Bangladesh J. Nuclear Agric, 38(2): 49-63, 2024 *ISSN 0258-7130*
DOI: https://doi.org/10.3329/bjnag.v38i2.79553

INSIGHT INTO THE PHYSIOLOGICAL AND MOLECULAR RESPONSE OF LOW LIGHT STRESS TOLERANCE IN RICE

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Abstract

Rice is a sensitive crop, and its growth is highly affected by abiotic stresses. Among the abiotic stresses, low light intensity is one of the most critical environmental elements influencing plant growth and development. It regulates plants development and production by determining photosynthetic rate and accumulative assimilation. Plants, on the other hand, are often exposed to excessive or insufficient light intensities, and such variations, commonly referred to as light stress, have an impact on their agronomic traits by restricting physiological metabolic processes such as photosynthesis, antioxidant machinery, and their ability to fix atmospheric carbon and nitrogen. Photosystem II (PSII) and its reaction centres are particularly vulnerable to these disturbances and have thus been identified as main targets of light stress at the physiological, biochemical, and molecular levels. This paper reviews the response of low light levels on rice productivity and quality from morphological, physiological, biochemical, and molecular perspectives. We have attempted to present the advancements of molecular studies in this crucial field of low-light stress tolerance in rice. We also summarised the need for future research, emphasising the need for techniques that can effectively increase rice grain yield and quality in low-light conditions.

Key words: Rice; physiological; molecular; low -light stress; response; grain quality

Introduction

Rice (*Oryza sativa* L.) is the second most important cereal crop after wheat, feeding approximately half of the world, with Asian countries accounting for 75% of total global rice production (Leridon, 2022). In Bangladesh, over 95% of the population relies on rice for their daily diet, and it employs more than 85% of all agricultural farm laborers. Bangladesh ranks third in area and fourth in production among nations that cultivate rice. During 2022–23 fiscal year, rice production in *Aus, Aman, and Boro* seasons is 2.90 MMT of *Aus*, 15.43 MMT of *Aman*, and 20.77 MMT of *Boro*, respectively in Bangladesh (BBS, 2023). But the growth and production of rice is severely affected by environmental factor such as low-light stress. To minimizes the detrimental effect of low-light stress on production of rice, the physiological and molecular response of low light stress need to be addressed. When compared to other crops, rice is particularly sensitive to seasonal and planting-time variations in high temperature, day length, solar radiation, precipitation,

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sunshine hour, low light intensity, relative humidity, etc. Among these variabilities, low light intensity is the prime issues related to rice growth and yield. Plants undergo modifications to their cellular, biochemical, and molecular processes at many levels of plant organisation in response to low light stress (Dutta *et al.*, 2017). But persistent cloud cover or precipitation, particularly during the grain-filling stage, causes a significant loss in yield and leads to poor grain quality. Low light intensity can reduce grain yield by 34-55% depending on the stage of rice growth by reducing tiller number, dry weight, spikelet number with photosynthesis parameters (Dash *et al.,* 2022). The mechanism underlying low-light stress tolerance involves the identification of genotypes with a higher net photosynthesis rate and less reduction in test weight (Liu *et al.,* 2014).

Low light intensity cannot be agronomically mitigated under open field conditions, in contrast to other stresses like drought and salinity. Consequently, breeding low-light-tolerant/light-use-efficient (LUE) genotypes and choosing them is essential to increasing rice productivity (Nokkaul *et al.*, 2022) particularly in areas that experience low light stress during the rice-growing season. Although several studies suggested that genes and pathways associated with photo-protection as opposed to photo-inhibition may play a role in improving yield under higher light intensity (Panigrahy *et al.*, 2019), there are many studies that specifically address the response mechanism of adaptation to low-light stress (Dutta *et al.,* 2018).

We have a reasonable grasp of how plants react to low light thanks to several studies that have examined the physiological and biochemical impacts of low light and shade in a variety of model plants, including rice. Still, our understanding of the genetic pathways controlling resistance to low light levels is still developing. The review article discusses a variety of morphological responses, physiological, and biochemical processes that are affected by or responsive to low light levels, as well as the possibility of using genotypic variants for these characteristics to create low light resistant cultivars. The future perspectives of low-light stress tolerance in rice are also discussed in this review.

Low-light intensity

A summary of light intensity in response to plants growth

Light intensity or light quantity refers to the total amount of light that plants receive. It is also described as the degree of brightness that a plant is exposed to. In contrast to light quality, the description of the intensity of light does not consider wavelength or colour (Guenni *et al.,* 2018). The intensity of light is usually measured by the unit's lux (lx) and foot candle (fc). One-foot candle means the degree of illumination 1 foot away from a lighted standardized wax candle; 100 foot-candles is 1 foot away from 100 candles that are lighted simultaneously. Lux (pl. luces) is the unit of illumination that a surface receives one meter away from a light source. One-foot candle is equal to 10.76391 luces and 1 lux is approximately equal to 0.093-foot candle. According to Runkle (2006), the better unit of light intensity for studies involving plant responses is the $\mu molm^{-2}s^{-1}$. Light is an absolute requirement for plant growth and development (Shafiq *et al.,* 2021). However, different plants have optimum requirements and both deficient and excessive light intensities are injurious. Subject to physiological limits (Saha *et al.,* 2023), an increase in the intensity of light will result to an increase in the rate of photosynthesis and will likewise reduce the number of hours that the plant must receive every day (Wimalasekera *et al.,* 2019). According to Chapman and Carter (1976), the minimum limit for the process of photosynthesis in most plants is between 100 and 200 fc. Deficient light intensities (low light) tend to reduce plant growth, development and yield (Naveed *et al.,* 2024). This is because low amount of solar energy restricts the rate of photosynthesis (Vergara, 1978).

Correlation between temperature and light intensity

The correlation between temperature and light intensity has been hypothesised to be significant. Crop growth and production are negatively impacted by higher temperatures (35–42°C) in combination with either high or low light intensities. Additionally, low light intensities (150-200 call) and low temperatures (25–30°C) have a deleterious impact. However, moderate conditions (28 to 32°C) and light levels (350 to 450 call) are highly beneficial for greater yield (Dutta *et al.,* 2017). Although this combination is extremely uncommon, when it does happen, greater yields result. As a result, the severity of low-light stress is inevitably influenced by all these variables, which vary according to latitude, height, closeness to the ocean, landslides, and rain forests (Venkateswarlu and Visperas, 1987).

Morphological and physiological responses of rice plants under low light stress

Leaf area, leaf area index, leaf length, and width, along with growth durations, were significantly increased under low-light stress conditions (Figure 1; Deng *et al.,* 2022). Leaf area increased only 5.76% under 50% natural light, and it expanded up to 29.83% under 20% natural light (Ding *et al.,* 2004). The number of cells and thickness of mesophyll tissue per square millimetre decreased in leaves under 50% and 20% natural light conditions (Liu *et al.,* 2014). Chlorophylls a and b are significant pigments that participate in both the transmission and absorption of solar energy, with chlorophyll a contributing to the electrochemical conversion of solar energy (Wang, 2011). Different varieties generate different amounts of chlorophyll in response to low-light stress conditions (Zhu *et al.*, 2008; Liu *et al.*, 2009). In comparison to low-light-susceptible cultivars that perform poorly in low light, those that are tolerant of low light have higher chlorophyll b and lower chlorophyll a/b concentrations in their leaves when exposed to low light stress for 15 days (Figure 1; Zhu *et al.,* 2008). Similar to this, after being exposed to low light from the transplanting to the booting phases, low light-tolerant varieties have significantly higher levels of chlorophyll a and b during the grain-filling stage, but the inverse is true for low light-intolerant varieties (Liu *et al.,* 2009). The tolerant varieties capture more solar energy through increased leaf area and higher chlorophyll b content under low light stress. Low-light stress significantly affects stomatal conductance (stomata production per square millimetre), which is why intercellular CO_2 concentration is also enhanced (Yang *et al.,* 2011). Stomatal conductance drops by 24.31% and 29.23% with increasing in the intercellular CO_2 concentration of 11.11% and 16.67% under 45% and 15% reduced natural light, respectively. When compared to natural light, the net photosynthetic and respiration rates also decrease by 79.84% and 34.33% in low light stress, respectively. According to Liu *et al.,* (2014), the ratio of respiration to net photosynthetic rates is greater in low light than in natural light because the respiration rate declines more than the net photosynthetic rate does. According to Liu *et al.,* (2009), stomatal closure is the primary obstacle when stomatal conductance and intercellular CO_2 concentration are decreased significantly. However, they didn't take into account the elements that contribute to a reduction in photosynthesis when intercellular CO_2 concentrations rise and stomatal conductance falls. These findings suggest that the stimulation of stomatal closure and the decreased number of stomata generated in low-light stress may not be substantially related to a drop in net photosynthetic rate (Wimalasekera *et al.,* 2019). Photosynthesis is an intricate process in plants that is involved with adenosine triphosphate synthesis, light absorption, energy conversion, electron transport, and other enzyme activities. Shi *et al.,* (2006) revealed that the ribulose bisphosphate carboxylase (Rubisco) activity in chloroplasts drastically decreases under low-light stress conditions. Rubisco is an essential enzyme that controls photosynthesis through a biochemical process and also plays a role in measuring the photosynthetic rate in the leaves of rice plants (Sui *et al.,* 2012). kemaladze *et al.,* (2016) demonstrated that the rates of non-photochemical quenching, electron transfer, and PS II quantum yield are all affected by light intensity. As a result, reduced Rubisco activity and altered electron transformation may play a role in the lower net photosynthetic rate seen in rice leaves under low-light stress conditions.

Antioxidant responses in rice leaves under low light stress

Depending on the genotype involved, low light can have varying impacts on rice leaf antioxidative and osmotic control characteristics. Reduced malondialdehyde (MDA) content, decreased peroxidase activity (Figure 1), increased superoxide dismutase and catalase activities, and decreased soluble sugar and protein content are all seen in the low light-stress resistant strain (Panda *et al.,* 2019). Conversely, the underperforming variety exhibits the opposite traits. Superoxide dismutase, peroxidase, and catalase are commonly employed as essential enzymes for eliminating reactive oxygen species, whereas soluble sugar plays a crucial role in osmotic control within plant cells (Wang, 2013). Depending on the genotype involved, low light can have varying impacts on rice leaf antioxidative and osmotic control characteristics. Superoxide dismutase, peroxidase, and catalase are commonly employed as essential enzymes for eliminating reactive oxygen species, whereas soluble sugar plays a crucial role in osmotic control within plant cells (Dash *et al.,* 2022). Since MDA is a by-product of lipid peroxidation in cells, its level is frequently regarded as a sign of plant health and a measure of the severity of cell membrane damage caused by stressful conditions, i.e., when MDA levels are higher, more severe cell membrane damage takes place (Kusvuran *et al.,* 2016). Plants' physiological metabolism and biosynthesis are primarily regulated by soluble proteins, which contain a variety of metabolic enzymes (Liu *et al.*, 2012). It is possible to regulate the scavenging of reactive oxygen species and the water potential in cells under low light conditions and to reduce the negative effects of low light on plant physiological metabolism by encouraging anti-oxidative enzyme activity and osmotic regulation in low light tolerant varieties (Nokkaul *et al.*, 2022). Moreover, cultivars that are not tolerant to low light levels frequently experience problems with their antioxidant and osmotic regulating systems, indicating that adverse consequences lead to cell membrane damage. By examining the relevant parameters reported in multiple studies, this has been demonstrated (Zhu *et al.*, 2008; Liu *et al.*, 2012).

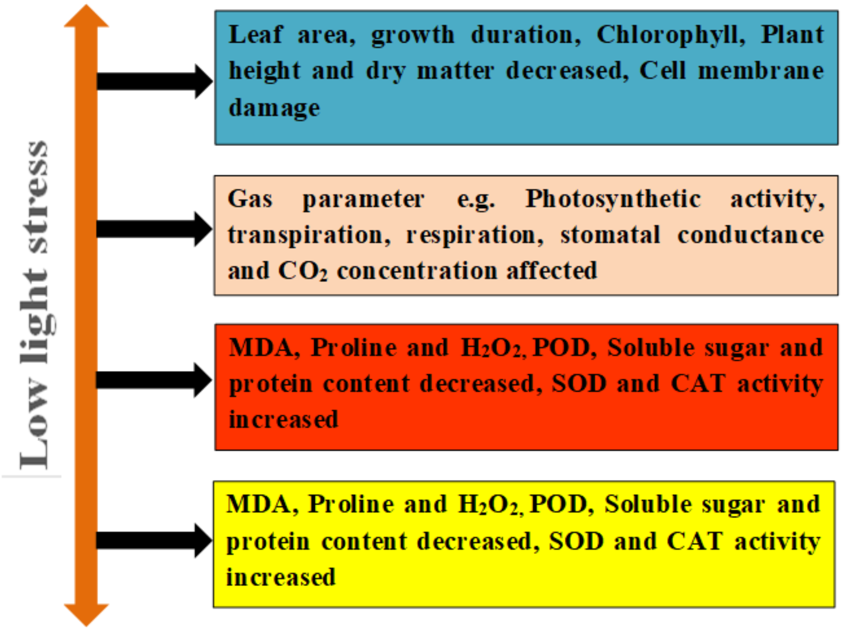

Fig. 1. The effects of low-light stress on rice morphological, physiological and biochemical mechanisms.

Oxidative stress, anti-oxidative defence system and starch synthesis responses under low light stress

Low-light stress has a significant effect on oxidative stress and the anti-oxidative defence system. The responses of tolerant and sensitive varieties to low light are markedly different (Ren *et al.*, 2023). Low-light-resistant genotypes can scavenge reactive oxygen species and cell water potential (Kang *et al.*, 2018). This reduces the negative effects of low light on plant physiological metabolism by promoting anti-oxidative enzyme activity and osmotic control (Liu *et al.*, 2020). On the other hand, cell membrane damage is seen in low-light-sensitive cultivars (Liu *et al.*, 2012). Superoxide dismutase and catalase activities were enhanced in the low-light stress-tolerant varieties. Whereas, light-sensitive antioxidant enzymes such as catalase and peroxidase are more active in susceptible varieties than in tolerant ones under low light stress conditions. Soluble sugar, malondialdehyde, protein content, and peroxidase activity were decreased in the low-light stress-tolerant varieties (Luo *et al.,* 2023). The type that performs badly, however, exhibits the opposite traits. In general, the main enzymes for scavenging reactive oxygen species are superoxide dismutase, peroxidase, and catalase, with soluble sugar serving as an essential osmotic regulator in plant cells (Wang, 2012; Liu *et al.,* 2012). Since MDA is a by-product of lipid peroxidation in cells, its level is frequently regarded as a sign of plant health and a measure of the severity of cell membrane damage caused by stressful conditions, i.e., when MDA levels are higher, more severe cell membrane damage takes place (Zhu *et al.*, 2017)). Plants' physiological metabolism and biosynthesis are primarily regulated by soluble proteins, which contain a variety of metabolic enzymes (Liu *et al.*, 2012). It is possible to regulate the scavenging of reactive oxygen species and the water potential in cells under low light conditions and to reduce the negative effects of low light on plant physiological metabolism by encouraging anti-oxidative enzyme activity and osmotic regulation in low light tolerant varieties. Moreover, cultivars that are not tolerant to low light levels frequently experience problems with their antioxidant and osmotic regulating systems, indicating that adverse consequences lead to cell membrane damage. By examining the relevant parameters reported in multiple studies, this has been demonstrated (Zhu *et al.,* 2008; Liu *et al.,* 2012). Chen *et al.,* (2014) found that when exposed to low light, starch, amylose, and sucrose levels reduced while ADP-glucose pyro-phosphorylase (*ADPGPPase*) activity increased. They also observed that soluble starch synthase activity dropped, whereas soluble starch branching enzyme and granule-bound starch branching enzyme activity increased. The activity of starch-debranching enzymes varies with varieties. According to Wang *et al.,* (2013), low light during the grain-filling stage leads to a lower supply of carbohydrates to grains as well as a drop in starch synthase activity in grains, which directly hinders grain filling and increases the occurrence of chalky rice.

Grain sterility and pollen viability under low light stress

High grain sterility was caused due to poor translocation of carbohydrates from sources to sink under low light stress (Sridevi and Chellamuthu, 2015). The combined effects of fewer panicles m^{-2} and grain number panicle^{-1}, lower test weight, and a larger proportion of spikelet sterility are blamed for the decreased grain production in low-light conditions. Under low light stress, the content of carbohydrate, proline, cytokinin, and protein synthesis decreases while suluble nitrogen and gibberllins increase in the panicles at the flowering stage. which results in a spikelet sterility rate that is very high (Liu *et al.,* 2014; Dutta *et al.,* 2017). Since rice is a short-day plant, pollen sterility affects it, especially in later-formed florets grown in low light conditions. Grain growth is mostly determined by the contribution of reserve carbohydrates or dry matter generation prior to flowering (Xie *et al.,* 2021; Hebbara *et al.,* 2003). It has been found that if the harvest index is low due to inadequate dry matter partitioning in the panicle, spikelet sterility is high (Barmudoi and Bharali, 2016).

The response of light intensity on the yield and yield attributing traits in rice

Light intensity is one of the most important environmental factors that determine the basic characteristics of rice development. Previous research has shown that rice plants grown under low light intensity from the transplanting to the booting stages have a 34.51% reduction in grain yield, which is due to a significant decrease in the number of fertile panicles and grains per panicle produced (Qi hua *et al.*, 2009; Liu *et al.*, 2009). Rice grain yield decreases by 14.99% when exposed to low light for 10 days (beginning with the heading stage) because the seed-setting rate is significantly reduced (Table 1). Rice grain yield declines noticeably (by 55.45%) when grown in low light from the first heading to maturity stages, which is directly attributed to significant declines in the seed-setting rate and 1000-grain weight (Table 1). These findings demonstrate that low light conditions have a greater negative impact on rice grain yield during the panicle differentiation or grain-filling stages than they do during other growth stages, which helps to explain why low light during the reproductive stage results in a greater loss of grain yield (Ren *et al.*, 2002). Because of the reduced photosynthetic rate in low light, nutrient source organs (leaves, culms, and sheaths) are unable to provide sufficient amounts of assimilates to support tiller emergence and grain growth (Murty & Sahu, 1987). In earlier research, hypotheses about potential physiological mechanisms causing this change were made (Dey *et al.*, 2019). Numerous researchers discovered that different varieties of grains respond differently to low light. Because they are more tolerant to low light conditions and have higher chlorophyll content and photosynthesis efficiency as well as stronger antioxidant abilities, tolerant varieties maintain their carbohydrate production levels despite the negative effects of low light on carbohydrate accumulation and transportation (Liu *et al.*, 2012).

Table 1. The effects of low light stress on yield and yield contributing traits in rice

Treatment	No. of effective panicles/m^2	1000-grain weight (g)	No. of filled grains per panicle	Seed-setting rate (%)	Grain yield (g/m^2)
Natural light intensity (CK) [a]	301.5	25.2	85.3	87.5	639.8
50% of natural light intensity [a]	226.5	25.0	79.0	96.2	419.0
Natural light intensity (CK) [b]	197.4	30.3	147.9	82.1	883.3
40% of natural light intensity [b]	195.3	30.0	127.9	71.5	750.9
Natural light intensity (CK) [c]	269.9	21.5	121.5	83.2	704.8
55% of natural light intensity [c]	257.9	17.4	70.0	48.6	314.0

[a] Low light treatment conducted from the transplanting to booting stages for the rice variety Xingfeng;
[b] Low light treatment conducted from the heading to 10 d after heading stages for Chuanxiang 9838;
[c] Low light treatment conducted from the initial heading to maturity stages for the rice variety Jingxian 39.

The response of low light on grain quality characteristics in rice

From the transplanting to the booting stages, low light exposure to rice increases head rice yield and amylose in grains while decreasing the proportion of chalky kernels and protein content (Table 2). Previous research suggested that the source-sink ratio is significantly changed when low light is applied during these stages. In other words, the biomass of sink organs, as measured by the quantity and size of fertile panicles and grains within each panicle, is significantly decreased (Wang *et al.*, 2015). When full light becomes available during the heading stage, the photosynthetic capacity of source organs (leaves) recovers to a normal level (Liu *et al.*, 2014). Chen *et al.*, (2022) hypothesize that such variations in light intensity might affect the physicochemical metabolism of plants during the development of grains and affect quality. For instance, after plants are exposed to low light before the heading stage, especially during the booting stage, a relatively adequate supply of assimilate to grains invariably reduces the formation of chalky rice (Panda *et al.*, 2023); Thangaraj & Sivasubramanian, 1990). Brown rice, milled rice, and head rice yields, as well as grain amylose content and gel consistency, decrease when rice is grown in low light for 32 days (beginning at the first heading stage), whereas grain protein content and the proportion of chalky kernels increase (Li *et al.*, 2022)). These results demonstrate that low light levels during the grain-filling stage lead to poor rice grain appearance and milling qualities (Ren *et al*, 2003b). According to Li *et al.*, (2006), when grain amylose content is decreased under low light, increased activity of the soluble starch branching enzyme hinders the accumulation of amylose in grains. Though the amount of N imported from the culm and sheaths to the grains decreases in low light, it should be noted that grain protein content increases (Ren *et al.*, 2003). These findings lead us to the conclusion that grain protein content increases under low light conditions because the amount of starch in grains decreases more than grain protein does.

Table 2. The effects of low light stress on rice grain quality traits (Liu *et al.*, 2014)

Treatment	Brown rice yield (g/kg)	Milled rice yield (g/kg)	Head rice yield (g/kg)	Percentage of chalky kernel (%)	Amylose content (%)	Gel consistency (mm)	Protein content (%)
Natural light intensity (CK) [a]	793	643	529	12.5	13.5	-	10.37
50% of natural light intensity [a]	789	621	554	0.0	16.1	-	9.83
Natural light intensity (CK) [b]	817	728	510	35.3	22.2	64.0	9.53
51% of natural light intensity [b]	814	719	458	46.0	22.1	51.7	10.57
31% of natural light intensity [b]	809	708	408	56.3	20.2	39.7	12.57

[a] Low light treatment conducted from the transplanting to booting stages for the rice variety Xingfeng;
[b] Low light treatment conducted from the initial heading to 32 d after initial heading stages for Gangyou 527.

Relationship between sink and source under low light stress

The amount of soluble sugar and soluble protein in rice leaves, as well as the quantity of fertile panicles, significantly decrease when rice plants grown under low light conditions from the tillering to booting stages (Dey *et al.*, 2019). However, when the low light stress is stopped, the levels of soluble sugar and protein return to normal, showing that the shading treatment has improved the ratio of source to sink capacity (Chen *et al.*, 2022). The photosynthetic ability of rice plants is inhibited when exposed to low light from the heading to maturity stages (Shao *et al.*, 2021), as shown by the decreased chlorophyll content and impaired photosynthetic rate in leaves (Figure 2). In addition, the seed-setting rate and 1000-grain weight are also significantly decreased. According to Kobata *et al.*, (2000), when rice is shaded during the early stages of grain filling, shade has no effect on the grain dry matter increment. However, if sufficient assimilates are not present during the remaining stages of grain filling, the final grain weight will be significantly decreased. Therefore, Liu *et al.*, (2014) hypothesize that from the heading to maturity stages of rice, under low light conditions, the ratio of source to sink may decrease.

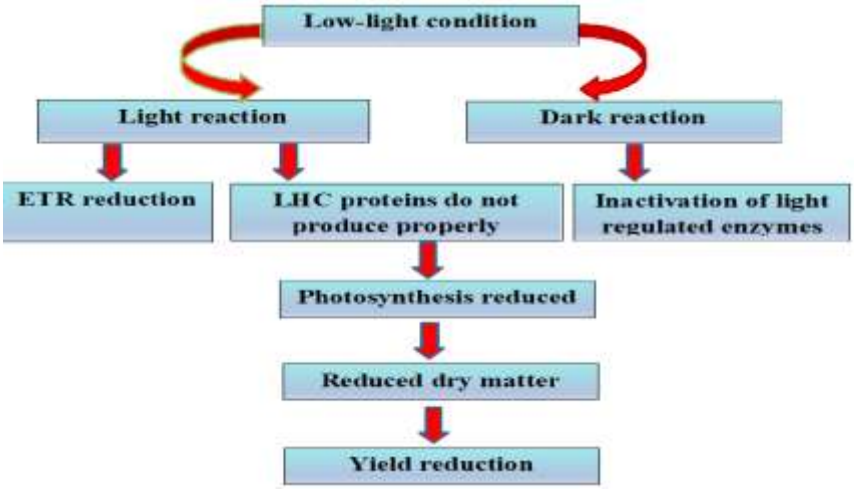

Fig. 2. A flow diagram representing low light, reduction in photosynthesis and dry matter partitioning (Dey *et al.*, 2019).

Molecular response of low light stress tolerance in rice

Low light stress tolerance is the ability of a photosynthetic organism to tolerate low light levels, and it is typically characterised by a set of morph-physiological traits, including a decrease in growth rate, a light compensation point, a dark respiration rate, a chlorophyll content, a chlorophyll a/b ratio, an increase in quantum yield, and carbohydrate storage, among many other traits (Dash *et al.*, 2022; Valladares and Niinemets, 2008) Numerous chlorophyll proteins are engaged in the process of photosynthesis, but the light-harvesting chlorophyll a/b binding (*LHC*) proteins are particularly important (Ganguly el al., 2020). In rice, there are six genomic loci that code for early light-inducible proteins (*ELIP1* to *ELIP6*), two loci for stress-enhanced proteins (*SEP1 and SEP2*), two loci for one-helix proteins (OHP1 and OHP2), and one locus for light-induced protein 1-like (*LIP1-like*) (Sekhar *et al.*, 2022); Umate, 2010). There are 17 genomic loci that code for chlorophyll a/b binding proteins. According to Liu *et al.*, (2014), the rice *LP2* gene promoter was discovered to be extremely light-sensitive. Numerous QTLs have been identified in rice, and their contribution to low light intensity is just now beginning to be recognised (Aloryi *et al.*, 2022). With regard to its impact on C source (flag leaf size, leaf physiology) and sink (panicle size, spikelet quantity per panicle), one of the previously discovered QTL, *qTSN4* (SPIKE gene), was examined (Fabre *et al.*, 2016). According to the findings of this study, *qTSN4* is a candidate locus for more physiological research under low-light stress conditions (Dutta *et al.*, 2018). In a related investigation, it was discovered that the *qTSN4* influence on panicle spikelet quantity under low light availability is indirect and is driven by assimilating resources at tiller level (Adriani *et al.*, 2016) using near-isogenic lines (NILs) in IR64 or IRRI146 background (Sahu *et al.*, 2023). A thorough understanding of the molecular underpinnings of low light tolerance would enable the identification of potential genes and the development of molecular markers that may be used to potentially increase yield through marker-assisted selective breeding into elite rice varieties (Ashkani et al., 2015). Rice is the first crop to have a high-quality genome sequence that is publicly available. Since 2004, the whole genome sequence of rice has revolutionised our understanding of the evolution of rice and other cereal crops. The rice genome sequence has been decoded in order to mine DNA-based markers for marker-assisted breeding (Singh et al., 2010). Any gene of interest can be mapped through the utilisation of the rice genome sequence and the adaptability of microsatellite or SSR markers, as well as knowledge of their physical location (Rai. *et al.*, 2021). Through SSR markers screening many low-light-tolerant genotypes, including Swarnaprabha, Rudra, and Purnendu, have been reported earlier13, but the tolerance mechanisms vary depending on the genotype (Saha *et al.*, 2023). These markers could be applied to gene pyramiding and fine mapping gene using marker-assisted selection methods.

Future perspectives

The weather has the greatest influence on the growth and yield of rice among the abiotic stresses. Sunshine hours, light intensity, and a late transplanting date are three critical factors that affect rice growth, development, and yield. Crop growth is also influenced by temperature stress, solar radiation, relative humidity, and rainfall. Despite technological advancements, rice cultivation remains a dangerous business. By using the best time for sowing or planting, we can take advantage of weather variations. Rice yield loss due to late transplanting could be managed by manipulating the transplanting time that is best for yield and yield-contributing traits. Numerous experiments and related reports have validated that low light has a significant impact on rice plant agronomic and physiological traits, inhibiting the fundamental physiological metabolisms such as photosynthesis, respiration, antioxidant properties, and the conversion and distribution of carbon and nitrogen. Such modifications eventually lead to decreased rice grain yield and quality due to poor tiller production, impaired panicle differentiation, abnormal grain filling, and the complex variability of enzyme activities regulating starch grain synthesis. Previous research has led us to the conclusion that there are two key channels for increasing rice grain yield and quality in low-light stress. In areas with poor lighting conditions, varieties with a high tolerance for low light should first be planted and monitored. To find out whether some of the physiological characteristics mentioned above, like chlorophyll content, can be used as markers of tolerance to low light conditions for breeding work, more research is required. According to Thilmony *et al.*, (2009), *LP2, a* gene promoter, is highly light-responsive in rice crops. To breed a tolerable cultivar that can thrive under low light stress, a molecular method must be used to improve rice's inherent resistance to low light. Second, corresponding studies must develop the best agronomic measurements to handle low light stress. Silica and/or organic fertilizer can be applied to rice fields to reduce the harm caused by low light levels during rice development. Therefore, future research should concentrate on enhancing the ability of rice plants to withstand low light levels through the adoption of suitable cultivation practices, such as enhancing the supply and translocation efficiency of assimilate and examining the proper application of new fertilizers and commercial plant growth regulators to rice plants and fields. Under low-light conditions, an ideal phenotype for tolerance would have better photosynthetic efficiency, an erect leaf, delayed senescence, efficient grain filling, and more grains/panicle (Rai *et al.*, 2021).

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