



## Genetic Improvement of Grain Quality Traits in Rice

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### Abstract

Rice grain characteristics such as appearance, milling, cooking, aroma and nutrition are central to consumer perception, farmer livelihood and food security particularly in rice-based areas such as India. Genetic principles (e.g., *Wx* amylose, aroma, GS3 shape) and technology such as MAS, QTL mapping, genomic selection and CRISPR/Cas9 which allow making specific improvements without trade-offs. Modern innovation (replacement of traditional breeding and shift to higher yields), success of Pusa Basmati 1121 (8.3mm extra-long aromatic grains, 5M ton exports), DRR Dhan 100 and biofortified CR Dhan 310 (12% protein). Challenges like climate-related chalkiness have been solved through strong pyramids, which yield healthier and tastier rice to billions of people.

**Keywords:** Milling, CRISPR/Cas9, Pusa Basmati 1121, Biofortified

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### Introduction

Rice (*Oryza sativa*) is not just a grain. It is a cultural symbol, a staple food and the main source of calories of over half of the world's population. Rice fields in Asia, Africa and some place of Latin America are the breadwinners of the rural communities and the heart of the family dinner table. Rice is the energy source of millions of people and their livelihood, heritage and source of food every day. But not all rice is equal.

The quality traits of the grain, i.e. the very characteristics of the rice grains that define the appearance, the texture, the aroma, the cooking properties, the nutritional value and the market value. And the modern science - particularly genetics and breeding has proven to be an effective tool in bettering these qualities in both the farmers and consumers. Genetic research and breeding innovations are changing the quality of rice grains to be tastier, healthier and more resilient than ever before.

### What is the quality of rice grain?

The quality of rice grains covers physical appearance, milling performance, cooking attitude, taste, smell and nutrition. Market appeal is based on attributes of appearances

such as length, width and chalkiness; the thinner the grain, the more it will attract high prices in the foreign market.

Eating quality is a combination of these and is usually quantified in gel consistency (GC) and alkali spreading value (ASV). The quality of food contains protein, vitamins, minerals and bioactive compounds. There are differences in tastes: Indians prefer long and aromatic basmati; Japanese like sticky sushi rice. These are the ones that breeders are aiming at through genetics to increase the income of farmers and food security.

**1. Milling quality:** The amount of intact edible rice that we obtain after the endosperm has been removed by wearing away the hard exterior husk and the bran.

- Milling yield (percentage of whole rice after husk removal)
- Head rice recovery (proportion of unbroken grains)
- Grain hardness

**2. Appearance quality:** We eat first with the eyes. The looks are evaluated based on the grain shape (length and width) and on the merchandising translucency.

- Grain length and width
- Grain shape and size
- Chalkiness (opaque white portions)
- Colour (white, red, black, purple)

**3. Eating and cooking quality (ECQ):** These influence how rice behaves in the pot and on the palate:

- Amylose content (a key determinant of texture)
- Gel consistency
- Gelatinisation temperature
- Stickiness
- Aroma (e.g., fragrant rice like Jasmine or Basmati)

**4. Nutritional value:** Polished white rice is deficient in some of the micronutrients as well as loaded with easily digestible starches. Rice provides calories but often lacks essential micronutrients like:

- Iron
- Zinc
- Vitamins (e.g., Vitamin A through provitamin A carotenoids)
- Protein quality

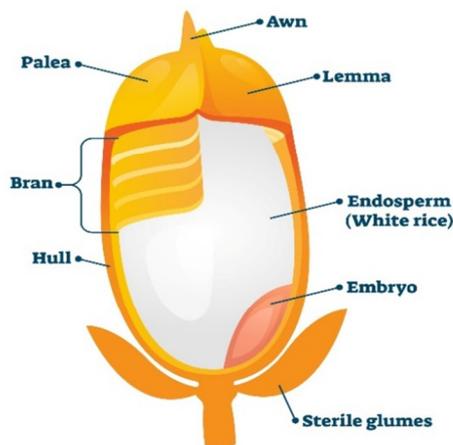


Fig.1. Rice Grain

**Why enhance grain quality with the help of genetics?**

#### 1. Meeting Consumer Preferences

When the rice conforms to the tastes of the consumers, farmers make more. Aroma is very important in certain markets, whereas, in others, it is a texture or grain shape that counts. Genetic enhancement gives breeders an opportunity to customize rice varieties to certain tastes.

#### 2. Improving nutritional value

Billions of people are fed on rice, but milled rice usually has low concentrations of micronutrients. Improved nutrition of rice can

be used to enhance population health without making any changes to their diets.

#### 3. Improving cooking and storage characteristics

Consumers would like rice that cooks and stores well. The aim of improvement is genes that regulate starch properties, gel consistency and shelf life.

#### 4. Climate change and sustainability

Genetic advancements can add genetic enhancement to rice that enables rice to retain its quality under heat, drought, salinity or low-nutrient soils, a necessary factor with climate change threatening to reduce productivity.

#### Genetic foundation of quality traits

There are a variety of genes controlling rice quality traits - some of which are major controlled by single players whereas other genes are minor and controlled by multiple minor players.

**1. Amylose content:** Amylose is a constituent component of starch (the other component being amylopectin). The percentage of it mostly defines the rice texture:

- High amylose - stiff, individual grains (fried rice)
- Low amylose - sticky and mushy texture (sushi or East Asian preferred)

The major gene that influences amylose content is *Waxy (Wx)*. Variations in *Wx* produce different levels of amylose due to their different versions (alleles). An illustration is that a low-activity *Wx* allele results in soft rice.

**2. Fragrance:** Some varieties of rice such as Basmati and Jasmine, are valued because of their smell. *Badh2* (betaine aldehyde dehydrogenase 2) is the gene that regulates fragrance. This pleasant smell is a result of a certain mutation in *BADH2* that causes the build-up of aromatic substances, including one, 2-acetyl-1-pyrroline (2-AP).

**3. Chalkiness:** Chalkiness describes the grains that have opaque spots that decreases the market value and minimizes the milling quality. It is caused by impaired deposition of starch in the endosperm. Chalkiness is a complex trait, which is affected by numerous genes and environmental variables that need to be improved.

**4. Nutrition:** Protein composition is also affected by a number of quantitative trait loci (QTLs). Transporter genes and storage proteins regulate the action of micronutrients such as iron and zinc. Provitamin A carotenoids - made notorious with the help of Golden Rice - need

engineered pathways with genes such as *psy* (phytoene synthase) and *crtI*.

### Tools of genetic enhancement

#### 1. Traditional breeding

The process of breeding plants crossing generations has been long-standing among farmers and scientists who choose plants that possess desirable characteristics. This method is also good, though it is slow and inaccurate.

#### 2. Marker Assisted Selection (MAS)

MAS works with the involvement of DNA markers associated with desirable genes. Genetic screening of seedlings provides breeders an opportunity to avoid occurrence of the trait, rather than wait until it manifests. This increases the mating rate and is more accurate.

As an example, breeders can easily select seedlings with the low-amylase *Wx* allele when the marker marked has been known to be associated with that allele.

#### 3. Quantitative Trait Loci (QTL) mapping

Numerous quality attributes are governed by a number of genes. QTL mapping determines the regions of the chromosomes linked with such traits so that breeders can target them.

#### 4. Genomic Selection

Genomic selection involves whole-genome profiles to predict trait performance instead of using a few markers. It is particularly applicable in complicated characteristics such as quality of milling or micronutrient contents.

#### 5. Genetic Engineering and Genome Editing

The following tools can be used to have a specific introduction, deletion or modification of genes:

- a. Transgenic methods involve incorporation of new genes (such as provitamin A in Golden Rice).
- b. CRISPR/Cas9 and other editing technologies are able to modify existing genes in elite varieties without the incorporation of foreign DNA.

Genome editing promises such characteristics as chalkiness, amylose content, aroma boost, and stress resilience.

#### Success Stories

India leads with the world's first genome-edited rice varieties approved in 2025, boosting yield and quality without foreign DNA.

#### Pusa Basmati hybrids

Pyramids of Pusa Basmati 1121 (2013) of ICAR-IARI of pyramids *fgr/bad1* for aroma (0.66 mg/kg 2-AP), GS3/GW5 of 8.3-8.4 mm extra-

long grains, low chalkiness with 2M plus ha and exports 5M tons/year at 20-50% premiums. Pusa Basmati 1509 will bring drought resistance and mature in 115 days with retained cooking value.

#### DRR varieties Basmati and scented

DRR Dhan 45 (Pusa Basmati 67 improved) of ICAR-IIRR boosts milling (72% recovery), kernel length (7.2 mm). Improved Samba Mahsuri maintains the quality of its eating and provides submergence ability through *Sub1*, which is common in eastern India.

#### CRISPR varieties genome edited (2025)

India pioneered approvals:

- CRISPR-edited *OsCKX2* allele of DRR Dhan 100 (Kamla) results in +19%, early maturity (20 days), low-fertiliser/drought tolerance; identical preferred grain/cooking qualities.
- Pusa DST Rice 1 of MTU1010: Stress-suppressor gene (+9.66-30.4%) knocked out to obtaining +9.66-30.4% yield in saline/alkaline soils, stomatal density lowered to savings of water; climate-sensitive to coastal areas in Bihar-like.

#### Nutridense varieties by CRRI

In 2016, ICAR-CRRI published the biofortified CR Dhan 310 (high protein 10-12%), DRR Dhan 45 (zinc-iron), and others, which are superior to quality trade-offs, parents of 244 national varieties.

#### Yield-Quality increases in rainfed India

Rainfed varieties increased 0.87% per year yield maintaining yield quality (e.g. better milling, AC stability) in 50 years, through ICAR networks-vital to poor farmers in Bihar.

Variety	Institute	Key Traits Improved	Impact nature
Pusa Basmati 1121	IARI	Aroma, length (8.3mm)	5M ton exports
DRR Dhan 100	IIRR	+19% yield, early maturity	Drought/low-fertilizer
Pusa DST Rice 1	IARI	+30% saline yield	Water-saving, resilient
CR Dhan 310	CRRI	High protein (12%)	Nutrition boost

#### Conclusion

Rice has nourished cultures since ancient times, yet the 21<sup>st</sup> century with its climate change to malnutrition demands innovations. Genetic enhancement of the grain quality features is not only on long or shiny grains, but it is making sure that rice will keep feeding billions of people with taste, dignity and health. Science has

provided us with means of such precision. By applying these tools in a wise way and adhering to traditions, environment and human necessities, the future of rice can be even better than the golden grains.

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