

A COMPREHENSIVE REVIEW ON DEVELOPMENT AND
BIOTECHNOLOGICAL APPROACHES USED FOR THE SUSTAINABLE
PRODUCTION OF RICE (ORYZA SATIVA)

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Abstract

Rice (*Oryza sativa*) is a staple food and is considered as a primary source of nutrition and calories. It is widely grown in various regions of the world. There are about nine major varieties of rice including Arborio, Basmati, Jasmine, Valencia, Calrose, red rice, black rice, parboiled rice and wild rice. All these varieties have their own nutritional values and characteristics that make them differentiable from one another. Furthermore, development of these varieties of rice depends of growing conditions like water and solar radiation availabilities. The development of rice passes through a series of phases i.e. vegetative phase, development phase and maturation phase. Moreover, as the need of staple crops is increasing day by day biotechnological approaches are being used to produce rice crops with more yield having better quality of rice. CRISPR cas9 is the most recent technique used for the production of rice. Additionally, crop monitoring is also being enhanced with the help of biotechnology. Presently, researchers are working on the sustainable production of rice as the demand of food is increasing with the increase in population of the world. In future, artificial intelligence and machine learning can be integrated in combination with biotechnology to optimize the sustainable production of rice. To conclude the whole, it is reviewed that biotechnology is considered as rapidly emerging field for sustainable development and production of rice.

1 INTRODUCTION

Rice is a starchy grain having scientific name *Oryza sativa* and is a member of family Poaceae. Rice is considered as a staple food for almost one-half of the whole world (Tao et al., 2006). Approximately, 95% of the rice crops in the world are eaten by

humans (Birla et al., 2017). Rice plants are cultivated annually and they grow 1.2 meters in height which is about 4 feet. The leaves of these plants are generally flattened and are supported on vacant stems. The root system is fibrous and is frequently spreading and broad. Their shape,

length and amount may vary on the basis of their varieties cultivated (Zhou, Yun, & He, 2019). Rice can be grounded into the flour or can be cooked to meal. The shape and length of the rice decides its physical appearance when cooked. On the basis of shape and length of grain, rice can be divided into three major types, short grain, medium grain, and long grain (Mestres, Briffaz, & Valentin, 2019). Short grain rice which are also known as japonica rice, physically they have shorter and rounder kernels, accommodates more starch than that of the long grain rice and they may stick together and become moist after being cooked. Medium grain rice are typically known as table rice, they are cooked slowly and they ransom their starches making a creamy texture (Mackill, 1995). In addition to this, long grain rice are known because of their strong aroma when cooked and they are light, does not stick and their kernels are separated (Cameron & Wang, 2005). Rice is commonly paired with a variety of nutrient-rich foods like fruits, legumes, nuts, poultry, seafood and vegetables. Rice is cost effective and versatile budget friendly option which can be cooked easily (De Steur et al., 2012).

1.1 NUTRITIONAL VALUE OF RICE

Rice is effective for those who have any kind of sensitivity against gluten then that person can add rice to his diet because of specialty that it is gluten free and do not cause any kind of inflammation in the human gut (de la Hera, Martinez, & Gómez, 2013). Rice is the great source of different varieties of vitamin B. Vitamin B helps in improvement of bodies' nervous system to make it able to run swiftly by producing neurotransmitters (Williams, 1944). Many other useful components like minerals, vitamins, and carbohydrates are also present in the rice. Rice also has ability to provide 15 types of essential nutrients and minerals which includes folic acid, potassium, iron, fiber, selenium, and zinc (Shrestha, Kandel, Subedi, & Shah, 2020). Rice water is also an important source for skin care by cooling the skin that is inflamed. In vegetarian diet, rice is the richest protein containing food (Bao, 2023). Moreover, rice is food crop that is most grown in developing

countries because it is staple food as they rely on the primary sources for food. Rice is important source for reducing hunger, poverty, in improving human health and nutrition in the developing countries (Onyango, 2014). As half of the world population use rice as their staple food and it is also a source of income for many farmers, for this reason farmers as well as researchers are doing experiments to increase the yield and productivity of rice (Muthayya, Sugimoto, Montgomery, & Maberly, 2014). In addition to this, it can also be used to produce alcoholic beverages by rice fermentation (Pakuwal & Manandhar, 2020).

2 VARIETIES OF RICE

Different varieties of rice have different taste, texture and aroma as well as all the varieties of rice have their own unique properties (Jamil et al., 2012). A variety of factors are involved in the selection of suitable needs of establishment. According to different researches, around 120,000 varieties of rice that are cultivated all around the world (Khush, 1997). These varieties are characterized on the basis of their mode of production, size of kernel, starch content available in rice and its unique aroma as described in Table 1 and shown in Figure 1 (Sangeetha et al., 2020). In the whole world, every culture of the world had clinched it in different ways. Furthermore, the increase in the varieties of rice is still going because of the use of biotechnological and scientific approaches to produce modified rice crops having greater yield and good quality (Biswal et al., 2017).

2.1 ARBORIO

Arborio is short grain or medium size grain rice having white dot at the grain center which is an Italian variety having scientific name *Oryza sativa japonica* (Vidotto & Ferrero, 2009). It contains very high starch amylopectin content in it which can be used in Italian dishes to be cooked. These rice show creamy consistency when it is used for making rice puddings (Ansari, Iwasaki, Yoshida, Yamamoto, & Miyazaki, 2016). It was named Arborio because of the town where it was grown for the first time in 15th century who's named Arborio which was located in the Po valley of Italy

but today it can be grown in other regions of the world like it being grown in the state of California and Texas (Fransisca et al., 2015). The special thing about Arborio is that, it require less milling as compared to the long grain rice and reserve natural starch content present in it. The limitation of the Arborio rice is that they are difficult to grow and they have comparatively very low yield than the other varieties of the rice (Vici et al., 2021).

2.2 BASMATI

Basmati is a variety of rice which conventionally came from India and they are long grain rice that made it the “King of rice” (Bhattacharjee, Singhal, & Kulkarni, 2002). India is the foremost exporter of the Basmati rice in the whole world global market and Pakistan is the second largest exporter. Basmati rice can be white or brown and they have great aroma and amazing flavor (Singh, Singh, & Khush, 2000). This is non-sticky having dry and stiff texture of grain. Basmati rice, due to low to medium glycemic index lead the way to more balancing of energy level which means that the energy will be retained at a very slow rate. After seeding, they get mature within 140 days which is approximately four to five months (Siddiq, Vemireddy, & Nagaraju, 2012). Basmati rice as compared to the non-basmati rice responds very differently to the applications of nitrogen. Crop yield is greatly affected by excessive use of nitrogen as the requirement of nitrogen in the Basmati is utterly low (Kamath et al., 2008).

2.3 JASMINE

Jasmine rice originally cultivated in Thailand and is slender shaped and long grain rice (Poramacom, 2014). These rice is bit stickier than that of the Basmati rice but they have great aroma like it. There are two major types of Jasmine rice which are available i.e. white and brown rice. Both have different characteristics as white rice is mostly put forward because of the dry texture and ease of

being digestible (Leelayuthsoontorn & Thipayarat, 2006). On the other hand brown jasmine rice have better health significance as compared to the white rice because this can be used to decrease cholesterol in blood vessels. This is rich in vitamins like vitamin A, vitamin B and have antioxidants that can help in supporting the nervous system (Wasan et al., 2022). The jasmine rice can be paired with Thai dishes and steaming should be done instead of boiling jasmine rice for the best results (Lanceras et al., 2000). The major drawback of this rice is high glycemic index which is 68 to 80 that must be lower than 55 glycemic index for the diabetic person for this reason they are often cooked and eaten with other foods that can turn down the 20 to 40% of glycemic index (Truong, Yuet, & Hall, 2014).

2.4 VALENCIA

Valencia rice traditionally came from the country Spain and they is medium grain rice. Their shape is slightly round and pearl like color. The major varieties of Valencia rice included Bomba rice, Bahia, and Senia (Garcia-Yzaguirre, Dominguis, Carreres, & Juan, 2011). In these varieties, short grain rice is Bomba which is cultivated in the region of Valencia in Spain which needs more liquid while cooking to absorb than that of the other varieties of rice (Marzal et al., 2005). Furthermore, Bahia rice is short grained rice having ability to cook rapidly and without becoming sticky, it can absorb liquids so that its grains remain discrete. Bahia is a little bit closer to Bomba but it has lower prices as compared to Bomba (González, Armenta, & De La Guardia, 2011). Senia is the type of Valencia rice which is medium grain rice and have ability to absorb liquids without becoming sticky when it is being cooked to meal (Ballesteros, 1997). This is also a lower priced rice than that of the other two varieties of Valencia i.e. Bahia and Bomba.

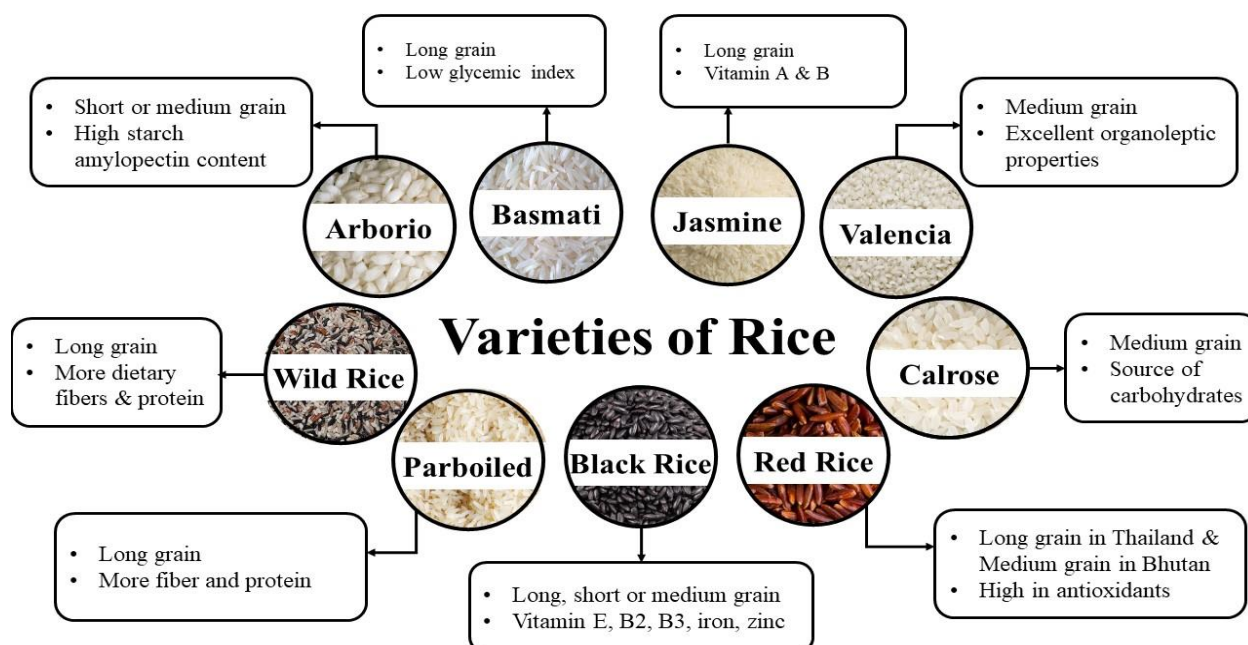


Figure 1. Varieties of rice and their unique characteristics

2.5 CALROSE

Calrose is medium grain rice variety that was first cultivated in California for this reason it is name as “Cal” and word “rose” indicates the shape of the grain is medium (Jia & Jia, 2023). Calrose rice has flavorful grain and its grains can easily stick together. About 80% of rice crop which is cultivated on California is Calrose (Geoghan, 2022). It is generally crossbreed which is produced by Japanese and American rice. The ability of holding moisture together makes it appropriate to be used for various cooking methods like steaming, boiling and frying. Calrose rice is rich source of carbohydrates and can provide essential nutrients in moderate amount (Wasan et al., 2022).

2.6 RED RICE

This rice carries hull of red color and is considered as a whole grain rice (Noldin, Chandler, & McCAULEY, 1999). Its nutritional value is high and it is high in antioxidants because of the availability of hues of red color (Sompong, Siebenhandl-Ehn, Linsberger-Martin, & Berghofer, 2011). It has chewy consistency and

nutty taste. Its varieties are of two types on the basis of grain size that one is long grain rice which is grown in Thailand while the other is medium grained which is from Bhutan (Ahuja, Ahuja, Chaudhary, & Thakrar, 2007). Red rice helps in the improvement of the bowel movement and can also help to get relief from diseases like constipation.

2.7 BLACK RICE

Black rice can be in any of the three varieties of the rice (long grain, short grain, or medium grain). It also known as purple or forbidden rice (Kushwaha & Kushwaha, 2016). It has a dark purple or black colored hue which is because of the anthocyanin content which is an antioxidant present on rice like blueberries and blackberries have (Sompong et al., 2011). The weight of the grain is quite higher than the other colored grains. Furthermore, black rice is considered to be a source of iron, fiber and protein. It has resemblance with the brown rice as it has same amount of fiber content and similar nutty, earthy and mild taste like brown rice (Ito & Lacerda, 2019). It causes reduction in appetite which can

help in the promotion of weight loss. The pigments present in it can help to suppress the risk of condition like inflammation and cardiovascular disorders. It can help in boosting up heart health and all-inclusive fitness (Thanuja & Parimalavalli, 2018). Moreover, black rice is a good source of essential nutrients like vitamin E, vitamin B2 (riboflavin), vitamin B3, iron, zinc, and potassium.

2.8 PARBOILED

Parboiled rice is edible grain, also known as easy-cook rice or sella rice which is not completely boiled but it does steam pressure process before milling in the husk (Malik, Garg, & Nehra, 2011). This process is done for the improvement of the texture of the rice, reduction of the time for cooking, and also some of the original nutrients like vitamins and minerals are saved which originated in the rice (Bhattacharya & Subba Roa, 1966). Physical appearance of the parboiled rice is long and slender and after being cooked it size doubles (Islam, Shimizu, & Kimura, 2001). This is suitable for diabetic people because its glycemic index is low. It is available in long grain, medium grain and short grain varieties (Luh & Mickus,

1991). In comparison with white rice, parboiled rice is more fibrous and more protein containing while it contains less carbohydrates and fewer calories. Having more fiber and protein make it healthier than that of the white rice. It can be used for the improvement of the gut health as it contains prebiotics in it and can also be suitable for reduction of diabetic symptoms (Chukwu & Oseh, 2009).

2.9 WILD RICE

Wild rice is a type of wheatgrass which is not a true or traditional rice but it is the seed of grass having grains that have pleasant fibrous texture and nutty flavor (Tikapunya et al., 2017). It is quite healthier than the other rice like brown or white rice because it has more dietary fibers and more proteins which helps in keeping cholesterol level low. It has special properties like it can lower the lipid and is also a powerful antioxidant (Surendiran, Alsaif, Kapourchali, & Moghadasian, 2014). It is mostly mixed up with the brown rice and can be paired up with various fruits, soups, nuts, meats, and fish in salad (Oelke & Boedicker, 2000).

Table 1. Properties of various varieties of rice

Varieties of Rice	Grain Size	Color of grain	Quality of rice	References
Arborio	Short or medium grain	Pearly white dotted	High starch amylopectin content	(Vici et al., 2021)
Basmati	Long grain	White or brown	Low glycemic index	(Bhattacharjee et al., 2002)
Jasmine	Long grain	White or brown	Vitamin A and vitamin B	(Kamath et al., 2008)
Valencia	Medium grain	Pearl like	Excellent organoleptic properties	(Wasan et al., 2022)
Calrose	Medium grain	White	Rich source of carbohydrates	(Jia & Jia, 2023)
Red Rice	Long grain in Thailand, Medium grain in Bhutan	Red color	High in antioxidants	(Ahuja et al., 2007)

Black Rice	Long, short, or medium grain	Dark purple, black	Vitamin E, vitamin B2 (riboflavin), vitamin B3, iron, zinc, and potassium	(Ito & Lacerda, 2019)
Parboiled	Long grain	White	More fiber and protein	(Islam et al., 2001)
Wild Rice	Long grain	Chalky gray	More dietary fibers and protein	(Tikapunya et al., 2017)

3 DEVELOPMENT OF RICE

Development and growth of rice depends on the availability of water and solar radiations for the growth as growing conditions (Moldenhauer & Slaton, 2001). It duration ranges from 100 to 120 days for short, 120 to 140 for medium, and it may take more than 160 days for long duration. On an average, the variety of rice matures in 4 to 5 months which is equal to 137 days approximately after seeding and can be grown in between May to June (Maruyama & Kuwagata, 2010). The plant has an average height of 104 centimeters. The leaf of rice is similar in the appearance of the wheat but differs because of the length. Each year, rice crops can be possibly grown for three times. Rice can be grown in irrigated condition in the rainy season. Rice crops can be grown by direct seeding and by transplantation. In direct seeding, the seed is directly put into the field while seed are grown primarily in the seedbeds in transplanting before transferring them into the field (Kumar & Ladha, 2011). Development of rice starts from germination of seed to the formation of grain. The process of development can be divided into majorly three phases i.e. vegetative phase, reproductive phase, and maturation or ripening. Vegetative phase is further subdivided into four stages emergence, development of seedling, tillering, and internode elongation. Reproductive phase is also subdivided into pre-booting, booting and heading (Dunand & Saichuk, 2014).

3.1 VEGETATIVE PHASE

It is an initial growth stage in which plant generally focuses on the growth of leaf and stem development. This is the stage at which farmers manage the plant by proper irrigation, controlling

pests and fertilization to ensure the optimum conditions for the growth of plant. The duration of vegetative phase is about 60 to 62 days which is around 2 months (Vergara, 1991). During this phase, the plant undergoes several sub-stages which includes emergence, seedling, tillering and elongation where root establishment, stem systems and vigorous development of the leaf takes place shown in **Figure 1** (Chang, Li, & Vergara, 1969). An adequate amount of water, nutrition and proper sunlight causes the proper formation and healthy growth of the plant.

3.1.1 Emergence

When the seed coat of plant has consumed reasonable amount of water to become elastic and soft. The covering of primary embryonic root, the sheath (coleorhiza) elongates slowly and emerges through the seed (Chen et al., 2016). This allows anchorage in the soil and the radicle to break from the coleorhiza. After that the initial leaf elongates in size. The germination of the seed occur generally within 1 or 2 days when the temperature is 50° to 97°F (Vergara, 1991). Due to the fluctuations of temperature, it requires more time to germinate. The overall events that take place during emergence include emergence of coleoptile which may emerge from the roots, emergence of radicle and after that emergence of prophyll (Kordan, 1977).

3.1.2 Seedling

Seedling development initiates when the coleoptile is exposed to light which results in appearance of the primary leaf and coleoptile opens up at the end (Chang et al., 1969; Kordan, 1977). The leaf which appears from the coleoptile

is about 1 inch or less than 1 inch in its length. This leaf acts as protection for the growth and development of the next coming leaf. The developing leaf elongates and passes through the tip of the initial leaf, as the growth of the seedlings take place (Sasaki, 2004). Furthermore, as the growth and development continues, the leaf divides into sheath, collar and blade. This differentiated leaf is considered as a complete leaf in which sheath is central portion of the completed leaf. At first stage, the leaves originate from the primary leaf which is the same point for all other leaves (Tan et al., 2022). In the vegetative phase, there is no growth of the stem. The leaves are tightly packed around the sheath which helps the leaves to avoid laying down flat to the ground and are called as leaf blades. At this point, the process of photosynthesis take place which is conversion of sunlight, water and CO₂ to glucose, O₂ and H₂O takes place in the plants (Moradi & Ismail, 2007). During this phase, the leaves are fully visible.

At this point of seedling, the plant has distinct parts of root and shoot and differentiation of leaf takes place which is the basic structure of the rice plant during vegetative phase (Mondal & Borromeo, 2016).

3.1.3 Tillering

The process of tillering occurs when the production of stalk takes place from the crown which is the part of plant at which joining of shoot and secondary roots occurs. After the emergence stage of vegetative phase, tillering initiates after 20 days (three weeks) when the 4th leaf is fully completed. Depending on the method used for seeding, the plant of rice may develop from 2-5 tillers (Vergara, 1991). Like main shoot, tillers grows and develop but they stay behind in their development from the main shoot which usually become late due to production of fewer leaves and having dwarfism in height and maturation of tiller

after the main shoot (X. Li et al., 2003). At this point, some older leaves of the rice plant turn into yellowish and brownish color. Furthermore, curve shape tillering amplification occurs until the most number of tiller is attained (Jaffuel & Dauzat, 2005). Nitrogenous fertilizers and other tools are used to enhance the population of tiller. Moreover, at this stage mature vegetative rice plant, many tillers, green healthy leaves, yellow leaves and secondary developed root system composition takes place (Yoshida & Hasegawa, 1982).

3.1.4 Elongation

Elongation is the stage at which internode formation takes place and it elongates. On a stem, each internode is longer and slender shaped which is newly formed (Golam & Prodhon, 2013). Basal most internode is the first one internode which is formed. This basal most internode is present directly at the top of the crown. The difference between basal and uppermost internode is presence of secondary roots which may develop at the node which is uppermost in the crown while the other will generally have no roots (Zhong et al., 2020). The longest and slenderest internode is the last one which is connected straightly with the panicle base. Panicle is exerted from the sheath due to the uppermost internode elongation (Sunohara, Satoh, & Nagato, 2003). Generally, in semi-dwarf varieties have 1 inch length of basal internode and 10 inch length of the uppermost internode while in tall varieties, the length may vary from 2 inches basal internode to 15 inches uppermost internode (Nagai & Ashikari, 2023). This length is determined on the basis of the date at which planting started, fertility of the soil, plant population and much more. The elongation of internodes is the sign of completion of the vegetative growth phase. After that, the phase of reproductive growth initiates.

Table 2. Overview of the development phases of Rice (*Oryza Sativa*) and their steps along with their functions

Phases	Steps	Time Period	Functions
Vegetative Phase	Emergence	1-2 days	Emergence of sheath (coleorhiza) from the seed
	Seedling	20 days	Appearance of primary leaf and coleoptile from seed
	Tillering	20 days	Growth and development of tillers
	Elongation	25 days	Formation of internodes
Reproductive Phase	Pre-Booting	30 days	Development of flag leaf and clum elongation
	Booting		Clear panicle development
	Heading		Elongation of panicle from main stem
Maturation	Grain filling	40 days	Small florets on stem become grain of rice
	Maturity		Loss of moisture and harvesting

3.2 REPRODUCTIVE PHASE

Reproductive phase of rice plant is the depiction of development of panicle to flowering by reducing activity of tillers. Time period of reproductive phase is 30 to 35 days on the basis of the conditions like variety of rice plant and environment (Dunand & Saichuk, 2014). First the panicle development initiates and then the formation of branches of panicle occurs (Yonghong Wang & Li, 2011). Flag leaf collar of rice plant is formed which is the closest leaf to the panicle which is grain is producing. The major sign of reproductive phase is the “green ring” stage in which band is observed having bright green color (Nawaz & Farooq, 2017). The sub-divisions the reproductive phase includes pre-booting, booting and finally heading (Figure 1).

3.2.1 Pre-Booting

Pre-booting occurs in between the internode elongation and before the completion of the flag leaf. The leaves which were further needed to be develop, complete their development at this stage (Mahmood et al., 2021). Furthermore, the stem or clum elongates which results in the increase of height of plant and at the uppermost branches formation of panicle initiates proceeding downward (Sunohara et al., 2003). Since there are more than single branch of the panicle, overlapping of the florets development occur inside panicle (Yonghong Wang & Li, 2011). Florets (small or reduced flowers) which are near the upper branch of the panicle are less advanced

than that of the florets at the tip of the descending branch (Fahad et al., 2019). From the perspective of management, panicle length defines the development and growth of plant during this stage. For instance, a fungicide label might specify from 2-4 inch panicle. Once the panicle reaches about 4 inches in size, individual florets on the most panicle branches can be recognized (Crowell et al., 2014).

3.2.2 Booting

The stage at which development as well as growth of a panicle and other corresponding parts reaches their completion within the sheath of the flag leaf is called booting (Mahmood et al., 2021). The boot is the sheath of the flag leaf. Booting stages are categorized according to clear panicle development without cutting it open. For accommodation, it can be divided into three further stages i.e. early boot, middle boot and late boot. When the collar of the flag leaf first appears at the top of the collar of the second to last leaf on the main stem, the recognition of the early boot takes place which lasts for about 2 inches above the collar. Furthermore, middle boot occurs as the length of the flag leaf collar is about 2-5 inches while last boot occurs at the length which is more than 5 inches above the penultimate leaf (second to last leaf) collar (Dunand & Saichuk, 2014).

3.2.3 Heading

Heading is the elongation of the panicle through the main stem. This phenomenon is brought

about generally by the spontaneous and continuous extension of the uppermost internode. The extended uppermost internode pushes panicle upward exposing the panicle tip which is present at the stem and has headed. The elongation of the uppermost internode continuous, exposing more panicles at the top of the sheath of flag leaf (Honda et al., 2021). Once the elongation of the uppermost internode is completed, this stem is fully headed now. Before tillers, the main stem of the every single plant heads. A considerable variation in the heading stage of rice growth in the field of rice can be seen. For instance, some of the main stem may be fully headed but some may just have begun heading stage (Moldenhauer & Slaton, 2001). With the progression of heading stage, flowering of the plant will begin. During the mid-day time, adult florets open, and stigma and anthers in the air are exposed. When the anthers dry, the pollens shed away. This pollen is carried by the wind and spread into the nearby plants stigmas. At this point, the fertilization takes place and grain formation is initiated (**Figure 1**) (Itoh et al., 2005; Walker & Street, 2003).

3.3 MATURATION

Maturation phase can be sub-divided into two stages i.e. grain filling and maturity. In the grain

filling stage, the small florets present on the main stem become grains of rice which are further needed to be mature (Itoh et al., 2005). By the accumulation of the carbohydrates, the grain formation is resulted. Photosynthesis is the reason behind the occurrence of the primary source of carbohydrates in the first 3 to 4 leaves and the stem. The carbohydrate is stored in the form of starch that accumulates in the grain. Endosperm is the starchy portion of the grain (Nakamura, Yuki, Park, & Ohya, 1989). Foremost, the starch has milky white consistency. When the accumulation of the milk in the florets is visible and noticeable, this stage is called milk stage. The increase in the weight of florets occur due to the accumulation of the carbohydrates (Yuwen Wang, Xu, Zhang, Wu, & Chen, 2017). After this, the panicle lean and gradually turns down. By losing the moisture, the milky consistency also changes for the endosperm. When the floret is pollinated, the texture is like bread dough which is referred as the dough stage. As the solidification of carbohydrates continues in the florets, the endosperms become more firm and start having chalky texture. During the stage of grain filling, the florets grow and mature differentially because of the uneven pollination and occurrence of subsequent grain filling.

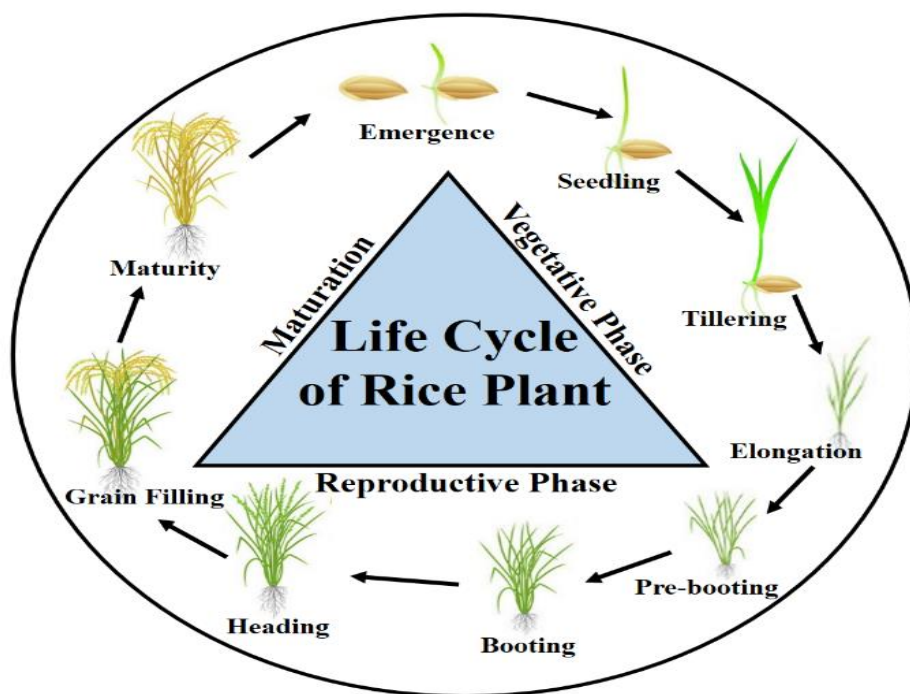


Figure 2. Life cycle of the development at different stages of rice plant

Moreover, with the development and maturation of florets, the panicle changes in color and shape. For many varieties of rice, the panicle changes its color from light green to the shades which are mixture of brown and green. Along with the change in color, the shape of the grain also changes. At the end of this stage, the panicle has bent and a little open shape and it is in different shades of brown and green which remain unchanged till maturity (Rajanna & Andrews, 1970).

The initial process, which occurs during the maturity in the panicle, is the loss of moisture present in the grain. This moisture content is used for judging the maturity of the rice plant. When the process which are associated with the grain filling stops and the moisture content become 25 to 30%, the rice plant reaches it maturity. Endosperm of all grains becomes firm and hard at this stage. Most grains are in the shade of brown and few have greenish tint. As the progression of maturity continuous, moisture is lost and endosperms become uniformly hard. When the

moisture content reaches to 15-18% moisture content, the plant reaches the point at which it can be easily harvested (Dunand & Saichuk, 2014).

4 BIOTECHNOLOGICAL APPROACHES FOR SUSTAINABLE PRODUCTION

As the demand of rice is increasing day by day because of increasing population in the world, there is a need to identify and produce new and modern techniques for sustainable production of rice (Biswal et al., 2017). Biotechnological approaches are playing an essential role in the sustainable production of rice for the increase in its yield, quality and quantity (Brar & Khush, 2013). Biotechnology is providing a variety of strategies for the production of rice which includes smart farming by the utilization of modern information communication technologies (ICT), adopting significant and appropriate practices, and utilization of advanced researches for preparing new technologies like gene editing (Bennett, 1995; Mittal, 2012). Furthermore, it can

also be used for the preparation of insecticides and pesticides to get rid from the insects and pests that are harmful for the rice. New technologies in the field of biotechnology have been used for the sustainable production of rice i.e. marker assisted

breeding, genetically modified organisms, CRISPR cas-9, and RNA interference (Jena & Mackill, 2008; B.-R. Lu & Snow, 2005) and their examples are described in

Table 3. Moreover crop monitoring is also required, for this reason biotechnology is also making new ways for easy and safe monitoring of rice crops.

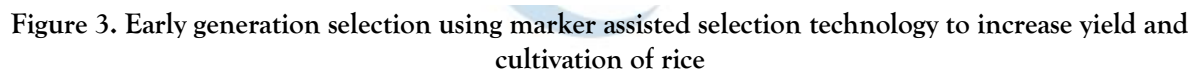
Table 3. Biotechnological approaches and their example in the utilization of sustainable production of rice

Technique	Process	Example	References
Marker Assisted Breeding	Utilization of DNA markers for the incorporation in an early breeding program of rice	Scuba Rice	(Haque et al., 2023)
Genetic Engineering of Genetically Modified Organisms	Use of DNA of organism and its modification using recombinant DNA and cloning	Golden Rice	(Beyer et al., 2002)
CRISPR/Cas9	Creation of modification to the organisms genome using guide RNA and cas9 gene	Agrobacterium mediated transformation of rice	(Molina-Risco et al., 2021)

4.1 MARKER ASSISTED BREEDING

Marker assisted breeding is the utilization of DNA markers related to the desirable characteristics for the selection of plant for incorporation in an early breeding program in its production as shown in **Figure 3** (Jena & Mackill, 2008). This technology mainly reduces the time which is required for the identification of varieties which can express the

required characteristics in the breeding program. DNA marker have been utilized in the improvement of rice (Mackill, 2007). These DNA markers must have following characteristics in them, they must be easily available, cheap to detect, reproducible, frequently distributed throughout the genome, and must be polymorphic.



medical benefits, and enhanced food quality (Paoletti & Pimentel, 1996). In rice production, this technique has been utilized in which modification of rice plants have been done to increase size of grains, produce nutrients, boost photosynthesis, and produce flavors or human proteins. In 2000, genetically modified rice which had resistance against herbicides, were approved by the United States (Khush et al., 2007). This was also approved by other countries but in 2009, China reported about the biosafety concerns related to the GM rice. However, this particular genetically modified strain was not able for commercialization (Y. Li, Peng, Hallerman, & Wu, 2014). Later in 2018, golden rice was approved by both countries Canada and United States because Health Canada and FDA (Food and Drug Administration) agencies confirmed its safety for the human consumption (Amna et al., 2020).

Genetically modified organisms are produced by using DNA of the organism and modifying it by using different technologies including recombinant DNA technology and cloning (B.-R. Lu & Snow, 2005). The significances associated with the genetic engineering in agriculture are increase in crop yield, reduction of pesticide need,

4.2.1 Golden Rice

Golden rice is the enhanced type of rice that is produced using biotechnological approach of genetic modification (Datta & Datta, 2020). It is genetically modified having yellow colored rice but no difference in taste genetically engineered from beta-carotene producing genes of other species as

shown in **Figure 2**. In this variety, the biosynthesis of the beta carotene and vitamin A was produced in the edible portions of the rice. These were intended to be grown and consumed in the places where there is shortage of food and deficiency of vitamin A.

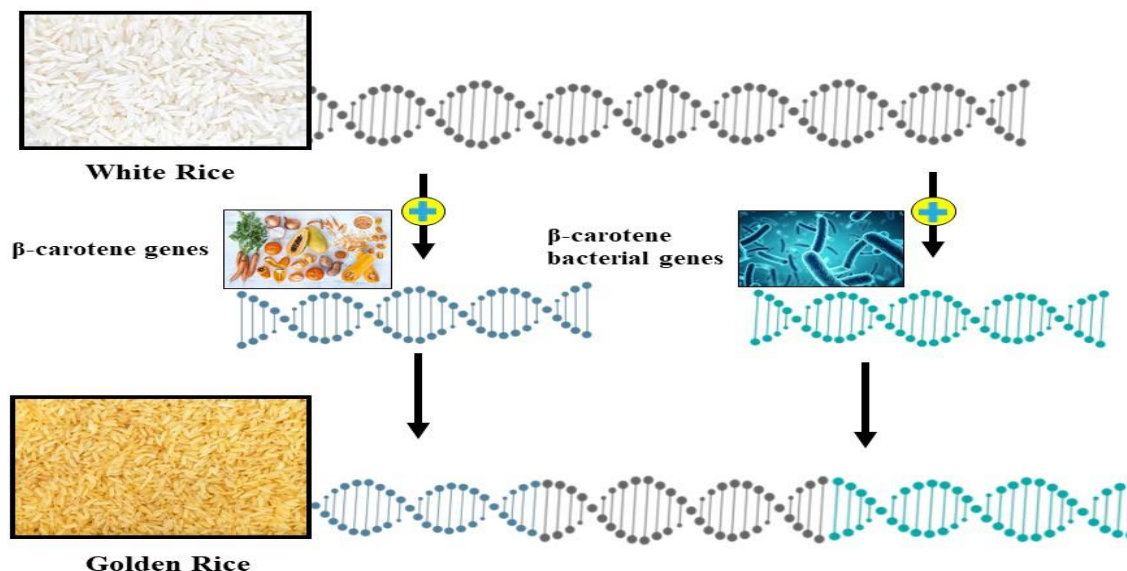


Figure 4. Production of golden rice from white rice using genetic engineering technique

Vitamin A deficiency can cause a variety of eye conditions like night blindness to permanent blindness (Dubock, 2019). Furthermore, its deficiency can also produce risk of diarrhea and measles in children. However, there are some disadvantages as well, which are associated with production of golden rice as they can disturb and contaminate wild rice, can cause toxicity in human body, are more expensive as compared to traditional crops (C. Zhang, Wohlueter, & Zhang, 2016).

4.3 CRISPR CAS-9

CRISPR Cas-9 has transfigured the field of biotechnology by creating and enabling accurate modifications to the living organisms' genome (Redman, King, Watson, & King, 2016). Scientists have used this technique in the research of rice to

enhance its yield as well as quality of its grain during production. Researchers have utilized and successfully edited genes that were related to grain shape, color, size, texture, and its nutritional value with the help of CRISPR technique of precise targeting. CRISPR has been utilized to enrich the amylose content in starch of rice and resulted in the creation of varieties with improved cooking quality. Furthermore, it has been utilized in improvement of nutritional value, development of rice with increased resistance against diseases and pests, and allergenicity reduction (Romero & Gatica-Arias, 2019). This technique has been greatly used for advancement in research to enhance and improve the livelihood worldwide and for addressing world food security competitions.

The process of using CRISPR-Cas9 in rice production involves several key steps: The process of using CRISPR-Cas9 in rice production several key steps shown in **Figure 3** includes, Designing the Guide RNA (gRNA) that determine which particular gene/ genomic locus needs to be targeted in the rice genome (Y. Lu & Zhu, 2017). Develop a guide RNA sequence that will correspond to the target region so that the Cas9 protein will go to the right area. Thereafter, clone the gRNA and Cas9 gene into a plasmid vector (J. Li, Sun, Du, Zhao, & Xia, 2017). An approach is to carry these CRISPR-Cas9 components into rice cells using the following vector. Transfect rice cells with CRISPR Cas9 vector. This can be done through Agrobacterium-mediated transformation

whereby *Agrobacterium tumefaciens* is used to transfer the DNA or through particle bombardment otherwise known as gene gun method (Molina-Risco et al., 2021). Generate cells where the CRISPR-Cas9 vector has been efficiently delivered and internalized. This is normally done by the selectable markers present in the vector of choice for the process of transformation. Develop the transformed rice cells into whole plants by residing to tissue culture methods. This entails growing plants from calli which are plant tissue cultures and make sure that the plant grows as required. Screenshot the regenerated plants to ensure the tissue culture and transformation with CRISPR-Cas9 system for the correct genetic changes (Romero & Gatica-Arias, 2019).

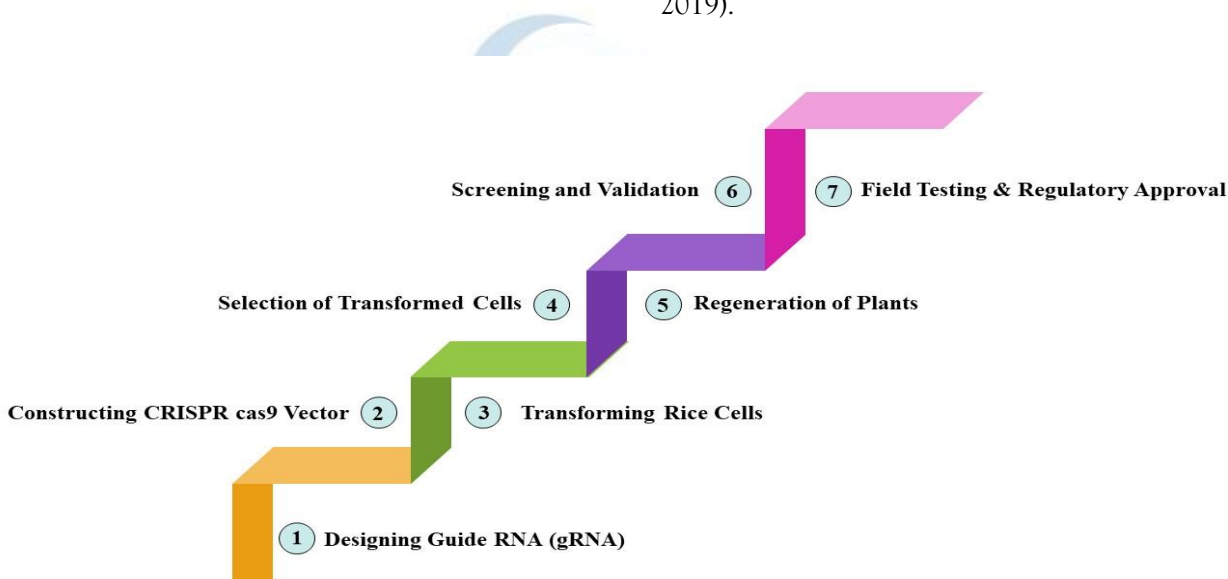


Figure 3. Steps involved in the production of rice with the help of CRISPR Cas-9

This comprises of gene sequencing of the target genes and identifying the specific edits meant by the process. Undertake a number of Gratz/Field/On Farm tests to monitor the performance of the edited rice plants in the experimental environment. When use, assess other characteristics for instance, resistance to disease, yield, and nutritional value. Manage bureaucratic procedures to seek the approval on the new rice variety (Sinha, 2022). This requires that the rice has to meet safety and environmental

compliance before it can be grown large scale and sold to the market. They also help in ensuring that the CRISPR-Cas9 technology is well utilized to help in developing improved rice varieties with particular desirable genetic traits (Gupta, Kumar, Patel, & Kumar, 2021).

5 CROP MONITORING

Crop monitoring with biotechnology for sustainable rice production entails adopting technologically developed processes to monitor

the rice crops with the aim of having a good yield and at the same time professionally monitor the production process to avoid any mishaps. This approach uses better resource management and biosensors for bio-ecological impacts. Resource management is important in the conservation of resources that are required in rice production which include water, land and nutrient (Kuhad & Singh, 2013). Techniques such as the System of Rice Intensification (SRI) are framed in terms of water saving and reduction of methane emissions from rice paddies (Toungos, 2018). Cropping system is conducted through crop rotation, use of organic matters, and conservation tillage that minimize the use of chemical fertilizers (Deep, Kumar, Saha, & Singh, 2018). Soil and nutrient testing, together with nutrient placement techniques and release form fertilizers combined, reduces nutrient loss. Integrated pest management (IPM) incorporated the use of non-chemical solutions such as bio control and use of resistant varieties (Prakash et al., 2014). The above mentioned strategies increases efficiency, reduce cost and reduce the effects of environment on rice farming hence making the farming sustainable.

Furthermore, use of biosensors is also very crucial in sustainable rice monitoring to provide immediate and actual details concerning the environmental and physiological conditions that influence rice crops. These sensors assist farmers to increase efficiency on the management practices hence lowering the impacts of rice farming on the ecology. Some of the chemical sensors are nitrate and phosphate sensors which monitor the levels of nutrients in the soil, hence enabling the use of fertilizer with a high precision, this reduce the overuse of fertilizer and thus reducing environmental pollution (Elli et al., 2022). According the modern technology, water quality sensors assess pH and salinity of irrigation water which should be adopted with rice growing requirements for maintaining the health of the soil and avoiding salinization (Yudhana & Kusuma, 2018). Among plant health sensors, chlorophyll sensors detect rice leaf photosynthetic performance, which can indicate the presence of nutrient deficiencies or stress; ethylene biosensors

detect stress hormones so that measures can be taken in case of drought or disease (Kundu, Krishnan, Kotnala, & Sumana, 2019; H. Zhang, Zhu, Hu, Zheng, & Jin, 2011). Pathogen detection biosensors are also sustainable because again it focuses on the particular pest or disease hence the need for broad chemical control without prejudice to the environment. There are also monitoring sensors of microclimate, including the air temperature and humidity, which facilitates the Heat stress and diseases (Khater, De La Escosura-Muñiz, & Merkoçi, 2017). When these biosensors are incorporated within a precision agriculture system, the farmers can have a decision support system which enables them to decrease the chemicals used in the production of rice, use water efficiently, and in effect produce higher yields in a sustainable manner.

6 CURRENT RESEARCH

Recent research in the production of sustainable rice is directed towards exploring new methods that would help in the fight against environmental problems and the improvement of yield. In several research articles published lately, there has been emerging a consensus of the need to embrace the cross disciplinary approach that complements the farmer style of crop production with care for the environment and its inhabitants. This entails water efficient irrigation techniques, water efficient rice varieties, and innovative methods of financing the small holder farmers (Gao et al., 2024). One of the particular areas of emphasis is to decrease the impact of the rice production on the environment as the process requires vast amounts of water and leads to methane emissions. New research is emerging in what has been termed nature-based solutions, as global carbon markets could facilitate financing of conservation and restoration (Phelan, Chapman, & Ziv, 2024).

Moreover, there are organizations such as the International Rice Research Institute (IRRI) on a mission to scale up dissemination of practice and technology to the farmers around the globe. These are the pre requisites for the modern farming such as the technologies for mapping of farm and real time decisions in matters concerning sustainable

rice farming for scale up (Zheng, Wei, Cheng, & Qian, 2024).

7 FUTURE PROSPECT

In future, artificial intelligence and the use of machine learning will be used to optimize sustainable rice production along with the biotechnology which can be utilized to predict crop performance and analyze data (Sharma, Anand, Budhlakoti, Mishra, & Jha, 2024). Furthermore, innovative genetic engineering practices should be taken to reduce environmental impact to enhance sustainability of rice production. Base editing technique will be also integrated for rice production as it allows the precise modification to the rice genome.

8 CONCLUSION

To conclude the whole discussion, it is reviewed that biotechnological approaches have modernized the development of sustainable rice crops over the traditional breeding. Additionally, various techniques for crop monitoring are also becoming more precise with the benefit of advanced biotechnology. This has allowed many researchers to find novel techniques for improvement of rice (*Oryza sativa*) for better quality, amplified yield, and production of rice with resistant gene for stress conditions. In recent times, CRISPR technology is considered as the most progressive tool for rice production because of its versatility. In future, artificial intelligence and machine learning will enhance the sustainability as well as crop monitoring of rice crops.

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