Genetic resources of sticky rice in India: status and prospects

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REVIEW

Genetic resources of sticky rice in India: status and prospects

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Abstract Glutinous rice or sticky rice (*Oryza sativa* L. var. *glutinosa*) is a special category of rice as it contains no gluten and therefore, is used as an important, gluten-free carbohydrate. The genetic resources on sticky rice are less documented due to limited consumption in India. Collection, evaluation and documentation of the glutinous rice are important for ensuring germplasm exchange, food security and sustainable agriculture across countries. Therefore, the study of glutinous rice distribution can partially fill the information gap for further policy making strategies of the nation. Therefore, the major objective of this review was to analyze and gather the information on distribution of glutinous rice, their genetic resources status and varieties released in order to map the glutinous rice heritage of the India. Therefore, this status paper documents all the comprehensive information available on sticky rice in India.

Keywords Amylose · Rice germplasm · Japonica rice · Released varieties · Quality traits

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Introduction

As per estimates, Asia alone will be responsible for world's half of the economic output to the largest quality food including higher quality grain rice (Calingacion et al. 2014). Globally, white rice production is about 476 mt of milled rice wherein sticky rice or also called as glutinous rice (*Oryza sativa* L. var. *glutinosa*) makes up 5% (23.8 mt) of it. Glutinous rice is primarily grown in Laos, Vietnam, Cambodia, Thailand, Indonesia, Malaysia, Nepal, Myanmar, Bhutan, China, Northeast India, Korea, Japan, Philippines, and the Taiwan. It is a multi-dimensional crop important in food, socio-economic and, community livelihood culture, mainly in ASEAN countries (Isvilanonda 2013; Isvilanonda and Pananurak 2015). This specialty rice-type in Asia

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also ensures socio-cultural diversity and provides basic nutritional security to the families of poor rice farmers (Naivikul 2013). Further in Southeast Asia, Laos PDR and Thailand are the major glutinous rice producing countries in the where, an estimated 85% of Laos People's Democratic Republic (PDR) rice production is of glutinous type and therefore, recognized as glutinous rice biodiversity center (Delforge 2001; Manivong and Cramb 2020). Other ASEAN countries, also contain small areas for the production of the sticky rice (Sengsourivong and Ichihashi 2019).

Amylose content and sticky rice

Contrary to its name, glutinous rice does not contain gluten (Naivikul 2013). Amylose content (AC) is considered as the major predictor of quality of rice due to its association with textural features like hardness and stickiness and it is relatively simple to measure (Klaochanpong et al. 2015). The amylose content in rice is a very complex trait and generally influenced by the multiple genes especially the *waxy* (*Wx*) gene, and environment. The *Wx* gene present in rice, encodes the granule bound starch synthase I enzyme, that helps in the synthesis of amylose (Roy et al. 2020). This allele of the *Wx* gene leading to formation of granule bound starch synthase (GBSS) governing low amylose is also reported to be sensitive to high temperature (Calingacion et al. 2014). The starch component in the normal rice (non-glutinous) grain is mainly composed of amylopectin and amylose, whereas glutinous rice is a mutant type and contains little or no amylose. More than 95% amylopectin in glutinous rice causes milky-white endosperm (Setyaningsih et al. 2015; Liu et al. 2019; Teng et al. 2021). Though glutinous grain feature is mostly associated with *japonica* rice cultivars, yet some *indica* varieties are also glutinous types (Roy et al. 2020). Studies on screening for α-amylase inhibitory activity using different varieties of indigenous rice seeds showed that debranched starch of waxy rice has lowest viscosity and highest solubility (Sarnthima et al. 2020). International Network for Quality Rice has classified and defined rice varieties as per their amylose content (Table 1). Sticky or glutinous rice varieties include waxy (< 2% amylose) and low (2–19%) amylose types.

People in the Isan region of Thailand and Lao PDR prefer to consume sticky or waxy rice. In Taiwan, Japan, Thailand, Cambodia, Australia, Egypt and, parts of Lao PDR, people consume low amylose rice as do consumers in the south-western and northern provinces of China and southern Vietnam (Fig. 1). The Thailand and Cambodia low amylose varieties are composed of 12–15% amylose, whereas varieties from China, Japan, Australia and Korea have approximately18–19% amylose. Steam-cooked glutinous rice, "khaonueng" is very important staple food for northeast, Thailand people and therefore, is a popular delicacy throughout the country (Ministry of Agriculture and Cooperatives, 2014). In India, Assam sticky rice is classified traditionally as *bora* (glutinous having < 10% amylose) and *chokuwa* (semi glutinous having 10–20% amylose) and both types are used for a great variety of culinary and ceremonial purposes (Roy et al. 2020). This glutinous rice could potentially be developed as supplement to control weight and blood sugar. Sticky rice can be used either hulled or dehulled. The hulled rice is white, whereas dehulled glutinous rice is black or purple in colour. Both white and black sticky rice can be used as flour, cooked

Table 1 Definition of sticky rice varieties as per international network for quality rice

Source: Calingacion et al. (2014), PLoS ONE: 9(1) https://doi.org/10.1371/journal.pone.0085106.g003)

Class	Amylose content (%)	Preference in countries
Waxy	< 2.0	Thailand, Lao PDR
Low	2–19	Thailand, Cambodia,Vietnam, Australia, USA, China, Japan, Taiwan, Korea, Portugal, Egypt
Intermediate	20–25	India, Philippines, Pakistan, USA, China, Brazil, Bangladesh,Myanmar, Indonesia
High	> 25	India, Myanmar, SriLanka, Bangladesh, Uruguay

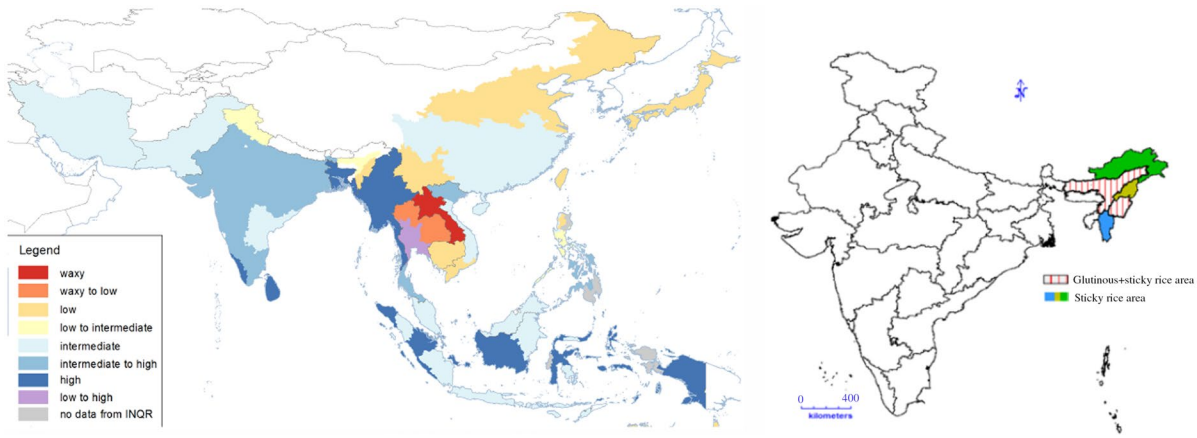

Fig.1 Occurrence and preference areas of sticky/glutinous rice in India and the world

as grains, or as a gel or paste (Klaochanpong et al. 2015).

Geographical distribution of glutinous rice

The glutinous rice zone is distributed throughout the mountainous regions of North Eastern region of India, the Indo-China Peninsula in South and, South East Asia covering China, Bangladesh, Laos, Myanmar, Philippines, as well as adjoining areas (Fig. 1). In India, acceptable taste with stickiness are the preferred characters of glutinous rice in NE states adjoining Assam. Lot of indigenous germplasm possessing low amylose/glutinous rice has been reported especially from the state of Assam (Roy et al. 2020; Pathak et al.2015; Yadugiri 2010; Rathi and Sarma 2012).

Major exporters and importers

Vietnam and Thailand are the major exporters of glutinous rice (GR) but Japan and Korea are the major importers (Sengsourivong and Ichihashi 2019). Glutinous rice is called "gạonếp" in Vietnam and among 1089 rice varieties, 459 are glutinous and 406 are waxy rice types (Nguyên 2001). Glutinous rice is known as "khaoniao" in Thailand and it produces 7.37 mt of glutinous rice, while its domestic consumption is 90%. The remaining 10% (0.74 mt) of GR of Thailand constitute nearly 90% export share of global GR export (Ministry of Agriculture and Cooperatives 2014). Data regarding production and consumption of GR in China is not available; however, it is estimated that China is the largest producer and consumer of GR. Using deductive method, it can be estimated that about 9.00 mt of glutinous rice maybe produced and consumed by China as countries other than top four countries producing glutinous rice have minor shares (Yang et al. 2009). Despite of discrete information scattered here and there; it has not received due consideration. Unfortunately, statistics are not readily available and are scarce. Even Thailand, the major exporter in the world, produces only 16 percent of total glutinous rice production and exports five percent or 0.2–0.5 million metric tonnes of glutinous rice (National Economic and Social Advisory Council, 2014).

Germplasm status in India

1. At ICAR-NBPGR

a. *Import*

Eleven low amylose accessions (EC1030717, EC1030718, EC1030719, EC1030720, EC1030721, EC1030722, EC1030723, EC1030724, EC1030725, EC1030726 and EC687223 and) have been imported from IRRI, Philippines.

b. *Germplasm of sticky/glutinous rice being conserved*

Table 2 State wise germplasm lines being conserved in the name of *Bora* and *Chakuwa* rice in the National Genebank (NGB) at ICAR-NBPGR, New Delhi

State	No. of Bora Accessions in NGB	No. of *Chokuwa/ Chakoha* accessions in NGB	Total accessions conserved as *Bora* and *Chokuwa* in NGB
Assam	260	25	285
Arunachal Pradesh	26	1	27
Manipur	1	59	60
Nagaland	1	2	3
West Bengal	4	0	4
Chattisgarh	3	0	3
Uttar Pradesh	3	1	4
Others	28	18	46
Total	326	106	432

A total of 432 accessions in the names of *Bora* and *Chokuwa* types are being conserved in National Genebank at ICAR-NBPGR, New Delhi wherein maximum number of accessions (285) were contributed by Assam state (Table 2). Similarly, in the name of Sticky and Glutinous rice, a total of 104 accessions are being conserved wherein maximum accessions emanated from Assam (49) followed by Nagaland (27) as shown in Table 3.

c. *Germplasm registered in NBPGR*

In rice, a total of 158 rice accessions have been registered for important traits (including biotic and abiotic stress resistance/tolerance, nutritional and other unique traits) in ICAR-NBPGR, New Delhi. However, of these only 1 accession (IC342367), Misimi Chakuwa has been registered as genetic stock for low amylose content (4.36%) from local collections of Assam. In addition, another 4 Chakuwa rice accessions viz. IC342353 (Boga Chakuwa), IC342354 (Boka Chakuwa), IC342361 (Kalamdani Chakuwa) and IC342368 (Nepali Chakuwa) have been registered for other grain related traits. Some references have reported the identification of indigenous glutinous rice germplasm as per their amylose content in India (Table 4).

2. *ICAR-NRRI and ICAR-IIRR, Hyderabad genebanks*

The ICAR-NRRI over past 6–7 decades have collected, conserved and evaluated 42 sticky rice accessions emanating from NE states. Out of the 42 accessions 17, namely Aghoni bora, Bhogali bora, Gandhi birion, Ghew bora, Gundhibirion, Joha bora, Kola bora, Lalbirion, Lusaibiroin, Nal bora, Pamoi bora, Panibirion, Sona birion-2, Tilbakol bora, Putti birion, Ranga bora1 and Kalobhat reported an amylose content (AC) ranging between 4.3 and 6.6%. The lowest AC was reported from Sona birion-2 followed by Panibirion, whereas highest was found in Nalbora (6.6%) (Bagchi et al. 2020). The variation for quality traits in the seventeen glutinous genotypes identified are presented in the Table 5. Aghoni bora was also reported by NRRI as one of the 'soak and eat type' rice genotype (Yadugiri et al. 2010; Bhakta et al. 2011 and Sharma et al. 2012).

Table 3 State-wise germplasm lines being conserved in the name of Sticky and Glutinous rice in the National Genebank (NGB) at ICAR-NBPGR, New Delhi

NE States	Sticky rice accessions in NGB	Glutinous rice accessions in NGB	Total accessions as sticky and glutinous rice in NGB
Assam	34	15	49
Nagaland	25	2	27
Mizoram	16	0	16
Manipur	6	4	10
Others	2	0	2
Total	83	21	104

Table 4 Germplasm accessions identified for sticky rice with amylose content (waxy or low amylose) in India

Names of germplasm accessions	References
A. Extremely low amylose/waxy (< 2%)	
RikutoNorin mochi20, Miyagi Aikuu, C101, Hao-Nai-Huan, Bokul Bora, Memon Bora, Chandra Bora, Joha Bora, Gela Bora, Singphow Bora, Guad Nang, Malbhog Bora 1, ParoChakuwa, Kmj Bora 35, Kmj Bora 48, Moina Bora	Sarma (2012)
Beji Bora-1, Beji Bora-2, Beji Bora-3, Beji Bora-4, Beji Bora-5, Beji Bora-6, Beji Bora-7, Saudang Bora, Kola Bora-1, Kola Bora-2, Kola Bora 3, Ranga Bora-1,Ranga Bora-2, Ranga Bora-3, Ranga Bora-6, Ghew Bora-3, Ghew Bora-5, Ghew Bora-6, Bora-1, Bora-2, Bora-3, Bora-4, Bora-5, Bora-6, Bao Bora, Pakhiloga Bora, Jota-Bora, Tinhulia Bora-1, Tinhulia Bora-2,Tinhulia Bora-3, Malbhog Bora-1, Malbhog Bora-2, Ne lac Bora, Khamti Bora, Khaldor Bora, Rangli Bora, Chandra Bora, Kmj-B-13, Kmj-B-89, Kmj-B-64, Kmj-B-9, Kmj-B-90, Kmj-B-10, Bor Malbhog, Boga Bora-1,Chakua Bora-1, Kaun Bora, Til Bora, Gela Bora, Memon Bora, Ranga Bora-4, Ranga Bora-4, Oga Chakua-2, Lothow Bora, Misiri Bora, Sukoni Bora-2, Mon Bora-2, Mon Bora-3, Helochi Bora-1, Helochi Bora-2, Kajoli Bora-2, Kajoli Bora-3, Runohi Bora-1, Garuchakua Bora-1,Garuchakua Bora-2, Chefa Birain, Aki Birain, Kacha Birain, Pusha Birain, Das Birain, Mow Birain, Kala Birain, Tepra Birain, Pani Birain, Jhanki Birain, Agirjal Birain, Akib Birain, Jaisungam Birain, Uba Birain, Garuchakhuki Birain, Joha Bora, Jengoni Bora, Bora-7, Chokuwa Bora-2, Boga Bora-2, Chokuwa Bora-1, Rupohi Bora, Tangun Bora, Paro Chokuwa Sali, Sam Chokuwa, Kalamdani Chakuwa-1, Mon Bora-1,Sukoni Bora-1, Kmj-B-48, Kmj-B-50–2, or Chokuwa-1, Rangali Bora, Bor Bora	Rathi and Sarma (2012)
Jaisungam Birain, Chefa Birain, Jaisungam Birain, Chefa Birain, Pani Birain, Tepra Birain, Agirjal Birain, Akib Birain, Mow Birain, Jhanki Birain,Kacha Birain, Kala Birain, Das Birain, Aki Birain,Garuchakhuki Birain, Uba Birain, Pusha Birain, Joha Bora, Kaun bora, Rupohi Bora, Memon Bora, Boga Bora, Rangali Bora, Tangun Bora, Pakhiloga Bora, Til Bora, Ranga Bora-3, Chokuwa Bora-2, Gela Bora, Bor Bora, Chandra Bora, Ranga Bora-1, Jengoni Bora, Garuchakuwa Bora, Bora 2,Ghew Bora	Shaptadvipa and Sarma (2009)
B. Very low amylose (2–10%)	
Aghoni bora, Bhogali bora, Gandhibirion, Ghew bora, Gundhibirion, Joha bora, Kola bora, Lalbirion, Lusaibiroin, Nal bora, Pamoi bora, Panibirion, Sona birion-2, Tilbakolbora, Putti birion, Ranga bora1, Kalobhat, Kmj Bora-72, Garu Chakuwa Bora-1, Bora Pekhi	Bagchi et al. (2020)
Paro chokuwa Sali, Sam Chokuwa, Maju Chokuwa, Chokuwa Bora-1	Shaptadvipa and Sarma (2009)
Gamchakua Bora, Maju Chakuwa-1, Maju Chokuwa-2, Bor Chokuwa-2, Kalamdani Chokuwa-2	Rathi and Sarma (2012)
Gorusika Bora (IC0545259), SakoiBhanuBora (IC0323781), Rupohibora (IC0464660), Kala Bora Dhan (IC0280976), Silonia Bora (IC0466911), Pakhari Bora (IC0298297), Hukani Bora (IC0394293), Dholbao (bora) (IC0332881), Bora dahn (IC0381334), Kankoa Bora (IC0394522), Kala bora (IC0465275), Kakoa bora (IC0394333), Jeng Bora (IC0394476), Jeng Bora (IC0394272), Gomiri Bora (IC0459357), Sam Chokuwa (IC0342369), Ronga Bora (IC0394279), Bora Chokuwa (IC0323796), Til Bora (Sali) (IC0463722), Ganini Bora (IC0459356), Malbhogchokuwa (IC0342366), Bokul Bora (IC0332889), Lathing Bora (IC0462265)	Roy et al. (2020)
C. Low amylose (11–19%)	
Ronga Pekhi	Sarma (2012)
Boga Chokuwa1, Chokuwa Bora-3	Rathi and Sarma (2012)
Bor Chokuwa, Boga Chokuwa, Kalamdani Chokuwa	Shaptadvipa and Sarma, (2009)
Bora Dhan (IC0273181), Pesi Komal (IC0394584), Lahi Chokuwa (IC0342363), Kajoli Chakuwa (IC0342360), Ghiu Bora (IC0298291), Thopa bora dhan (IC0332926), Lahi Chokuwa (IC0323791), Boga Chokuwa (IC0323790), Bongari Bora (IC0323775), Chakowa (IC0464331), Latho Bora (IC0464681), Bora Jalpania(IC0381349), Paita Bora(IC0464430)	Roy et al. (2020)

Similarly, a total of 70 soft rice germplasm (*Bora* and *Chakuwa* types collected from Assam) are being maintained at ICAR-IIRR, Hyderabad for evaluation.

Malagkit or NSIC Rc 13, was the first glutinous rice variety, released by the National Seed Industry Council (NSIC), Philippines in 2005. It has low amylose content, uniformly opaque grains, and

Table 5 Physico-chemical and cooking properties of some Indian glutinous rice varieties

Sl. No	Varieties	Hull %	Mill %	HRR %	KL (mm)	KB (mm)	L/B	Grain Type	ASV	VER	KLAC (mm)	ER	AC%
1	Aghoni bora	76.00^{M}	64.00^{G}	60.00^{F}	5.40^{M}	1.53^{Q}	3.53^{G}	SS	2.00^{Q}	3.75^{Q}	9.64^{B}	1.98^{A}	4.85^{I}
2	Bhogali bora	76.50^{K}	65.00^{F}	63.00^{C}	5.78^{F}	1.61^{N}	3.59^{E}	SS	2.00^{P}	5.30^{E}	9.45^{D}	1.63^{D}	5.50^{B}
3	Gandhibirion	78.00^{E}	63.00^{H}	59.00^{I}	6.38^{A}	1.68^{L}	3.80^{B}	LS	2.00^{O}	5.30^{D}	8.57^{G}	1.34^{M}	4.83^{K}
4	Ghew bora	80.00^{A}	66.50^{E}	64.00^{B}	6.06^{E}	1.68^{K}	3.61^{D}	LS	3.00^{L}	5.66^{A}	8.30^{I}	1.36^{L}	4.75^{L}
5	Gundhibirion	77.00^{I}	62.50^{I}	59.00^{H}	6.14^{C}	1.60^{P}	3.84^{A}	LS	2.00^{N}	4.00^{N}	8.21^{J}	1.33^{O}	5.36^{D}
6	Joha bora	74.50^{Q}	60.00^{O}	35.50^{Q}	5.15^{Q}	1.84^{C}	2.80^{P}	MS	3.50^{H}	5.00^{K}	8.00^{L}	1.50^{H}	5.02^{G}
7	Kola bora	76.50^{J}	61.00^{M}	49.50^{L}	5.24^{N}	1.71^{J}	3.06^{M}	SS	2.00^{M}	5.60^{C}	7.00^{O}	1.33^{N}	4.57^{N}
8	Lalbirion	77.00^{H}	60.00^{N}	40.50^{P}	5.40^{L}	1.92^{B}	2.81^{O}	MS	3.00^{K}	5.30^{H}	8.30^{H}	1.53^{G}	5.25^{F}
9	Lusaibiroin	75.00^{P}	62.00^{K}	60.50^{E}	5.44^{J}	1.76^{G}	3.09^{K}	SS	6.00^{B}	5.00^{J}	9.10^{E}	1.67^{B}	4.87^{H}
10	Nal bora	76.00^{L}	62.00^{J}	58.00^{J}	6.06^{D}	1.83^{D}	3.31^{H}	LS	3.00^{J}	5.30^{G}	9.60^{C}	1.58^{E}	6.63^{A}
11	Pamoi bora	78.50^{C}	68.00^{B}	43.00^{N}	5.18^{P}	1.74^{H}	2.98^{N}	MS	3.00^{I}	5.00^{I}	6.71^{P}	1.29^{P}	4.68^{M}
12	Panibirion	77.00^{G}	68.00^{A}	61.50^{D}	5.65^{H}	1.60^{O}	3.53^{F}	SS	5.00^{E}	4.66^{L}	7.71^{N}	1.36^{K}	4.35^{P}
13	Sona birion2	78.00^{D}	67.50^{C}	60.00^{G}	5.58^{I}	1.78^{E}	3.13^{J}	SS	5.00^{D}	4.00^{M}	9.64^{A}	1.64^{C}	4.27^{Q}
14	Tilbakolbora	78.50^{B}	58.50^{P}	48.50^{M}	6.16^{B}	1.66^{M}	3.71^{C}	LS	5.00^{C}	5.66^{B}	8.85^{F}	1.43^{I}	4.42^{O}
15	Putti birion	77.00^{F}	67.00^{D}	66.50^{A}	5.40^{K}	1.76^{F}	3.07^{L}	SS	6.00^{A}	3.75^{P}	6.61^{Q}	1.22^{Q}	4.83^{J}
16	Ranga bora1	75.00^{O}	55.50^{Q}	41.50^{O}	5.65^{G}	1.72^{I}	3.28^{I}	SS	4.50^{G}	5.30^{F}	7.80^{M}	1.38^{J}	5.32^{E}
17	Kalobhat	75.00^{N}	61.67^{L}	52.00^{K}	5.23^{O}	2.55^{A}	2.05^{Q}	SB	5.00^{F}	3.75^{O}	8.10^{K}	1.55^{F}	5.44^{C}
	Mean	76.79	63.07	54.24	5.64	1.76	3.25		3.65	4.84	8.33	1.48	5
	p-Value	< .0001	< .0001	< .0001	< .0001	< .0001	< .0001		< .0001	< .0001	< .0001	< .0001	< .0001

*Hull: Hulling%, HRR: Head rice recovery%, Mill: Milling%, KB: Kernel breadth, KL: kernel length (mm), ASV: Alkali spreading value, L/B: Length breadth ratio, KLAC: Kernel length after cooking, VER: Volume expansion ratio, AC: Amylose content, ER: Elongation ratio,

high consumer preference and acceptability. The main characteristics comprised of glossy appearance, cohesive texture and good taste with mean yield of 4.8 tons, better than IR64 especially in the dry season. The maturity time was 118–120 days with a mean plant height of 86–96 cm. (Borromeo et al. 2005).

Varieties released in India

Two high-yielding glutinous rice varieties *Bhogali* and *Rongili* were developed from a cross between Kmj 1-52-2, locally developed semi dwarf non glutinous rice and Ghew Bora, traditional tall, glutinous rice by AAU, Titabar (Ahmed et al. 1993, FAO-AGRIS 1974a, b). *Bhogali* and *Rongili* have been recommended for planting in sali (winter) season in Assam, medium to shallow water condition, under flood-free environment and accepted by the farmers. Bhogali is a semi-dwarf (100 cm) and Rongili is a tall (150 cm) and stiff-strawed variety. Both varieties are recommended for transplanting during Mid July and take 130 days for 50% flowering. *Aghonibora*-a unique rice was also popularly reported by NRRI-Cuttack as a 'soak and eat type' rice genotype which does not require cooking (Yadugiri et al. 2010; Bhakta et al. 2011; Sharma et al. 2012).ICAR-NEH-RC Manipur has developed and notified 4 low amylose containing varieties (RC Maniphou-6, RC Maniphou-10, RC Maniphou-12 and RC Maniphou-13) for state of Manipur (Table 6).

Yield and quality traits of Japonica rice in Punjab, India

Punjab is one of the highest rice productivity states in India contributing to about 40% rice to the central pool. Therefore, agronomic and production potential of glutinous rice needs to be seen for future preparedness for commercial production. Punjab Agricultural University (PAU), Ludhiana has initiated field evaluation of limited number of tropical japonica lines under Punjab conditions, with the objectives of identifying high yielding japonica types that could be grown in specific niches for export purposes. Multi-location yield and milling trait data are presented in Tables 7 and 8.

Although milling quality is an important characteristic of rice, only few breeding programmes are directed to improve the same (Min et al. 2008). During the study, japonica rice variation for different milling quality parameters was observed (Table 8) wherein, breeding lines RYT 3595, RYT 3599 and RYT 3600 were found superior for most of the traits studied.

A brief status of the germplasm in the world

Availability of glutinous rice germplasm in the gene banks of 25 countries is given in Table 9. The maximum accessions are with Beijing, China followed by Japan and Vietnam. IRRI, Philippines documented 33 glutinous, 1 sticky rice, 4 low amylose and 1 waxy accession whereas among 1089 Vietnam rice varieties, 459 are glutinous and 406 are waxy rice types, as discussed earlier.

Northeastern Indian traditional recipes

Sticky rice called bora saul is the major component in the traditional sweets in Assam i.e., Pitha (Narikolorpitha, Tilpitha, Ghilapitha, Tel pitha, Ketelipitha, Sungapitha, Sungasaul etc.). Whereas, the folk also uses its powder form directly with the

Table 6 Semi-glutinous rice varieties developed by ICAR-RC-NEH for the state of Manipur

S. No.	Genotype	Name of variety	Amylose (%)	Grain shape	Year of notification	Gazette notification no.
1	RCM-5	RC Maniphou-6	16.3	Long bold	2009	S.O. 449(E) 11.02.2009
2	RCM-10	RC Maniphou-10	16.1	Long slender	2009	S.O. 449(E) 11.02.2009
3	RCM-12	RC Maniphou-12	11.7	Short bold	2015	S.O. 268(E) 28.01.2015
4	RCM-30	RC Maniphou-13	13.0	Long bold	2018	S. O. 399 (E) 24.01.2018

Table 7 Paddy yield (kg/ha) of japonica rice genotypes (RYT3594-3600) and check varieties (PR121 and Pusa Basmati 1121) at PAU and its regional stations

Year	Location	RYT 3594[a]	RYT 3595[a]	RYT 3596[a]	RYT 3598[a]	RYT 3599[a]	RYT 3600[a]	PR 121	PB 1121
2014 (IIRON M2	Ludhiana	5937	5947	6372	6157	6533	6565	6925	–
2015 (RYT-8)	Ludhiana	6026	5431	6276	5392	5742	6198	7279	–
2016 (Japonica Trial)	Ludhiana	4669	4331	7977	4547	4918	4601	7306	4218
	Rauni	4738	4380	7477	4291	4691	4371	6606	–
	Average	4704	4356	7727	4419	4805	4486	6956	4218
2017 (RYT -BT-2)	Ludhiana	5583	6241	6251	5966	5463	5497	–	4511
	Kapurthala	4126	3779	3745	3371	3938	3610	–	4206
	Rauni	4592	4763	4778	4930	5211	5014	–	3510
	Gurdaspur	5170	4660	5560	5340	4330	4970	–	4646
	Average	4868	4861	5084	4902	4736	4773	–	4218
2018 (RYT-3)	Ludhiana	6449	6235	6443	6596	5182	4544	7710	–
	Kapurthala	3805	3492	3769	3998	4264	4092	6390	–
	Rauni	4527	5269	4981	4790	4371	4832	6303	–
	Gurdaspur	5433	6033	6367	6600	5433	4967	7800	–
	Average	5054	5257	5390	5496	4813	4609	7051	–
Days to 50% flowering	Ludhiana	111	111	112	113	113	112	110	112

[a]Developed from the cross IR68552-55–3-2* 3/Cheng Hui 448

Table 8 Milling quality characteristics of different japonica genotypes grown in Punjab state

Characters	Breeding line					
	RYT 3594	RYT 3595	RYT 3596	RYT 3598	RYT 3599	RYT 3600
1000-grain weight of paddy (g)	21.21	22.19	20.99	20.78	20.69	20.8
1000-grain weight of brown rice (g)	18.72	19.35	17.61	17.47	19.56	18.6
Grain length (mm)	5.03	5.1	5.01	5.15	5.22	4.93
Grain breadth (mm)	2.36	2.41	2.4	2.42	2.37	2.38
Length breadth ratio	2.13	2.12	2.09	2.12	2.2	2.06
Total rice recovery (%)	70.8	71.4	70.7	71.5	70.6	72.2
Head rice recovery (%)	62.7	65.5	65.9	64.7	64.3	66.0
Amylose content (%)	18.4	17.6	16.34	16.03	17.77	16.22

milk in breakfast, known as Pithaguri (here powder is prepared with no frying of the rice while rice is just crushed after soaking) or Handohguri (here rice is dry fried first, and then crushed). Sometimes, they cook soaked rice without water inside a special kind of bamboo (called sungasaulbnaah) and this recipe is known as sungasaul. During ceremonies, they make Mithoi (Kesamithoi and Pokamithoi) using Gnud with it. Sometimes Bhog, Payokh are also made from it using milk and sugar.

Various Assamese communities prepare beer from sticky rice and prefer it over other varieties as it has more alcoholic content and sweeter taste, to offer to their ancestors and God. At some occasions, they cook rice with it. There is a wide variation in the color from creamy white to black and purple glutinous rice. (Wikipedia 2022).

Way forward and future line of work

Glutinous rice is a strategic crop as it influences people's cultural and traditional preferences. Due to the limitation of data, there has been no policy for promoting or developing the glutinous rice production, which in turn can affect the management

Table 9 Major global Genebanks conserving rice germplasm including sticky rice

S. No.	Genebanks	Country	No. of rice accessions	No. of sticky/low amylose/glutinous rice
1	International Rice Genebank	IRRI, Philippines	132,563	33 glutinous documented (1 sticky rice, 4 low amylose, 1 waxy accession)
2	National Genebank, ICAR-National Bureau of Plant Genetic Resources	New Delhi, India	109,834	83 sticky rice, 21 glutinous rice, 326 Bora rice, 106 Chokuwa rice
3	The National Crop Genebank of China (NCGC), Chinese Academy of Agricultural Sciences (ICGR-CAAS)	Beijing, China	73,323	2333
	National Agrobiodiversity Centre	Republic of Korea	32,734	NA*
4	Biotechnology Research and Development Office (BRDO)	Thailand	25,600	NA
5	National Institue of Agrobiological Resources, Genebank	Japan	22,839	2100
6	AfricaRice'sgenebank	Cotonou, Benin	22,000	NA
7	The USDA-ARS World Rice Collection at Dale Bumpers National Rice Research Center	Stuttgart, Arkansas	19,976	NA
8	Philippine Rice Research Institute (PhilRice)	Laguna, Philippines	14,388	9 released varieties
9	Lao National Genebank, Agriculture Research Center, National Agriculture and Forestry Research Institute (NAFRI)	Lao PDR	13,193	85% of accessions are glutinous
10	MARDI rice seed genebank	Malaysia	12,770	NA
11	China National Rice Research Institute (CNRRI)	Hangzhou		NA
12	Bangladesh Rice Research Institute genebank	Bangladesh	8200	NA
13	Pyongyang Crop Genetic Resources Institute	DPR of Korea	7860	NA
14	Myanmar Seed Bank, DAR Yezin	Myanmar	7000	NA
15	National Genebank, The Plant Resources Center, Vietnam Academy of Agricultural Sciences	Viet Nam	6423	Among 1089 Vietnam rice varieties, 459 are glutinous and 406 are waxy rice types
16	The National Center for Applied Research on Rural Development (FOFIFA/ CENRADERU)	Madagascar	6681	NA
17	Institute of Agricultural Machinery (IAM/ NARO) genebank	Indonesia	4210	NA
18	Plant Genetic Resources Centre-Seed gene bank	Sri Lanka	4100	NA
19	Cambodian Agricultural Research and Development Institute (CARDI)	Cambodia	3691	NA
20	National Agriculture Genetic Resource Centre (NAGRC), alias Genebank, Nepal Agricultural Research Council (NARC), Khumaltar	Nepal	2400	NA
21	Australian Grains Genebank	Queensland Australia	1514	NA
22	US National Plant Germplasm System	USA	500	NA
23	National Agricultural Research Institute (NARI) Genebank	Papua New Guinea	260	NA

Table 9 (continued)

S. No.	Genebanks	Country	No. of rice accessions	No. of sticky/low amylose/glutinous rice
24	Rural Development Administration-National Institute of Crop Science (RDA-NICS)	R. of Korea	213	NA
25	National Plant Genetic Resource Centre (NPGRC)	Zambia	209	NA

*NA Data not available

strategies and planning of glutinous rice production in the future. Different distribution studies can partially provide the information for policy formulation in the future. Therefore, the objectives of the present review were to analyze and gather information in order to map the glutinous rice heritage of the world as a whole and India in particular.

In India, the sticky/glutinous rice varieties and indigenous landraces are currently grown mainly in the northeastern region of India besides some cultivation in north-western Himalayan states. This speciality rice is not popularly grown in other parts of India due to lack of eating preferences towards glutinous rice. Therefore, to cater to the emerging demands for sticky rice in the domestic and international markets, their production potential needs to be harnessed by following genetic approaches as given below:

I. *Validation and confirmation of the characterized rice germplasm for low amylose content and other economically important traits.*

   Low amylose content (AC) is an important trait when using rice as thickening agent and developing soft rice products which get cooked by simply soaking in water at room temperature. While for use as thickening agent has industrial demand as soft rice flour is neutral to taste and easily amalgamates with any flavour, soft rice is required for cooking in difficult situations such as in high altitudes, space shuttles. Therefore, phenotyping and characterization of the rice germplasm for low amylose content and other nutritionally important traits has become an emerging need.

II. *Understanding the genetic and molecular basis of glutinous trait through mapping studies* to conduct hybridisation for important nutritional traits within low amylose germplasm to generate mapping populations. Besides, genome wide association studies can be initiated immediately to link nutritional and other phenotypic traits with candidate genes.

III. *Germplasm survey and molecular profiling for the presence of waxy gene(s) in the validated lines for their use in marker assisted selection* would benefit the different breeding programs by introducing the *Wxhp* allele into other elite cultivars to obtain high-quality rice for food industrial applications.

IV. *Identification of indica-japonica status of the low amylose containing lines for their future utilization in rice improvement*. Germplasm collections are required to be screened for indica/japonica status to identify elite lines with low amylose along with high protein, oil, iron and zinc content for direct wide hybridization and pre-breeding.

V. *Import of low amylose rice lines from exotic gene banks to enrich the breeding program*. Low amylose sticky/waxy rice is majorly cultivated in Japan, China and South East Asian countries. Thus, germplasm from these countries should be augmented in Indian National Genebank and characterized for their locally adaptive agronomic and biochemical traits. Trait specific identified germplasm with good yield potential can be directly used as variety besides use as genetic donor.

VI. *Demand in domestic and global markets* for sticky rice assessed through market intelligence technologies will open the gates for production and supply across nations for a better trade.

**For recent status of glutinous rice in global trade, its trends and prices 'Tridge Market Intelligence (2022)'* (https://www.tridge.com/pricing/data?next=%2Fproducts%2Fglutinous-rice) *may be followed.*

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