, and prospective trajectory of aromatic sorghum varieties, positioning them as a potential transformative factor for ensuring sustainability.

1. Introduction

Fragrance has long held significance in diverse cultures and traditions, contributing to a myriad of practices ranging from religious ceremonies to culinary experiences (Hashemi et al., 2013; Strugnell and Jones, 1999). The allure and mood-boosting properties of aromatic crops have been highly esteemed throughout history. The inclusion of fragrant elements elevates the value of crops, capturing consumer interest and enabling premium pricing in the market. Notably, aromatic or fragrant rice stands out in both local and international markets due to its exceptional grain quality and enchanting aroma, resulting in its sale at a premium price (Abbas et al., 2023). The aroma holds great significance in determining the quality of the cereal and greatly enhances its potential value in the global market (Nayak et al., 2002; Verma and Srivastav, 2016). A crop that has recently gained attention for its aromatic properties is sorghum, a versatile, gluten-free, and resilient staple cereal crop for people in arid and semi-arid regions. It is rich in slow-digesting starch, protective polyphenols, and flavonoids, making it a promising addition to a healthy diet for preventing chronic diseases (Awika, 2017; Birhanu, 2021) and is specifically known for its extreme heat, drought, and salinity tolerance, along with the ability to adapt to climate change and produce sustainable yields with lower inputs (Chaturvedi et al., 2022).

Consequently, it is also called 'the camel of cereals' (Chadalavada et al., 2021). Table 1 enlists the nutritional components of sorghum. Furthermore, India ranks fifth in global sorghum production. What makes sorghum unique is its protein composition, which consists of albumins, globulins, glutelins, and kafirins, lacking gliadin and glutenin, the two components of gluten (Tanwar et al., 2023).

Table 1. Nutritional components of Sorghum (Mawouma et al., 2022).

Components	**Amount (per 100g)**	**Components**	**Amount (per 100g)**
Macronutrients (g)		*Micronutrients (mg)*	
Carbohydrates	72.71± 0.02	Calcium	11.20 ± 0.08
Protein	19.62 ± 0.01	Iron	2.75 ± 0.15
Lipids	3.49 ± 0.02	Phosphorus	256.74 ± 1.04
Fibers	2.56 ± 0.02	Zinc	1.34 ± 0.01
Ash	1.59 ± 0.01	Sodium	4.55 ± 0.03
Moisture (%)	9.33 ± 0.01	Potassium	328.70 ± 0.89
		Magnesium	130.47 ± 0.13

Similar to the esteemed *Basmati* rice, renowned for its exceptional aroma, fragrant sorghum varieties have the potential to enhance both production and market appeal. Drawing parallels with the premium pricing of *Basmati* and Jasmine rice, emphasizing the aromatic qualities of sorghum varieties may lead to increased demand and potentially elevate its market value (Zhang et al., 2022). This continuous approach highlights the comparable allure and market dynamics between these aromatic crops. *Basmati* rice prices fluctuated between ₹47.90 and ₹77.98 per kilogram from 2010-11 to 2019-20 (Kumar et al., 2021) and the Agricultural and Processed Food Products Export Development Authority (APEDA) also predicted a +6% CAGR for the Indian *Basmati* Rice Market from 2019 to 2025 showing potential for scented sorghum landraces in the upcoming years. Figure 1 illustrates the price disparity between *Basmati* and regular rice for 25 years.

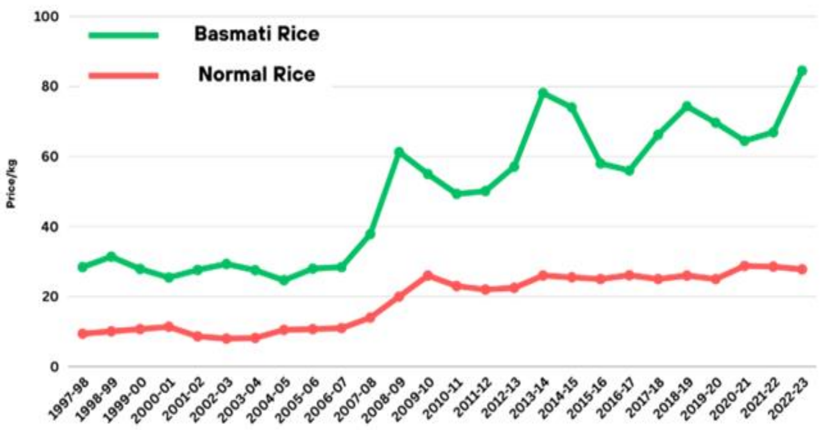

Figure 1. Price comparison between *Basmati* rice and regular rice throughout the years (DGCIS, Kolkata; APEDA and Kumar, 2019).

At times like these, when the world is continuously fighting against the scarcity of food resources and venturing towards new policies to establish food security, India's consistent placement at the bottom of the Global Hunger Index (GHI) has been a cause for concern, as it reflects the severe undernutrition prevalent in the country. In 2023, India ranked 111th out of 125 countries, and in 2022, it was 107th out of 121 countries. These rankings highlight the urgent need to address the issue of hunger in India. Nutritional security goes hand in hand with food security and is no less concerning than the latter. The GHI score graph for India tells a worrying story, with a continuous decrease indicating a progressing level of food and nutritional scarcity that has now reached a "serious" level. Additionally, the Indian population is mostly dependent on a cereal-based diet, which is predominantly limited to rice and wheat. Millets, on the other hand, tend to be a better option when it comes to nutritional enrichment through food resources. Nutritionally speaking, millets offer comparable or even higher energy value, protein, and macro-nutrient contents compared to conventional cereals (Kumar et al., 2018). They play a significant role in both human and animal diets due to their rich levels of energy, calcium, iron, zinc, lipids, and high-quality proteins. Moreover, millets are also excellent sources of dietary fiber and essential micronutrients (Dayakar Rao et al., 2017). In terms of production, India stands as the largest producer of millets, commanding a remarkable 41% share as of 2021. The country's major millet varieties include Sorghum, Pearl millet, and Finger millet, which are commonly referred to as Jowar, Bajra, and Ragi, respectively.

Despite being the fifth most important cereal (Maunder, 2002; Taylor, 2003) in terms of both area and production, sorghum often goes unnoticed by the majority of individuals, even though it surpasses staple cereals such as rice and wheat when it comes to nutritional value. Nonetheless, the introduction of scented sorghum varieties has the potential to significantly enhance its popularity among consumers and greatly benefit the health and well-being of undernourished populations. The enchanting aroma of scented sorghum instantly captures attention, sparking curiosity and paving the way for innovative culinary possibilities. This unique fragrance is not only expected to amplify its popularity but also contribute significantly to crop diversification, sustainable agriculture, and economic growth (Zhang et al., 2022) similar to fragrant rice. The natural and synthetic compounds present in scented sorghum varieties hold immense potential for applications in the food, beverage, and cosmetic industries. Table 2 presents such compounds associated with *pandan*-like aromas in different crops. Undoubtedly adding value to products, the distinct aroma creates new avenues for market opportunities. The growing demand for fragrant crops signifies the transformative influence of aroma on evolving agricultural practices and shaping market preferences.

Table 2. Volatile compounds associated with pandan-like aroma in different crops.

Crop	**Volatile Compounds**	**Reference**
Scented Sorghum (*Sorghum bicolor (L.) Moench*)	Tridecane, 2,7,10-Trimethyldodecane, Tetradecane, Pentadecane, Heptadecane, (1E)-1-Ethylidene-1H-indene, Carene, (+)-Longifolene, Cedrene, 6-Methyl-5-hepten-2-one, 4,6-Dimethyl-2-heptanone, (3E)-5-Ethyl-6-methyl-3-hepten-2-one, 2,6,6-Trimethyl-2-cyclohexen-1,4-dione, 2-Undecanone, Octanal, Nonanal, (2E)-2-Nonenal, 2-Butyl-2-octenal, 1-Octen-3-ol, 1-Octanol, 2-Butyl-1-octanol, 2-Hexyl-1-octanol, 2-Acetyl-1-pyrroline, 2,3,5-Trimethylpyridine, 1,2-Benzothiazole, 2-Pentylfuran, 2,4-Bis(2-methyl-2-propanyl)phenol	Zanan et al. (2016); Fan et al. (2021)
Aromatic mung bean (*Vigna radiata (L.) Wilczek*)	Hexanal, Heptanal, Octanal, Nonanal, Decanal, (6Z)-6-Nonenal, 3,7-Dimethyl-6-octenal, Phenylacetaldehyde, 1-Pentanol, 1-Hexanol, Oct-1-en-3-ol, (2E)-2-Nonen-1-ol, (2E)-2-Decen-1-ol, 2-Ethyl-1-dodecanol, Phenylmethanol, 2-phenylethanol, p-Cymene-8-ol, 6-Methyl-5-hepten-2-one, 3,5,5-Trimethyl-2-cyclohexen-1-one, 2,6,6-Trimethyl-2-cyclohexen-1,4-dione, 2-Acetyl-1-pyrroline, 4-Methyl Dihydro-2(3H)-furanone, Tetramethylpyrazine, 1H-indole, 1,2-dimethoxy-4-methylbenzene, Tridecane, 2,4,6-trimethyldecane, δ-Elemene	Attar et al. (2017)
Soybean (*Glycine max L.*) (Aromatic 7)	Hexanal, Trans-2-hexenal, cis-3-hexenol, p-xylene, 1-hexanol, heptanal, 2-acetyl-1-pyrroline, 6-methyl-5-hepten-2-one, octanal, limonene, nonanal, decanal	Wu et al. (2009)
Raw Almonds	Octanal, Nonanal, (E,E)-2,4-Decadienal, Vanillin, 1-Octen-3-one, 2-Acetyl-1-pyrroline*, Acetic acid, 4-hydroxy-2,5-dimethyl-3(2H)-furanone*	Erten and Cadwallader (2017)
Raw Walnut (*Juglans regia L.*)	2,3-Butanedione, Hexanal, (E)-3-Penten-2-ol, γ-Caprolactone, 1-Pentanol, Octanal, 2-Acetylpyrrole, Nonanal, (E)-2-Nonenal, (E,E)-3,5-Octadien-2-one, 2,3-Butanediol, γ-Butyrolactone, β-Bisabolene, 2,5-Dimethylbenzaldehyde, 1,2-Heptanediol, γ-Nonanolactone, (E,E)-2,4-Decadienal, Eugenol, Phenylethyl alcohol, Methyl palmitate, 2-(1,1-Dimethylethyl)-6-methylphenol	Liu et al. (2022)
Coconut Water (Nam Hom cultivar)	3-methyl-1-butanol, 1-heptanol, 1-dodecanol, 1-pyrroline, 2-acetyl-1-pyrroline, tetradecane, 1H-pyrrole, hexadecane, 2-propanol, 1-butanol, 1-hexanol, 2-ethyl-1-hexanol, 1-octanol, hexanoic acid, octanoic acid and nonanoic acid	Luckanatinvong et al. (2018)
Pumpkin Fruit (*Cucurbita moschata D.*) (44 cultivars)	Pyridine, (Z)-2-Penten-1-ol, Toluene, Hexanal, (E)-2-Hexenal, 1-Hexanol, 1,3-Dimethyl-benzene, Nonane, Methional, 2-Acetyl-1-pyrroline, 1-Methylethyl-benzene, Propyl-benzene, Benzaldehyde, 1-Octen-3-ol, 6-Methyl-5-hepten-2-one, β-Myrcene, 1,2,4-Trimethyl-benzene, Decane, Octanal, (E, E)-2,4-Heptadienal, Benzyl alcohol, 3,5,5-Trimethyl-3-cyclohexen-1-one, Benzeneacetaldehyde, 1,4-Diethyl-benzene, 1-(1H-pyrrol-2-yl)-ethanone, 2-Pyrrolidinone, (E,E)-3,5-Octadien-2-one, 1-Ethyl-2,4-dimethyl-benzene, Undecane, Nonanal, 2,6,6-Trimethyl-2-cyclohexene-1,4-dione, (E, Z)-2,6-Nonadienal, (E,Z)-3,6-Nonadien-1-ol, Decanal, 3-Ethyl-undecane, 5-Methyl-tridecane, 3-Methyl-tridecane, α-Ionone, (E)-6,10-Dimethyl-5,9-undecadien-2-one, β-Ionone, 4-Ethyl-tetradecane, 3-Methyl-pentadecane	Junxing et al. (2022)
Aromatic rice (IAC 500)	Nonanal, Dodecane, Pentadecane, Tetradecane, Isovanillin, 2-Acetyl-1-pyrroline, 3-methyltridecane, 1-Octanol, Hexanal, Acetic acid, Octanoic acid, Octanal, Hexadecane, 1-Nonanol, Decanal, 2-Nonenal, 1-Hexadecanol, Pyrolo[3,2-d]pyrimidin-2,4(1H,3H)-dione, Benzaldehyde, 2-Pentylfuran, 1-octen-3-ol, 6,10,14-Trimethyl-2-pentadecanone etc.	Dias et al. (2021)
Peruvian Carrot	3-methy-but-2-en-1-ol, Hexanal, 3- butyl acetate, Hex-2-enal, Heptanal, 2-acetyl-1- pyrroline, Octanal, Limoneno, Octenal, Nonanal, Non-2-enal, Decanal, Dec-2-enal, 2,4-decadienal, Eugenol, Caryophyllene, Caryophyllene oxide, Palmitic acid, 2,9-heptadecanone-4,6-dien-8-ol.	Nunes et al. (2013)

*: present in trace level.

2. History of Scented Sorghum

As given in Figure 2, the narrative of the discovery of scented sorghum commences with the agricultural exploration of various sorghum landraces in disparate regions. It was discovered that the landrace cultivar "Ambemohor" from India and "Kinungapembo" from Tanzania both have fragrant seeds (Kottur, 1919; Ayyangar, 1939). Kottur (1919) even mentioned that Ambemohar sorghum possesses a fragrance reminiscent of the rice variety 'Ambemohar', giving off a somewhat pandan-like aroma, which is often compared to a blend of grassy vanilla and a subtle touch of coconut. This distinct aroma was first reported in the landrace cultivar 'Ambemohar' from Maharashtra, as stated in various reports. This genotype is now registered with INGR no. 18022 of 2018, having IC no. 568489 (E228) for *Basmati*-like fragrance, and is currently being developed by the Indian Institute of Millet Research (IIMR), located in Rajendranagar, Hyderabad (Aruna et. al., 2020). During another agricultural exploration expedition, scented sorghum landraces IS19907 (KEP-472), IS19910 (KEP-475), and IS19912 (KEP-477), known as "*Basmati*," were collected for the first time from the villages of Karri and Sarwa in Madhya Pradesh's Chhatarpur district (Prasada Rao and Murthy, 1979). These samples belonged to the Durra race and had superior vegetative growth with white, medium-sized seeds and a powdery endosperm. Interestingly, locals have taken to calling it the "Shakuntala of Sorghum". Furthermore, additional research uncovered a seed sorghum landrace with a *Basmati* rice aroma during a germplasm collection trip to the Bundelkhand region of Uttar Pradesh in 2002 (Singh et al., 2005). The scented sorghum landraces (MASC-1/2002 and MASC-2/2002) were collected from Sarila village in the Hamirpur district, confirming the existence of this unique variety (Singh et al., 2005). As a result, scientists firmly believe that these scented sorghum landraces can be categorized as a farmer's variety native to Madhya Pradesh and Uttar Pradesh. The now-called E228 scented sorghum is characterized by dimpled and chalky white grains and an aroma similar to *Basmati* rice (Maruthamuthu and Tonapi, 2019), hence its association with the name "*Basmati*". After centuries of being lost in the annals of time, the ancient landrace known as "*Basmati* Jowar" has finally emerged from obscurity, thanks to the tireless efforts of scientists from the esteemed Indian Institute of Millet Research (IIMR). Their lengthy search culminated in the remarkable rediscovery of this scented grain, not only at its original collection location but also in two additional villages within Chhatarpur district: Katia (E 228) and Kerwan (E 254). This monumental finding, which took place during the Kharif season of 2008, sheds new light on the historical significance and cultural heritage of *Basmati* Jowar. (Maruthamuthu and Tonapi, 2019; Zanan et. al., 2016). In addition to the rediscovery of *Basmati* Jowar, it is to be noted that the Genetic Resources Unit at ICRISAT maintains a collection of 17 scented sorghum genetic stocks (Mengesha and Rao, 1990). These stocks contribute to the richness and diversity of sorghum varieties that are available for research and conservation purposes.

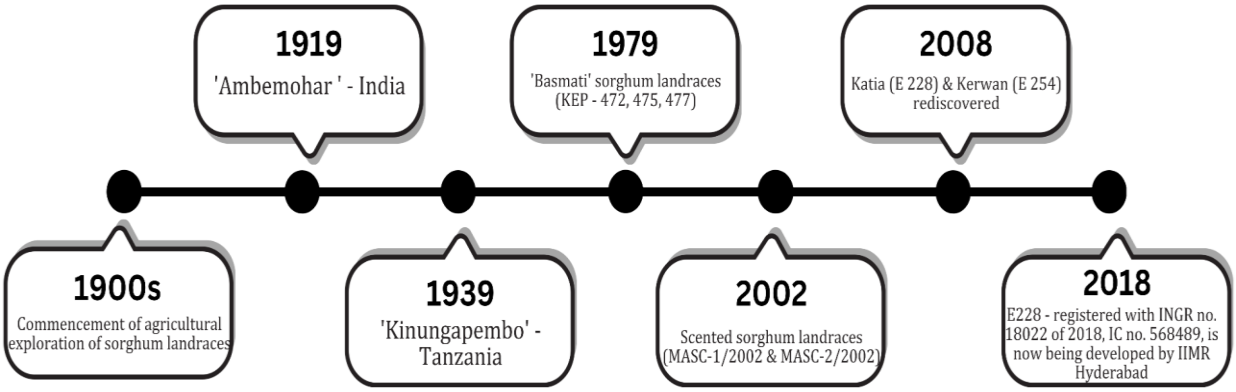

Figure 2. Historical timeline of scented sorghum exploration.

3. Genetic Basis of Aroma in Sorghum

Plants and animals show similarities in the case of attraction factors through volatile aromatic compounds (Xie et al., 2019). These aromas happen to be a prominent selection marker for the selection and characterization of food materials among humans, according to their taste and acceptance. Thus, the market for aromatic foods is always in high demand and achieves high remunerative returns to the farmers. Sorghum possesses numerous nutritional benefits, but it is still not the cereal of choice for a large number of people. In such cases, aroma happens to be a good way to attract the population to choose this particular nutritional cereal. Among the previous reported reports, it is well known that the fragrance in the cereals as well as a few other crops is a result of 2-acetyl-1-pyrroline (2 AP), having a chemical formula of C_6H_9NO. In nature, 2AP is also detected in pandan leaves (*Pandunus amaryllifolius*) (Buttery et al., 1983a) and is formed both in baking wheat bread (Schieberle and Grosch, 1991) and in cocoa fermentation (Romanczyk et al., 1995). The fragrance in sorghum is the same as the fragrance in rice and soybean, which is largely due to the compound 2-acetyl-1-pyrroline (2AP) (Fushimi and Masuda, 2001). Along with 2AP, some other compounds, viz., 2-acetyl-pyrrole, α-pyrrolidone, pyridine, guaicol, indole, p-xylene, and oct-1-en-3, enhance the consumer acceptability of rice, while compounds of lipid oxidation, such as hexanal, acetic acid, and pentanoic acid, have a negative influence on public acceptability (Zanan et al., 2016). 2 AP is controlled by a single recessive gene in sorghum as well as in rice and soybean (Ayyangar, 1939; Sood, 1978; Murty et al., 1982; Berner and Hoff, 1986; AVRDC, 2003).

Molecular genetic research has shown that the buildup of 2AP occurs in these crops due to mutation(s) in the betaine aldehyde dehydrogenase 2 (BADH2) gene, which end up in null or decreased activity of the BADH2 protein. Apart from BADH2, there is evidence linking betaine aldehyde dehydrogenase 1 (BADH1) to fragrance, particularly in rice (Amarawathi et al., 2008; Singh et al., 2010). The scent is mostly caused by the OsBADH2 gene, which codes for the protein betaine aldehyde dehydrogenase 2 (Bradbury et al., 2005; Wanchana, 2005). The aromatic rice possesses non-functioning OsBADH2. To date, the OsBADH2 gene has been shown to have nine fragrant alleles in rice as a consequence of nucleotide substitution, deletion, and insertion (Kovach et al., 2009). The most researched aromatic crop, rice, possesses the recessive gene (Fgr) for fragrance on the 8^{th} chromosome, and its dominant counterpart, Fgr, results in a lack of fragrance (Jin et al., 2003). Bradbury et al. (2005) discovered the first known badh2 allele by comparing the level of expression of 2AP to the activity of a gene that has an 8 bp deletion in exon 7. According to Juwattanasomran et al. (2012), the aromatic soybean genotype Kaori has a deletion in exon 10 of GmBADH2 that is linked to the generation of 2AP. According to reports now, soybeans have two aromatic alleles of GmBADH2 (Juwattanasomran et al., 2011; Juwattanasomran et al., 2012). Cucumber scent is induced by a single base-mediated amino acid shift in CsBADH (Yundaeng et al., 2015). According to Attar et al. (2017), the gene expression level of BADH2 is reduced in aromatic mung beans compared to non-scented mung beans, and 2-AP accumulates. Table 3. comprises all the candidate genes responsible for *pandan*-like aroma in different crops. Recent developments have already been effectively utilized to produce fragrant rice and maize, owing to the well-established genetic foundation of BADH2 and the significant economic significance of fragrance agricultural products (Tang et al., 2021; Wang et al., 2021).

Table 3. Candidate genes for pandan-like aroma in different crops.

Crop	Candidate Genes	Reference
Sorghum	SbBADH1	Monkhan et al. (2021)
	SbBADH2	Yundaeng et al. (2013)
Rice	OsBadh1	Pachauri et al. (2014)
	OsBadh2	IRGSP (2005)
	OsP5CS1	Kaikavoosi et al. (2015)
	OsP5CS2	
	OsGlyI	Talukdar et al. (2017)
	OsGlyII	Huang et al. (2008); Pachauri et al. (2014)
	OsGlyIII	
Soybean	GmAMADH1	Qian et al. (2022); Arikit et al. (2011)
	GmAMADH2	
Cucumber	CsBADH	Yundaeng et al. (2015)
Winter Melon	BhAMADH	Ruangnam et al. (2017)
Sponge Gourd	LcBADH	Saensuk et al. (2022)
Coconut	CnAMADH2	Saensuk et al. (2016)
Dolichos Bean	LpBADH2	Basanagouda et al. (2023)

The pioneering work regarding fragrance in sorghum has been led by Yundaeng et al. (2013). They have used ion sequence analysis and genetic mapping to locate the 1444 bp deletion in IS19912 when compared with KU630, which was found to be responsible for the untimely stop codon of SbBADH2, which results in the fragrance of the same (Yundaeng et al., 2013). Additionally, they also concluded that the character of fragrance was recessively inherited as in their experiment, in the F_2 population, non-fragrant: fragrant individuals were found to be in a 3:1 ratio (Yundaeng et al., 2013). The sequence data of sbBADH2 was retrieved in FASTA format from the NCBI database, bearing accession no

KC6897090.1. BLAST (https://blast.ncbi.nlm.nih.gov/Blast.cgi#) was run among all the databases in NCBI and the sequence alignment was used to build a phylogenetic tree to visualize the position of sorghum sbBADH2 among other crops carrying the same gene for fragrance. Figure 3. shows the phylogenetic placement of the same gene. On the other hand, Monkhan et al. (2021), revealed through their study that one of the very first reported fragrant sorghum cultivars "Ambemohar" doesn't possess 2 AP. Although the fragrance is inherited dominantly for the coconut juice-like fragrance, the gene responsible for fragrance is located on chromosome 6 and further analysis revealed BADH1 is responsible for the coconut juice-like fragrance in Ambemohar (Monkhan et al., 2021).

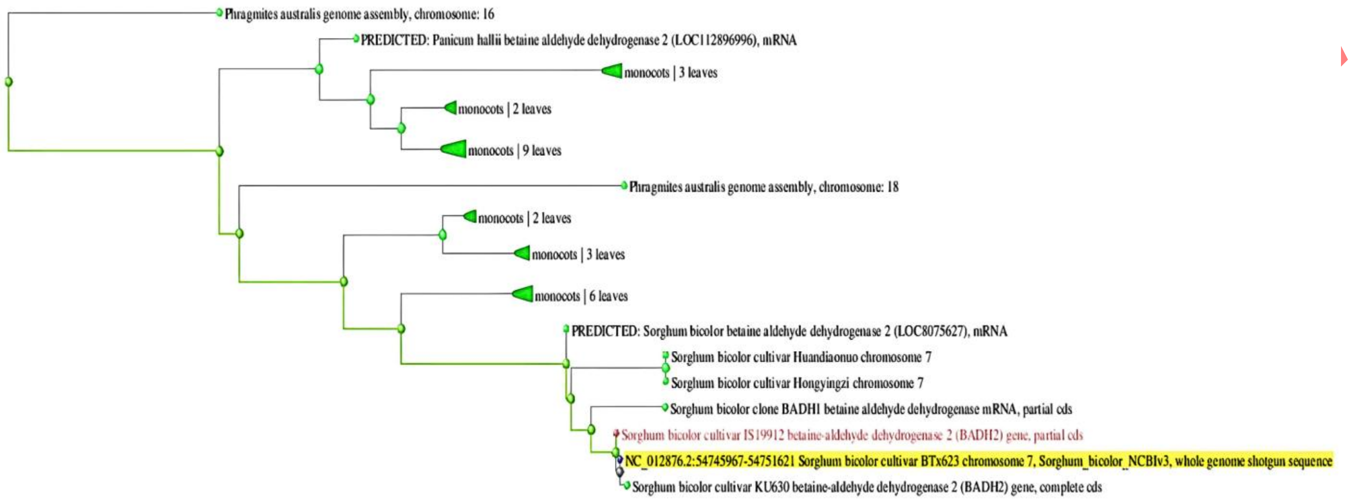

Figure 3. Phylogenetic tree showing the position of BADH2 gene of IS19912 (Source: NCBI).

4. Breeding for Aroma

4.1 Conventional Breeding

Breeding for fragrance or aroma is both complicated and intricate. In this paper, the term "fragrance" or "aroma" is used to denote crops with *pandan*-like fragrances, including rice, soybean, mungbean, and more specifically, sorghum, instead of aromatic plants or floral fragrances. Selection for aroma using conventional breeding methods is very burdensome as it is expressed by quantitative traits. The strong influence of the environment on the development of fragrance is one of the major reasons along with low selection efficiency and narrow-sense heritability (Hu et al., 2020; Vemireddy et al., 2021). Sensory evaluation, near-infrared spectroscopy, and gas chromatography are a few methods that are employed to evaluate fragrant lines (Hu et al., 2020). The improvement of locally adapted aromatic landraces through the application of pure line breeding has a longstanding history. In fact, the very first *Basmati* rice variety, *Basmati-370*, originated through the process of pure line selection (Sharma et al., 2021). The insufficient yield and inadequate response to inputs make it challenging for local scented varieties to compete with their high-yielding counterparts. Local landraces and wild relatives often serve as repositories of invaluable genes, contributing to tolerance and essential economic traits. Once they become extinct, a set of genes is lost forever, along with the possibility of incorporating them into breeding programs. Thus, to prevent the extinction of indigenous aromatic varieties, the approach has consistently involved hybridization through pedigree selection, backcrossing, and convergent breeding (Singh et al., 2000). Also, mutation breeding has been equally utilized to rectify specific defects in fragrant varieties.

4.2 Molecular Breeding and Genome Editing

To overcome the inconsistencies and inefficiencies of conventional breeding, such as the inability to generate new genetic variability, issues like linkage dragging, undesirable phenotypic effects, the limited scope of improvement, and the requirement of extensive land, labor, and time, the contemporary emphasis leans towards molecular breeding and genetic engineering. Extensive utilization of advanced tools such as MAS, QTL, NGS, and GWAS has been observed on a large scale. It enables the precise transfer of crucial genes accountable for aroma. The application of molecular breeding extends its benefits by enhancing resistance to both biotic and abiotic stresses in both *Basmati* and Jasmine rice varieties. In India, molecular breeding has yielded two *Basmati* rice varieties, Improved PB-1 and PB-1718, both characterized by their resistance to bacterial blight (Sharma et al., 2021). Molecular breeding of *Jasmine* rice involves incorporating genes for resistance to BPH, BLB, blast, and tolerance to salt and drought, aiming to enhance the popular KDML105 variety and produce varieties like HM80, HM812, and HM84 (Vanavichit et al., 2018).

To cater to the rising global demand, there is an ongoing quest for novel approaches to produce scented sorghum. The principal source of sorghum aroma stems from the accumulation of 2AP, a consequence of either null or missense mutations or the occurrence of a premature stop codon in the BADH2 gene (Yundaeng et al., 2013). A study by Zanan et al. (2016) has validated a new gene-specific marker, SbBADH2-EX12-15 for the identification and screening of fragrant sorghum cultivars. CRISPR/Cas9 has the potential to bypass the reliance on existing aromatic lines for improvement by generating novel alleles. The induction of fragrance in non-aromatic rice varieties has already been documented as an unscented rice variety, and ASD16 has been successfully converted into novel aromatic rice through CRISPR/Cas9 (Ashokkumar et al., 2020). Recently a team of scientists from China has succeeded in creating scented sorghum through CRISPR/Cas9 mediated knockout of SbBADH2 (Zhang et al., 2022). They created two distinct target locations in SbBADH2's fifth and eleventh exons. The OsU3 and OsU6a promoters regulated the transcription of the two sgRNAs containing the target sequences, which were then cloned into the CRISPR/Cas9 vector pYLCRISPR/Cas9Pubi-B through Agrobacterium-mediated gene transfer. The study resulted in alleviated amounts of 2 AP in the controlled population. Interestingly, when given the option among fragrant and non-fragrant pellets, they discovered that rabbits exhibited selective eating behavior and had an affinity for those that contained fragrant sorghum leaf powder (Zhang et al., 2022). Transcription activator-like effector nucleases (TALENs) technology can also be utilized to achieve similar outcomes. An attempt to elevate the 2-AP concentration to a range of 0.35–0.75 mg/kg by knocking out the Badh2 gene employing TALENs was found successful (Shan et al., 2015).

5. Future Perspective

While BADH2 stands as the major contributor to 2AP accumulation, it is essential to acknowledge the impact of additional gene expressions, diverse volatile compounds, and the surrounding environment on this process (Somta et al., 2019). Further research is essential to understand the correlation between environmental factors and fragrance. Likewise, a crucial aspect is to investigate the metabolic pathways of volatile compounds that contribute to aroma production. Balancing aroma development with yield preservation is equally essential, emphasizing the need to avoid compromising overall crop productivity. Besides sorghum, the effort to create scented varieties in other millets is observed only in the case of Foxtail millet (Zhang et al., 2023). In upholding the vision for the holistic revitalization of millets, there is a need to explore the creation of fragrant varieties in other millets, ensuring alignment with their broader breeding objectives like stronger culm, bigger seed, glutinous, shade tolerance, and disease resistance varieties (Pal et al., 2023). Utilizing CRISPR/Cas to create aromatic varieties in crops such as maize (Wang et al., 2021), where no previous records of fragrance exist, can serve as an inspiration.

6. Conclusion

The climate is becoming more unpredictable as the decades go by. In this case, a significant alteration in the genetic makeup of conventional crops is ultimately required to prepare them for future disasters, which include nutritional enrichment. Thus, in the coming days, a sudden shift in one's diet is not something to be surprised by. Even though sorghum is now widely acknowledged and well-established as a crop that is both climate-resilient and high in nutrients, consumers still do not prioritize it above other options. Sorghum is known to be consumed in certain regions around the globe as an animal feed as well as a food crop. As we explain in this study, fragrance is a highly specific attribute that consumers seek when selecting their preferred meal, and it has long been a feature of crops like rice. Therefore, if the crop has the potential to be developed traditionally or through genetic modification to enhance its fragrance value, it might make a great choice for customers. Better nutrients will be added to the plate by fragrant sorghum, and customers are believed to pick them according to their preference as a fragrant replacement. It is supposed to be the government's essential duty to plan carefully, create appropriate policies, and implement awareness campaigns on the nutritional advantages of sorghum. We firmly anticipate that the marketing and incorporation of fragrant sorghum will significantly address the global food and nutritional security issue.

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