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Rice Landraces as a Source of Valuable Traits for Future Rice Breeding

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ABSTRACT

Rice plays a crucial role in sustaining half of the global population by providing essential carbohydrates, minerals, and vitamins. Over generations, farmers have cultivated rice landraces tailored to their specific needs, resulting in the development of unique traits. These landraces exhibit diverse durations, resilience against biotic and abiotic stresses, and desirable grain quality. The wide range of duration enables farmers to select appropriate varieties for different agro-ecological regions and cropping systems. The significance of landraces lies in their innate ability to withstand stress through evolutionary adaptations, reducing the reliance on chemical inputs and promoting sustainable agricultural practices. Historically, landraces have been favoured not only for their nutritional value but also for their distinct aroma and secondary metabolites. Therefore, breeders can overcome these challenges by leveraging modern technologies such as Marker Assisted Selection and Genome Wide Association Studies. By employing these tools, breeders can transfer vital traits like biotic and abiotic resistant genes and improve nutritional aspects in modern-day varieties, ultimately enhancing the overall well-being of human beings. This review examines the distinct characteristics of landraces, including variations in duration, resistance to pests and diseases and grain quality.

Keywords: Landraces, duration groups, different seasons, biotic and abiotic stress, nutritional quality, aromatic rice, sustainable agriculture

INTRODUCTION

The commencement of crop domestication approximately 10,000 years ago signifies a profound milestone in human history. Through deliberate human intervention, wild species underwent a remarkable transformation, adapting to cultivation techniques tailored for human consumption [8]. This process of domestication encompassed a fusion of natural and artificial selection, with specific traits such as high yields, quality suitable for human consumption, and resistance to pests and diseases taking precedence. Across multiple generations of selective breeding, humans effectively molded the genetic makeup of these plants. As a result, domesticated field crops have become more productive and better aligned with the needs of human societies [46] [52].

Farmers played a pivotal role in this progression by meticulously selecting plants exhibiting desirable traits, giving rise to what is known as regional germplasm or landraces. These landraces adapted to local conditions, displaying characteristics such as high yield, disease resistance, and adaptability to specific microclimates, soils, and farming practices. The accumulated knowledge and experiences of farmers were instrumental in the development of crop varieties that thrived in particular geographical locations. This decentralized approach to crop improvement, driven by practical needs, resulted in a diverse array of locally adapted landraces [9] [15] [21] [50] [55]. Landraces or germplasm are undoubtedly valuable resources due to their inherent resistance to biotic and abiotic stresses, as well as their desirable quality traits. However, a significant drawback of landraces is their tendency to easily lodge, which can substantially reduce crop yield and grain production. This limitation became glaringly evident during the 1960s in India when the country experienced a severe famine crisis, resulting in food scarcity and tragically causing widespread deaths [18] [22] [29]. To address the food shortages, breeders in the late 1960s made a concerted effort to introduce high-yielding crop varieties that exhibited improved resistance to lodging. These varieties were characterized by shorter stature, an increased response to fertilizers, adaptability to different light and temperature conditions, and enhanced tillering capacity. The amalgamation of these traits in semi-dwarf varieties played a pivotal role in the development of green revolution cultivars. By harnessing the advantages of semi-dwarfism, breeders successfully created crop varieties that showcased exceptional yields, leading to a significant boost in agricultural productivity and effectively tackling challenges related to food scarcity [10] [11] [38].

The remarkable increase in yield provided by modern varieties compared to landraces has resulted in a noticeable shift among Indian farmers, who now predominantly cultivate these high-

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yielding varieties, often overlooking the potential benefits offered by landraces and germplasm. However, this preference for modern varieties in contemporary plant breeding programs presents the risk of genetic erosion when breeders primarily focus on crossing a limited number of genetic resources. Such narrow utilization of genetic resources can render crops genetically vulnerable, making them more susceptible to significant biotic and abiotic stresses [10] [26]. In breeding programs, it is crucial to expand the genetic base and enhance genetic variability in order to effectively address these challenges. This can be accomplished by incorporating diverse germplasm resources, which encompass landraces, wild relatives, and exotic germplasm. Recognizing the importance of germplasm conservation, extensive efforts are being made to promote its preservation, raise awareness among farmers regarding the inherent value of preserving traditional varieties, and foster the sustainable utilization of diverse genetic resources [45] [54].

This review explores the unique attributes of landraces, such as variations in duration, resistance to pests and diseases, and grain quality. Its objective is to offer valuable understanding regarding the substantial importance of landraces in effectively addressing a diverse range of biotic and abiotic stresses, maximizing the potential for enhanced yields, and elevating grain quality.

1. Landraces for Different Durations

Rice landraces, characterized by their varying durations, demonstrate remarkable adaptability to diverse environmental conditions. The presence of landraces with both shorter and longer durations offers farmers strategic advantages in different agro-climatic contexts. In regions with limited growing seasons, shorter-duration landraces prove invaluable. These landraces are adept at navigating challenges such as pest and disease susceptibility and unpredictable weather patterns. They enable farmers to mitigate climate risks and achieve successful harvests despite adverse events like droughts or floods. By maturing quickly, these landraces minimize exposure to unfavorable conditions, increasing the likelihood of a productive crop. Their adaptability to challenging environments enhances the resilience of local agricultural systems and helps safeguard food security.

Conversely, in areas with extended growing seasons and abundant water availability, landraces with longer durations thrive. These landraces are well-suited for stable and favorable environments, where they can maximize their growth potential and optimize resource utilization. Their ability to withstand and adapt to specific climatic conditions enhances climate resilience and contributes to sustainable agriculture. By harnessing the longer durations of these landraces, farmers can capitalize on optimal growing conditions, ensuring higher yields and greater productivity. The diverse durations exhibited by rice landraces hold immense value for crop improvement programs and breeding initiatives. Beyond their agronomic significance, the diverse durations of rice landraces contribute to broader aspects of agricultural adaptation and cultural heritage preservation. These landraces embody genetic diversity, safeguarding valuable genetic resources for future generations. The preservation and promotion of landraces with varying durations are imperative for fostering sustainable agriculture and safeguarding global rice diversity [51] [56] [57]. A comprehensive examination of the diverse durations exhibited by rice landraces will be presented in the subsequent discussion.

1.1 Very extra early duration rice landraces

In Central Africa, Madi-a-jumbo exhibits a duration of 70-80 days, whereas Barun is another extra early landrace with a duration of 70 to 80 days in Manipur (India). Tamil Nadu is home to Vellai Poongkaar, which has a duration of 80 days. The landrace called Sathi takes approximately 80 to 90 days to mature in West Bengal; Kerala is known for the landrace Navara, which has a duration of 90 days. Sri Lanka is home to Kaluheenati, which also requires 90 days to reach maturity. The landrace Kalonuni, found in the Philippines, also has a duration of 90 days. In Manipur, Naga Chakhae stands out with a duration of 90 to 100 days [2] [7].

1.2 Extra early rice landraces

Poongkaar is an indigenous landrace from Tamil Nadu which takes approximately 100 days to mature whereas, Domsiah, originating from Yemen, has a duration of 100 days. Tainung, hailing from Taiwan, has a duration ranging from 100 to 115 days. Jaya, another landrace from Tamil Nadu, typically requires 100 to 110 days to reach maturity. Arupatham Kuruvai, Sempalai, Sada Kaar, and Pattarai Kaar are all landraces from Tamil Nadu with a duration of 105 days. Vaasanai Mundan, Vellai Kaar, Kalundai, and Kuruvi Kaar, all from Tamil Nadu, have duration of 110 days. Lastly, Ottukitchili, a landrace from Tamil Nadu, has a longer duration of 115 days [2] [25] [28].

1.3 Early rice landraces

In Tamil Nadu, the landraces Arupatham Samba, Illupaipoo Samba, Iraivaipandi, Kalanamak, Kalluraendaiyan, Karuppu Seeraga Samba, Karuthakaar, Magizhampoo Samba, Kuzhiadichaan, Rama Kalli and Kulla Kaar have a duration of 120 days. The landraces Asima, Dhala Putia, and Sathia also require 120 days to reach maturity in Odisha. Further in Tamil Nadu, the landraces Matta Kaar, Kuruvaikaar, Perungkaar, Rasakadam, Salem Sanna, Karikalava, Karungkuruvai, and Norungan have a slightly longer duration of 125 days [2] [25] [36].

1.4 Medium duration rice landraces

In Tamil Nadu, landraces Kaivara Samba, Kalarpalai, Sivappu Kavuni, Kothamalli Samba, Kottara Samba Kudavazhai, Arikiravai, Authur Kitchili, Bamathi, Seeraga Samba and Pisini requires 130 days to reach their full potential. Mathimuni, Kandasali, Salem Samba, Ambemohar and Bayakundathan, matures in 135 days; while, Jil Jil Vaigunda, Jiljeera, Kamban Samba, Adukku Nel, Cochin Samba, Sanna Samba, Kuruvikalangium, Jawadhu Malai Nel matures in 140 days. In Assam, the captivating landrace Kala Jeera, with a duration of 140 days is noteworthy. In Philippines, landrace Kinandang Patong, is equally with a duration of 140 days [2] [17] [25].

1.5 Long-duration rice landraces

Poovan Samba, with a duration of 145 to 150 days, thrives in Tamil Nadu, while Kala Joha displays over the same duration in Assam. Gandhasala, Kolonunia, Perumkoomvazhai, Kappa Kaar, Katta Samba, Kattuyanam, Ottadai, and Poompalai mature over 145 to 150 days in Andhra Pradesh, Bihar and Tamil Nadu. Bhuri matures in Odisha for 150 days, while Dubraj in Chhattisgarh also requires 150 days to mature [2] [4] [25].

1.6 Extra-long duration rice landraces

In Tamil Nadu, Kaliyan Samba, Kouni Nel, Sandi Kaar, Mapillai Samba, Pattar Pisin, Thanga Samba and Vellai Milaku Samba

mature over 160 days. In Malaysia, Warisan Padi captivates with its growth over the same duration. In China, Tai-Ping-Zhou also matures over 160 days. In Tamil Nadu Kadaikazhuthan complete duration of over 165 days whereas, Katcha Koomvazhai, Vellian, Samba Mosanam thrives over 170 days; landraces Kanak in Uttar Pradesh, Kanak Champa in Odisha, and Gandhakasala in Kerala matures over the same duration. Perumkoompalai and Sennel matures 175 days in Tamil Nadu and further exploration reveals that, Neelan Samba, Kalundai Samba, Kudhiraival Samba, Koompalai, Kondavarai and Nattu Samba were captivating with their growth over 180 days in Tamil Nadu. Odisha also boasts its own 180-day wonders, including Asima, Badibiyali, Basumati, Kalama, Puntia, and Satia [2] [25] [36].

1.7 Very long-duration rice landraces

In Tamil Nadu, Ottadaiyan matures over 200 days, while in Andhra Pradesh, Red Kara follows suit with the same duration. In Assam, the captivating landrace Lalat displays its splendor over 200 days. Finally, in Odisha, Karna mesmerizes with its growth over the identical duration [2].

2. Landraces for different seasons

2.1 Summer season: From 14th April to 15th June

In Tamil Nadu, a diverse range of rice landraces viz., Sembalai, with a duration of 100-115 days, Sornavari, maturing over 120-125 days, Kodai Samba, thriving for 100-105 days, and Chithirai Kaar, completes duration over 110-105 days. In Uttar Pradesh and Bihar, the renowned landrace Kalanamak requires duration of 200 days to reach its full potential. Across Uttar Pradesh, Bihar, and Jharkhand, the remarkable landrace Dular captivates with its growth over 125 days. Journeying to Punjab, Haryana, and Uttar Pradesh, the fragrant Basmati rice graces the fields. In Assam, the captivating Kala Jeera adds its unique charm to the region's agricultural landscape [2] [17].

2.2 Kuruvai season: From 16th June to 15th September

In Tamil Nadu, Ottu Kitchili showcases its growth over 115 days, while Kuruvai Kalayaan and Kuruvai Kalachiyam enchant with their presence over 140 days. Jirkudai offers its unique charm over 120 days, and the delightful Matta Kuruvai, Mutta Kuruvai, and Koonakuruvai grace the fields for 125 days each. Karunkuruvai and Vellakuruvai completes growth over 120 days, while Arupatham Kuruvai, Thirupathisaram, Varappu Kudaichan, Puzhuthikaal, and Noortipathu matures in 100 days [2] [25].

2.3 Samba season: From 16th September to 13th January

In Tamil Nadu, Ambemohar matures over 135 days, the royal Rajamudi, captivates with its growth over 160 days, and the delightful Iravai Pandi, completes its maturation over 120 days. In Punjab, Haryana, and Uttar Pradesh, indulge in the aromatic Basmati 370, taking 130 days to reach perfection. In Odisha, Tulsi Manjari completes its growth over 115 days. In Tamil Nadu, Jeeraga Samba delights with its taste over 130 days, while in Assam, the aromatic Joha matures over 120 days [2] [17].

2.4 Navarai season: From 14th January to 13th April

Arupatham Kuruvai (105 days), Arupatham Samba (120 days), Vellai Kuruvai (120 days), Arcot Kitchili Samba (130 days), Jirkudai (120 days), Kandasaali (135 days), Karuthakaar (120 days), Kaar Arisi (120 days), Kaar Nel (120 days), Kaar Samba (150 days), Kaarthikai Samba (145 days), Sornavaari (125 days), Samba Mahsuri and Konakuruvai (120 days) are suitable for Navarai season in Tamil Nadu [2].

3. Landraces for different Abiotic stresses

Landraces are the outcome of generations of traditional agricultural practices, finely honed to flourish within specific environmental conditions. Evolving through the careful selection and cultivation by farmers across time, these distinctive variants have become finely attuned to the unique challenges of their respective regions. A particularly striking aspect of landraces is their capacity to endure and tolerate abiotic stresses, encompassing extreme temperatures, drought, salinity, and unfavorable soil conditions. By means of natural adaptation and selective pressures, these crops have naturally developed inherent mechanisms that enable them to not just survive but thrive in environments where other plant varieties might struggle to subsist. This remarkable adaptability stems from the enduring interaction between landraces and their local surroundings, ultimately leading to the cultivation of specific attributes that bolster their resilience.

Furthermore, landraces hold the potential to bolster food security in regions where access to modern crop varieties might be restricted. Their adaptability equips landraces to generate consistent yields even when faced with arduous conditions, thereby ensuring a dependable supply of sustenance for communities. Moreover, their robustness against abiotic stresses positions them as invaluable genetic resources for initiatives in crop improvement. These initiatives are geared towards crafting enhanced varieties that boast superior stress tolerance, thereby contributing to the enhancement of agricultural practices and food security.

3.1 Landraces for Soil salinity

Soil salinity presents a significant and pervasive challenge to global rice productivity, manifesting in two primary forms: inland salinity and coastal salinity. The prevalence of elevated salt levels in the soil profoundly impacts various stages of rice growth and development, resulting in diminished productivity. The influence of soil salinity is particularly pronounced during the germination phase. Heightened salt levels can impede the germination of rice seeds, leading to irregular and delayed germination that hampers seedling establishment. This, in turn, diminishes the population of healthy plants, ultimately affecting overall productivity. Additionally, soil salinity during the vegetative phase disrupts the water equilibrium within rice plants. The accumulation of salts, notably sodium ions, in the soil triggers ion toxicity in rice plants, disrupting the uptake and transport of essential nutrients. This interference with nutrient absorption can result in physiological disorders and reduced productivity, which collectively adversely affect plant growth and development.

Beyond instigating water and nutrient imbalances, salinity stress triggers alterations in diverse physiological processes within rice plants. These changes affect pivotal functions like photosynthesis, enzyme activity, hormone equilibrium, and other metabolic processes. Consequently, the growth and development of rice plants are impeded, leading to a decline in grain yield. Furthermore, the taste, flavour, and culinary characteristics of rice can be unfavourably impacted by salinity stress. Recognizing the ramifications of soil salinity on rice productivity is pivotal for formulating effective mitigation strategies [27] [30] [43]. These studies illuminate the physiological, biochemical, and molecular mechanisms underpinning the detrimental consequences of soil salinity.

To ensure sustainable rice cultivation in saline environments, it is imperative to concentrate on developing salt-tolerant rice

varieties through breeding initiatives and implementing management practices that mitigate salinity's effects. By harnessing scientific knowledge and capitalizing on the genetic diversity inherent in landraces and modern varieties, we can augment the resilience of rice crops and enhance productivity in saline soils.

For instance, in the coastal saline soils of Tamil Nadu, landraces like Thengaipoo Samba and Ariyan have been identified [2]. Similarly, in West Bengal, landraces such as Gheus, Ghunsi, Kuthiahara, Sholerpona, Balam, Lal Joyari, Patnai, Chamarmoni, Baskati, Sita Sal, Agni Shikha, Nageswari, Alta Pati, Pnathua, Harma Nona, Harina Khuri, Meghna Dumuru, Tal Mugur, Mugi, Asfal, Khejur Chhori, Mach Kantha, and Kute Patnai have demonstrated salinity tolerance [1] [23].

Furthermore, in Assam, the landrace Kolajoha has exhibited salinity tolerance [31], while in Karnataka, the landraces Arya and Karekagga have shown salinity tolerance. In Kerala, landraces such as Cheltivirippu, Kalladachampavu, Kunjathikkara, Chottupokkali, and Cheruvirippu have demonstrated salinity tolerance. In Goa, landraces like Korgut and A 280 have shown salinity tolerance [40]. Additionally, in Bangladesh, landraces such as Vasieri, Nona Bokra, Ghunsi, Hogla, and Morishal have exhibited salinity tolerance [6]. Pokkali, Wagwag, Zawa Bonday, Nam, Khao Seetha, Cheriviruppu, Annaporna, Nona Bokra, Hamilton, Daeyabyeo, Giza 177, and Suweon have been identified as salinity-tolerant landraces across various regions [19]. Moreover, specific landraces like Kalarpaalai, Kalar Samba, Kallundai, Kuzhiadichaan, Uvarmundan, Kuzhiparichaan, and Samba Nel exhibit high tolerance to both saline and sodic conditions [25].

3.2 Drought-tolerant landraces

Drought poses a formidable challenge to both food security and agricultural sustainability, particularly in the context of rice production. This harsh condition significantly impacts critical growth stages of the crop, notably flowering and grain filling, leading to a decrease in productivity. The scarcity of water during drought periods disrupts the natural rhythm of rice growth, causing shifts in the timing and duration of flowering. This, in turn, leads to irregularities in the pollination and fertilization processes. As a result, the formation of grains is compromised, ultimately resulting in diminished grain yield. Extensive research has been conducted to delve into the adverse effects of drought on rice productivity [35] [37].

To counter the detrimental effects of drought on rice cultivation, a variety of strategies have been employed. A particularly effective approach involves the development and cultivation of drought-tolerant rice varieties, tapping into the genetic resources harboured within landraces. Landraces, with their innate genetic diversity and adaptation to local environments, represent a valuable reservoir of genetic traits that confer drought tolerance. By selectively breeding and integrating these traits into modern rice varieties, breeders can create cultivars that can better withstand and endure drought conditions. This process entails the identification and incorporation of specific genetic components from landraces that contribute to drought tolerance, including enhanced water-use efficiency, improved root systems, and genes responsive to stress.

Cultivating drought-tolerant rice varieties offers a pragmatic and sustainable solution to mitigate the impact of drought on rice production. These varieties exhibit heightened resilience and can maintain stable yields even when water is scarce. By curbing yield losses and ensuring a more consistent food supply, drought-tolerant rice varieties play a pivotal role in enhancing food security, particularly in regions susceptible to water stress. Leveraging landraces in breeding programs geared towards drought tolerance signifies a strategic and forward-looking approach to addressing the challenges posed by water scarcity in rice farming. By capitalizing on the extensive genetic diversity inherent in landraces, breeders can develop robust rice varieties capable of thriving in water-limited conditions, thus forging a more sustainable and secure future for rice cultivation.

In Tamil Nadu, landraces like Koodai Samba, Sembalai, and Sornawari (for the summer season), along with Karunkuruvai, Vellakuruvai, Arupatham Kuruvai, Arupatham Samba, Soorakuruvai, Thirupathisaram, Varappukudaichaan, Nootripathu, and Puzhuthikaal (for the Kuruvai season), as well as Athur Kitchili Samba, Anaikomban, Bhavani Samba, Kappa Kaar, Norungan, Illupaipoo Samba, Kandasaali, Kalanamak, Kottarasamba, Manjal Ponni, Thanga Samba, Muttrina Sannam, Rathasaali, Salem Sanna, Thengaipoo Samba, and Puzhuthi Samba (for the Samba season), and Karunkuruvai, Kullakaar, Mysore Malli, Singini Kaar, Vellai Chithirai Kaar, Navarai, Mattai Kaar, Kollikaar, and Kuruvai Kaar (for the Navarai season) have been identified [2] [25]. Similarly, in Odisha, drought-tolerant varieties such as Kala Jeera, Muchakanta, and Haladichudi have been recognized [34].

3.3 Flood tolerant landraces

The submergence of rice fields by floodwaters presents a critical threat to both crop survival and productivity, often culminating in the partial or complete destruction of crops. Prolonged inundation of rice plants can induce detrimental consequences, leading to suppressed growth, diminished tillering, and compromised grain quality. When rice plants remain submerged for extended periods, their growth and development experience severe hindrance. The lack of access to oxygen during submergence restricts the plants' capacity to execute essential physiological processes, including respiration and nutrient absorption. As a result, rice plants may encounter stunted growth and reduced tillering, leading to a reduced count of productive tillers and a decreased number of grains per plant. The stress induced by submergence can also exert negative effects on the quality of harvested grains, further eroding the overall productivity of the crop.

To tackle the challenges posed by flooding, scientists and breeders have been actively engaged in identifying and cultivating flood-tolerant rice varieties. These variants demonstrate extraordinary resilience against prolonged submergence and possess the ability to withstand the adverse impact of flooding on rice crops. In multiple regions across India, flood-tolerant rice varieties have been successfully pinpointed and cultivated. These variants have showcased the capability to endure submergence and sustain growth even amidst flooding. By harnessing the genetic diversity prevalent in both landraces and modern cultivars, breeders have effectively crafted flood-tolerant rice varieties capable of adeptly navigating the trials posed by flooding.

The identification and endorsement of flood-tolerant rice varieties hold immense significance for regions susceptible to flooding. By cultivating these variants, farmers can mitigate the devastating consequences of floods on their rice crops, thereby enhancing crop resilience, stability in production, and bolstered food security. Furthermore, the development of flood-tolerant rice varieties contributes to the conservation of agricultural biodiversity and the safeguarding of traditional genetic resources linked to flood-prone areas.

In West Bengal, flood-tolerant landrace varieties encompass Kelas and Bhutmoori [23]. Similarly, Tamil Nadu features flood-tolerant varieties such as Madumuzhungi, Maapillai Samba, Thidakaal, Neelan Samba, Kudiraivaal Samba, Koompalai, Kaliyan Samba, Chinna Ponni, and Swarna Mahsuri for the Samba season. For the Navarai season, Rasakadam, Kappakaar, Kudiraivaal Samba, Rose Kaar, Varappukudaichaan, Thidakaal, Matta Kaar, and Sivappu Kuzhiadichaan have also been identified [2]. Furthermore, in Odisha, flood-tolerant varieties including Biland, Rabana, and Patin have been recognized [36].

3.4 Submergence tolerant landraces

Submergence stands as a significant peril to the growth of rice plants, as it deprives them of essential oxygen. The impact of submergence on rice production leads to reduced photosynthesis, stunted growth, underdeveloped roots and shoots, and ultimately, diminished productivity.

In Odisha, a number of rice varieties showcase tolerance to submergence, encompassing Samudrabali, Basnamundi, Gadala, Surudaka, and Dokarakuji [36]. Furthermore, Tamil Nadu is renowned for its rice landraces that possess robust and deep fibrous roots, endowing them with the capability to withstand sea erosion. Among these landraces are Ariyan, Thengaipoo Samba, Uvar Mundan, Kaar Palai, Samba Nel, Kaattu Kuthaalai, Kuzhiparichaan, Koompalai, Magathae, Madhimuni, Sadaikaar, Mulen Kaima, Ottadam, Malai Nel, and Rasakadam [25].

3.5 Shade-tolerant landraces

In Tamil Nadu, the landrace Kaattu Ponni (with a duration of 130 to 140 days) displays shade tolerance, making it suitable for cultivation as an intercrop in coconut plantations and fruit orchards, including mango orchards [25]. In the north eastern region of India, shade-tolerant varieties such as Bhasamanik, Sasarang, Rudra, and Swarnaprabha have been identified, making them viable options for intercropping in plantation areas [14].

4. Landraces for biotic stress

The productivity of rice is profoundly influenced by an array of biotic stresses, presenting farmers with diverse challenges. Among these biotic stressors, pests stand out as a significant threat to rice cultivation. Stem borers, leaf folders, and brown plant hoppers, in particular, have been identified as major culprits, inflicting extensive damage upon rice plants. These pests target various parts of the rice plant, including its foliage, stems, and reproductive structures, resulting in decreased yield and compromised plant health. The cumulative effects of these pest infestations on rice plants can lead to growth stunting, reduced tillering, inadequate grain formation, and ultimately, diminished yields. As a consequence, farmers are confronted with substantial hurdles in safeguarding their rice crops from these destructive pests, aiming to ensure optimal productivity and minimize economic losses.

Noteworthy is the resistance exhibited by specific landraces in response to biotic stresses. For instance, in the north eastern region of India, certain landraces including Badshabhog, Gamra, Haldichuri, Janglijata, Kalabhat, and Khara have demonstrated resistance to brown plant hoppers, as emphasized by [45]. Similarly, in southern India, landraces such as Nazarbad, Bheemasaale, Nazarbaik, Kichadi Samba, Kattaru, Mouruda, Bagashaparimalaakki, Kempukaalu, Malgudisanna, Delhibogabhattha, Sannakki, Padma Rekha, Chitiga, Sharavathikempu, Andrabasumati, Orrisabhattha, Kasubai, Bangarakaddi, Meese Bhattha, Kemputadi, Kavadhari, Jeerige Samba, Tunuru, Dappavalya, Rasakadari, Nagabhatha, Baiganmanja, Bud Bhattha, and Siddasanna showcase resistance to root knot nematode (Meloidogyne graminicola) [42]. Moreover, Neelan Samba exhibits resistance to the ear head bug, while Sivappu Kuruvikaar rice displays resistance to the rice case worm [2]. Landraces such as Thengapoo Samba, Kamba Samba, Kandhasala, and Kandavali exhibit pronounced resistance to the rice yellow stem borer, while Kuruvikar, Seeraga Samba, Karudan Samba, and Kaivara samba showcase strong resistance to the gall midge. Furthermore, Seeraga Samba, Kandasala, Karudan Samba, and Thengapoo Samba exhibit notable resistance to the leaf folder [41].

Additionally, diseases such as blast, sheath blight, and bacterial leaf blight have the potential to cause significant reductions in yield by affecting plant growth, grain development, and overall productivity. Bacterial blight, for instance, results in leaf and grain discoloration, diminishing the visual appeal and marketability of the grains. Similarly, rice blast can lead to grain discoloration, shriveling, and chalkiness, adversely impacting the cooking and milling quality of rice. Encouragingly, certain landraces display resistance to these diseases. Landraces including Chandrahasini, Keshav, Swarna Mukhi, Jata Dhan, Kalo Bhutia, Kala Jeera, Samleshwari, Khaja, Sabita, Rasi, Manhar, Pathara, Sarathi, Paani Doola, Banitana, Kalo Mota, Shalimar, and Lakhi Chura exhibit resistance to blast [49]. In other regions, blast-resistant landraces such as Chame, Champei Sali, Chirakhey, Buda Atte, Lamo, Khimti, Jhapaoa, Akola, Jyoti, Jaya, Garomalati, Khasi, Upahar, Birun, Gujari, Jeeram, Dadri Kalam, and Dangir have been identified in Punjab, Maharashtra, Gujarat, and Tripura, as reported by [58].

5. Landraces for nutritional enrichment

Rice, hailed as a crucial source of dietary carbohydrates, often falls short of meeting overall energy and nutritional needs due to its deficiency in essential micro-nutrients. This insufficiency of micro-nutrients gives rise to a condition known as hidden hunger, prevalent especially in developing countries, where individuals suffer from nutrient deficiencies. To address this concern, various strategies have been proposed, including the fortification of food and the promotion of diversified diets abundant in vitamins and minerals. However, these approaches may not be economically feasible or universally implementable across all communities. Against this backdrop, bio-fortification emerges as an encouraging and pragmatic solution to augment the micro-nutrient content in staple foods. Within this context, rice landraces hold considerable promise as genetic resources naturally endowed with micro-nutrients, particularly iron and zinc. These landraces, with their genetic diversity, present an untapped repository of valuable attributes that could counter hidden hunger and enhance the nutritional value of rice.

Despite their potential, the exploitation of these invaluable genetic resources, namely rice landraces, remains largely unexplored [32] [48]. By tapping into the genetic reservoir of landraces, breeders and scientists have the opportunity to cultivate improved rice varieties that are inherently enriched with micro-nutrients, thereby offering a sustainable and cost-effective approach to combat hidden hunger and improve human health. To fully harness the potential of rice landraces, further research, breeding programs, and collaboration among scientists, farmers, and policymakers are indispensable. By prioritizing the investigation and utilization of these genetic

resources, we can pave the way for a more resilient, nutritious, and sustainable future, ensuring that rice, as a staple crop, satisfactorily addresses the nutritional requirements of global communities.

Some prominent landraces in this context include Kuzhiadichaan, Thailand Kavuni, Chennellu, Kalanamak, Salam Samba, Ottadai, Sembalai, Kandasali, Sivappumalli, Kavuni Nel, Sivappu Kavuni, Lalmati, Athira, Bhavani, Rajalakshmi, Altera, Mappillai Samba, Burma Kavuni, Melaki, Kattu Ponni, Kaivara Samba, Karuppu Kavuni, Paalkichadi, Poongar, Rasakadam, Kattu Vanipam, Thodipaliyan, and Norugan [53]. These landraces boast high protein content, surpassing 10 percent [2] [3]. Furthermore, landraces like Sivappu Kuruvikaar, Sivappu Kavuni, Jeeraga Samba, Sanna Samba, Poovan Samba, Poompalai, Navara, Mappillai Samba, Kudavaazhai, Kattuyanam, and Kappa Kaar are replete with magnesium content. Landraces such as Valiya Chennel, Thanga Samba, Sooran Kuruvai, Sivappu Kurivikaar, Sivappu Kouni, Poompalai, Ottadai, and Kuzhiachaan are recognized for their iron content. Those rich in potassium include Kalanamak, Kaivara Samba, Kadaikazhuthan, Kalar Paalai, Iravai Pandi, Garudan Samba, Ambemohar, Adukku Nel, Kattuyanam, Kuzhiadichaan, Navara, Neelan Samba, and Poovan Samba. Calcium-laden landraces encompass Kadaikazhuthan, Kaivara Samba, Kaliyan Samba, Iravai Pandi, Kattuyanam, Kuzhiadichaan, Kulla Kaar, Samba Mosanam, and Thanga Samba. Zinc-rich rice varieties include Sivappu Kuruvikaar, Poovan Samba, Ottadai, Navara, Kullakaar, Kuzhiadichaan, Kottara Samba, Kudavaazhai, Koomvazhai, Kalarpaalai, and Karunkuruvai. Notably, phosphorus-rich landraces encompass Ambmohar and Adukkunel [2] [25].

6. Landraces for aroma

Aroma rice stands out for its exceptional quality, natural fragrance, and exquisite flavor, leaving an indelible mark on regional cuisines, traditional recipes, and festive culinary preparations. Its unique and alluring sensory attributes play a significant role in shaping India's diverse culinary landscape and rich cultural heritage. As consumer preferences evolve and a greater appreciation for distinctive gastronomic experiences emerges, the demand for aromatic rice varieties has witnessed a surge both within India and on the global stage. This escalating interest presents a valuable opportunity to export these highly sought-after aromatic grains to international markets.

The remarkable flavors and enticing aromas of Indian aromatic rice varieties make them a coveted choice for diverse culinary journeys across the world. Functioning as premium or specialty rice, these aromatic varieties command higher market prices compared to their non-aromatic counterparts. The cultivation and trade of aroma rice bring substantial economic advantages to farmers and local communities, serving as a pivotal catalyst for rural development by generating income and fostering employment along the entire rice value chain [5].

Furthermore, the cultivation and conservation of aromatic rice varieties serve a pivotal role in upholding agricultural biodiversity and safeguarding traditional genetic resources. By nurturing and preserving these distinctive rice cultivars, we ensure the continuity of diverse genetic materials for generations to come. This conservation endeavour has grown increasingly crucial as modern agricultural practices often prioritize high-yielding varieties at the expense of traditional ones. The preservation of aromatic rice varieties becomes a means to safeguard the cultural heritage intertwined with these grains, guaranteeing the perpetual availability of their exceptional flavours and aromas.

Aroma rice holds a special and cherished place in India's culinary traditions, offering an array of premium-quality grains brimming with distinct flavours and captivating aromas. The mounting demand for these aromatic varieties creates an avenue for both domestic and international markets. By advocating for the cultivation, trade, and conservation of aroma rice, we can stimulate economic growth, safeguard traditional genetic resources, and contribute to the vibrant and diverse culinary experiences relished by people worldwide.

Notable examples of high aroma rice landraces encompass Gujinina, Kalonunia, Red Hira Sail, Kanakchur, Radhuni Tilak, Dangi, Bashful, and Kala Mogha [47]; Gujanonia, Kalajeera, Haldichudi, Machakanta, and Donger Basmati [33]; Tulsi Bhog, Lilabati, Dar Sal, Tulsi mukul, Karpurtal, and Kanakchur [44]; Ambemohr, Kagisali, Beeraga, Kumud, Yalakkisali, Huggi Bhatta, Karigajavile, and Belguam Basmati [16]; Jeeragasala, Gandagasala, Briyaniari, Mullanchenna, Gobindobhog 1, Gobindobhog 2, Kala Jeera, and Taraori Basmati [13]; and Hansraj, Mushkbudgi, Basmati, Larbeoul, Qudirbeigh, Shahie, Barpasso, Katyoor, and Thapachini [39].

7. Landraces for Grain quality

The assessment of rice quality parameters holds paramount significance in gauging the overall suitability and excellence of rice for consumption. Attributes such as visual appeal, texture, fragrance, taste, and cooking attributes play a direct role in determining consumer contentment. Furthermore, rice of superior quality, possessing sought-after attributes, commands higher value in the market. Parameters linked to cooking, encompassing water absorption, cooking duration, and texture, play a pivotal role in establishing the adaptability of rice for various cooking techniques, spanning from steaming and boiling to stir-frying [12].

These quality parameters ensure that the rice cooks evenly, maintains its form, and offers a delightful dining experience. As an illustration, specific rice landraces like Osawalkathalai, Aanaikomban, Seethavalli Kuruvai, Thirpathisaara, Hallaga, Kanwa, Aden Kelte, Alur Sanna, Bangar Kaddi, Karigajavili, Padmarekha, Raj Kamal, Putta Bhatta Local, Rajkhaima, Karigajavili, Padmarekha, Laljhini, Achoo, Madhumalti, Mushkan, Qudirbeigh, Habri, Patari, Mehwan, and Preneibar are celebrated for their exceptional cooking attributes and the ability to maintain quality [20] [24]. Aanaikomban, Seethavalli Kuruvai, and Thirpathisaaram are landraces that showcase remarkable keeping quality for up to two weeks [25], while Oswalkuthalai remains untainted overnight [33]. Laljhini, Achoo, Madhumalti, Mushkan, Qudirbeigh, Habri, Patari, Mehwan, and Preneibar fall within the range of intermediate amylose content [39].

Conclusion

The distinctive attributes inherent in landraces render them invaluable assets for elevating crop improvement techniques and enhancing agricultural methodologies. Their inherent features, including resistance to diseases and pests, tolerance to environmental stresses, and adaptability to local contexts, position them as potent tools for tackling pressing issues like climate fluctuations, emerging diseases, and evolving agricultural strategies. By integrating these attributes through hybridization initiatives, breeders can forge improved cultivars that are better equipped to surmount these challenges, thereby establishing resilient and sustainable agricultural systems. Moreover, landraces encompass heightened levels of essential

nutrients, vitamins, and antioxidants when compared to contemporary varieties. This nutritional edge opens avenues to combat malnutrition and advocate healthier diets, especially within regions heavily dependent on staple crops. By integrating the nutritional attributes of landraces into modern varieties, breeders can contribute to the fight against malnutrition and elevate the overall health and well-being of communities. Furthermore, landraces often showcase favorable agronomic characteristics, including early maturation, drought resistance, elevated yield potentials, and superior grain quality. These traits hold pronounced significance in resource-constrained regions, where the cultivation of landraces can substantially augment agricultural productivity and amplify food security. Leveraging landraces exhibiting these desirable traits can optimize resource allocation and provide sustainable solutions to address escalating food demands.

Harvesting the genetic diversity inherent in landraces remains pivotal in the construction of enhanced crop varieties that embody resilience, nutritional richness, and alignment with local environments. By conserving and harnessing the genetic resources encapsulated in landraces, breeders can craft crop varieties that not only confer benefits upon farmers and consumers but also contribute to the realm of environmental sustainability. The diversity harbored within landraces furnishes the essential genetic material to breed for attributes that amplify productivity, nutritional content, and adaptability to shifting environmental dynamics.

In culmination, by harnessing the genetic diversity enshrined in landraces, breeders can pioneer crop varieties that concurrently address multifaceted challenges—bolstering resilience, nutritional value, and agronomic efficacy. Ultimately, this approach benefits farmers through heightened productivity and income, consumers through access to healthier and more nourishing sustenance, and the environment through the endorsement of sustainable agricultural methodologies. The conservation and utilization of landraces chart a promising trajectory towards a more sustainable and food-secure future.

Future scope: The comprehension of the vast array of available rice landraces undoubtedly offers an abundance of choices for selecting source materials with diverse quantitative and qualitative traits for rice improvement programs. In our current scenario, where we are grappling with the severe repercussions of climate change, the extensive reservoir of rice landraces could emerge as a transformative solution, akin to a magical tool, for enhancing future rice improvement efforts.

Conflict of intrest: There is no conflict of intrest.

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References

1. Ali, M. N., Yeasmin, L., Gantait, S., Goswami, R. and Chakraborty, S. (2014). Screening of rice landraces for salinity tolerance at seedling stage through morphological and molecular markers. Physiology and Molecular Biology of Plants. 20:411-423.
2. Balasubramanian, A. V., Vijayalakshmi, K., Parimala, K., Subhashini Sridhar, Subramanian, K. and Manikandan, R. (2019). Traditional rice varieties of Tamil Nadu: A source book, The Centre for Indian Knowledge System (CKIS).
3. Banerjee, S., Chandel, G., Mandal, N., Meena, B. M. and Saluja, T. (2011). Assessment of nutritive value in milled rice grain of some Indain rice Landraces and their molecular characterization. Bangladesh Journal of Agricultural Research. 36: 369-380.
4. Behera, P. K., Kumar, V., Sharma, S. S., Lenka, S. K. and Panda, D. (2023). Genotypic diversity and abiotic stress response profiling of short-grain aromatic landraces of rice (Oryza sativa L. indica). Current Plant Biology. 33:100269.
5. Behera, P. K. and Panda, D. (2023). Germplasm Resources, Genes and Perspective for Aromatic Rice. Rice Science. 30:294–305.
6. Bhowmik, U., Kibria, M. G., Rhaman, M. S., Murata, Y. and Hoque M. A. (2021). Screening of rice genotypes for salt tolerance by physiological and biochemical characters. Plant Science Today. 8:467–472.
7. Blakeney, M., Krishnankutty, J., Raju, R. K. and Siddique, K. H. M. (2020) Agricultural Innovation and the Protection of Traditional Rice Varieties: Kerala a Case Study. Frontier in Sustainable Food System. 3:116.
8. Bohra, A., Kilian, B., Sivasankar, S., Caccamo, M., Mba C., McCouch, S. R. and Varshney, R.K. (2022). Reap the crop wild relatives for breeding future crops. Trends in Biotechnology. 40:412-431.
9. Casañas, F., Simó, J., Casals, J. and Prohens, J. (2017) Toward an Evolved Concept of Landrace. Frontier in Plant Science. 8:145.
10. Cheng, X., Huang, Y., Tan, Y, Tan, L., Yin, J. and Zou, G. (2022). Potentially Useful Dwarfing or Semi-dwarfing Genes in Rice Breeding in Addition to the sd1 Gene. Rice. 15:66.
11. Chigira, K., Kojima, N., Yamasaki, M, Yano, K., Adachi, S., Nomura, T., Jian, M, Katsura, K. and Ookawa, T. (2020). Landraces of temperate japonica rice have superior alleles for improving culm strength associated with lodging resistance. Scientific Reporter. 10:19855.
12. Cuevas, R. P., Pede, V. O., McKinley, J., Velarde, O. and Demont, M. (2016). Rice Grain Quality and Consumer Preferences: A Case Study of Two Rural Towns in the Philippines. PLoS ONE. 11: e0150345.
13. Das, B., Sengupta, S., Parida, S. K., Roy, B., Ghosh, M., Prasad, M. and Ghose, T. K. (2013). Genetic diversity and population structure of rice landraces from Eastern and North Eastern States of India. BMC Genetics. 14: 71.
14. Ganguly, S., Saha, S., Vangaru S, ,Purkayastha, S., Das, D., Saha, A. K., Roy, R., Das, S., Bhattacharyya, P. K., Mukherjee, S. and Bhattacharyya, S. (2020). Identification and analysis of low light tolerant rice genotypes in field conditions and their SSR-based diversity in various abiotic stress tolerant lines. Journal of Genetics. 99:24

15. Govindaraj, M., Vetriventhan, M. and Srinivasan, M. (2015). Importance of Genetic Diversity Assessment in Crop Plants and Its Recent Advances: An Overview of Its Analytical Perspectives. Hindawi Publishing Corporation Genetics Research International. 2015: 14.

16. Hanamaratti, N. G., Sathisha, T. N., Veeresha, B. A., Surendra, P. and Salimath, P. M. (2015). Stability analysis of protein content in traditional land races of rice. The Ecoscan. 9: 481-485.

17. Hazarika, M. (2017). Prehistory and archeology of Northeast India. Multidisciplinary Investigation in an Archaeological Terra Incognita. New Delhi, Oxford University Press.

18. Hour, A., Hsieh, W., Chang, S., Wu, P., Chin, H. and Lin, Y. (2020). Genetic Diversity of Landraces and Improved Varieties of Rice (Oryza sativa L.) in Taiwan. Rice. 13:82.

19. Islam, M, R., Gregorio, G. B., Salam, M. A., Collard, B. C. Y., Singh, R. K. and Hassan. L. (2012). Validation of SalTol linked markers and haplotype diversity on chromosome 1 of rice. Molecular Plant Breeding. 3:103-114.

20. Jakkeral, S. A., Patil, S. U., Hanumantappa, M., Shashikala, K. and Dhanlaxmi, T. N. (2018). Medicinal uses of red rice in coastal Karnataka. Journal of Pharmacognosy and Phytochemistry. 7: 436-439.

21. Kaisera, N., Douchesa, D., Dhingrab, A., Glennc, K. C., Herzigd, P. R., Stoweb, E. C., Swarup, S. (2020). The role of conventional plant breeding in ensuring safe levels of naturally occurring toxins in food crops. Trends in Food Science & Technology 100:51-66.

22. Kapazoglou, A., Gerakari, M., Lazaridi, E., Kleftogianni, K., Sarri, E., Tani, E. and Bebeli, P. J. (2023). Crop Wild Relatives: A Valuable Source of Tolerance to Various Abiotic Stresses. Plants 12:328.

23. Karmakar, J., Roychowdhury, R., Kar, R. K., Deb, D. and Dey, N. (2012). Profiling of selected indigenous rice (Oryza sativa L.) landraces of Rarh Bengal about osmotic stress tolerance. Physiology and Molecular Biology of Plants. 18: 125-132.

24. Khera, P., Priyadarshi, R., Singh, A., Mohan, R., Ulaganathan, K. and Shenoy, V. (2012). Scope for utilization of native specialty landraces, cultivars and basmati types in rice heterosis breeding. Journal of Plant Breeding and Crop Science 4: 115-124.

25. Krishnan, V., Anuratha, A., Thamzharasi, M. and Anandhan, T. (2022). Special attributes of Land races, Pachai Bhoomi, ISBN 978-81-955977-5-8.

26. Kumar, A., Shalabh, D., Ram, T., Yadaw, R. B., Mishra, K. K. and Mandal, N. P. (2014). Breeding high-yielding drought-tolerant rice: Genetic variations and conventional and molecular Approaches. Journal of Experimental Botany. 65:6265–6278.

27. Kumar, P. and Sharma, P. K. (2020) Soil Salinity and Food Security in India. Frontier Sustainable Food System. 4:533781.

28. Liu, L., Ma, X., Liu, S., Zhu, C., Jiang, L., Wang, Y., Shen, Y., Ren, Y., Dong, H., Chen, L., Liu, X., Zhao, Z., Zhai, H. and Wan, J. (2009). Identification and characterization of a novel Waxy allele from a Yunnan rice landrace. Plant Molecular Biology. 71: 609–626.

29. Liu, J., Wang, Z. and Guo, X. (2022). Stem Characteristic Associated with Lodging Resistance of Rice-Changes with Varied Alternating Drought and Flooding Stress. Agronomy. 12: 3070.

30. Liu, Y., Wang, F., Zhang, A., Chen, Z., Luo, X., Kong, D., Zhang, F., Yu, X., Liu, G. and Luo, L. (2023). Improvement of Salinity Tolerance in Water-Saving and Drought-Resistance Rice (WDR). International Journal of Molecular Science. 24:5444.

31. Mazumder, R., Hoque, H., Sinha, B., Chowdhury, W. R., Hasan, M. N., Prodhan, S. H. (2020). Genetic variability analysis of partially salt tolerant local and inbred rice (Oryza sativa L.) through molecular markers. Heliyon. 6: e04333

32. Majumder, S., Datta, K. and Datta, S. K. (2019). Rice Biofortification: High Iron, Zinc, and Vitamin-A to Fight against "Hidden Hunger." Agronomy. 9: 803.

33. Mishra, S., Chaudhury, S. S. and Mohanty, R. B. (2013). Diversity of some threatened indigenous rice varieties cultivated in Odisha, India. Environment and Natural Resources Journal. 11:41-57.

34. Mishra, S.S., Behera, P. K. and Panda, D. (2019). Genotypic variability for drought tolerant related morpho-physiological traits among indigenous rice landraces of Jeypore tract of Odisha. Indian Journal of Crop Improvement. 33: 254-278.

35. Mishra, B. K. and Chaturvedi, G. S. (2018). Flowering Stage Drought Stress Resistance in Upland Rice in Relation to Physiological, Biochemical Traits and Yield. International Journal of Current Microbiology and Applied science. 2: 2319-7706.

36. Panda, D. and Sarkar, R. K. (2013) Characterization of Leaf Gas Exchange and Anti-oxidant Defense of Rice (Oryza sativa L.) Cultivars Differing in Submergence Tolerance Owing to Complete Submergence and Consequent Re-aeration. Agricultural Research 2:301–308.

37. Panda, S., Gupta, A. D. and Dey, N. (2022). Impact of Drought Stress on Grains Filling in Rice and its Management: A Review. Agricultural Reviews. 3.

38. Peng, Y., Hu, Y., Qian, Q. and Ren, D. (2021). Progress and Prospect of Breeding Utilization of Green Revolution Gene SD1 in Rice. Agriculture 11: 611.

39. Rana, J. C., Negi, K. S., Wani, S. A., Saxena, S., Pradheep, K., Kak, A., Pareek, S. K. and Sofi, P. A. (2009). Genetic resources of rice in the Western Himalayan region of India: current status. Genetic Resources Crop Evolution 56: 963–973.

40. Rasel, M., Tahjib-Ul-Arif, M., Hossain, M. A., Hassan, L., Farzana, S. and Brestic, M. (2021). Screening of Salt-Tolerant Rice Landraces by Seedling Stage Phenotyping and Dissecting Biochemical Determinants of Tolerance

Mechanism. Journal of Plant Growth Regulation. 40: 1853–1868.

41. Roseleen S. J. S. Chitra K and C Gailce Leo Justi. (2020). Reaction of land races of rice against major chewing pest of rice under saline conditions. The Pharma Innovation Journal. 9(8): 211-214.

42. Ravindra, H., Sehgal, M., Narasimhamurthy, H. B., Imran Khan, H. S. and Shruthi, S. A. (2015). Evaluation of rice landraces against rice root-know nematode, Melidogyne graminicola. African Journal of Microbiology Research. 9:1128-1131.

43. Rodríguez Coca, L. I., García González, M. T., Gil Unday, Z., Jiménez Hernández, J., Rodríguez Jáuregui, M. M. and Fernández Cancio, Y. (2023). Effects of Sodium Salinity on Rice (Oryza sativa L.) Cultivation: A Review. Sustainability 15:1804.

44. Roy, S., Banerjee, A., Pattanayak, A., Roy, S.S., Rathi, R. S., Mishra, A. K. and Bansal, K. C. (2014). Chakhao (delicious) rice landraces (Oryza sativa L.) of North-East India: Collection, conservation and characterization of genetic diversity. Plant Genetic Resources, 12: 264-272.

45. Roy, B., Tulsiram, S. D., Debbarman, S., Sundarrao, G. S., Roy, M., Saha, P., Poddar, S., Maity, U. H. A., Murali, H.A., and Kumar, R. (2022). Conservation and successful utilization of landraces for rice improvement. Environment Conservation Journal, 23: 114–123.

46. Salgotra, R. K. and Chauhan, B. S. (2023). Genetic diversity conservation and utilization of PGR, Gene. 14:174.

47. Semwal, D. P., Pandey, A., Bhandari, D. C., Dhariwal, O. P., and Sharma, K. (2014). Variability study in seed morphology and uses of indigenous rice landraces (Oryza sativa L.) collected from West Bengal, India. Australian Journal of Crop Science, 8: 460–467.

48. Senguttuvel P, GP, C J, D SR, CN N, V J, P B, R G, J AK, SV SP, LV SR, AS H, K S, D S, RM S and Govindaraj M. (2023). Rice biofortification: Breeding and genomic approaches for genetic enhancement of grain zinc and iron contents. Frontier Plant Science 14:1138408.

49. Shikari, A. B., Khanna, A., Gopala Krishnan, S., Singh, U. D., Rathour, R., Tonapi, V., Sharma, T. R., Nagarajan, M., Prabhu, K. V. and Singh, A. K. (2013). Molecular analysis and phenotypic validation of blast resistance genes Pita and Pita2 in landraces of rice (Oryza sativa L.). Indian Journal of Genetics and Plant Breeding 73(2): 131-141.

50. Singh. K., Gupta, K, Tyagi, V. and Rajkumar, S. (2020). Plant genetic resources in India: management and utilization genetics resources and biocollections 24:306-314.

51. Sivakumar, P., Chitra M., Gatta, V. V., Harshavardini K., Karunakaran, V. and Velayutham, A. (2021). Exploration of traditional rice (Oryza sativa L.) land races: Scope for the future sustainable food production. The Pharma Innovation Journal 10: 1039-1043.

52. Smykal, P., Nelson, M. N., Berger, J. D. and Wettberg, E. J. B. V. (2018). The impact of genetic changes during domestication. Agronomy 8:119.

53. Theertha, P., Banumathy, S., Sassikumar, D., Ramalingam, J. and Ilamaran, M. (2021). Study on physicochemical properties of rice landraces for amylose, gel consistency and gelatinization temperature. Electronic Journal of Plant Breeding. 12: 723-731.

54. Umakanth, B., Vishalakshi, B., Kumar, P. S., Ramadevi, S. J. S., Bhadana, V. P., Senguttuvel, P., Kumar, S., Sharma, S. K., Sharma, P. K., Prasad, M. S. and Madhav, M. S. (2017). Diverse Rice Landraces of North-East India Enables the Identification of Novel Genetic Resources for Magnaporthe Resistance, Frontier Plant Science 8: 1500.

55. Vaughan, D. A., Balázs, E. and Heslop-Harrison, J. S. (2007). From Crop Domestication to Super-domestication. Annual Botany 100:893–901.

56. Velprabakaran, S., Rajeswari, S. and Brindadevi, S. (2020). Diversity of traditional rice varieties and their medicinal benefits for human benefits. Life Sciences Leaflets,124:20-25.

57. Wang, Y., Wang, Y., Sun, X., Caiji, Z., Yang, J., Cui, D., Cao, G., Ma, X., Han, B., Xue, D and Han, L. (2016). Influence of ethnic traditional cultures on genetic diversity of rice landraces under on-farm conservation in Southwest China. Journal of Ethnobiology and Ethnomedicine 12 :51.

58. Yadav, M. K., Aravindan, S., Ngangkham, U., Raghu, S., Prabhukarthikeyan, S. R., Keerthana, U., Marndi, B. C., Adak, T., Munda, S., Deshmukh, R., Pramesh, D., Samantaray, S. and Rath, P. C. (2019). Blast resistance in Indian rice landraces: Genetic dissection by gene specific markers. PLoS One. 14: e0211061.