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Society For Advancement of Rice Research

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- To disseminate knowledge on latest developments in rice research through publications, seminars, lectures and training programmes.
- To provide consultancy in rice production and development.
- To facilitate research and industry collaboration and public private partnership at national level.
- To honour outstanding achievers in rice research and development.
- To cooperate with other organizations having similar aims and objectives.
- To promote any other scientific/professional activities conducive for the advancement of science of rice and rice improvement.

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The Principles that Constitute System of Rice Intensification (SRI) and the Practices for Applying them at Field Level

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Abstract

Understanding the System of Rice Intensification (SRI) begins with a distinction between its *principles*, which are general, and the *practices* that give effect to these principles when applied, which are and adapted for particular situations. This makes SRI more like a menu than a recipe. It is not something to be promoted by rote learning, glossing over the reasons for its principles and practices of SRI, but rather something that emerges from an understanding of agronomic processes.

Put in simple straightforward terms, SRI management elicits the growth of more robust and more productive plants, *i.e., phenotypes*, from a given crop variety, *i.e., genotype*. Application of SRI's principles and practices evokes the fuller expression of plants' genetic potential than do most currently prevailing practices, such as high plant density, continuous flooding, and ignoring the contributions of the soil biota and the implications of profuse root growth. This paper enumerates and elucidates the agronomic principles and practices of SRI, considering how and why they achieve the effects that are widely and consistently observed.

Key words: System of Rice Intensification, SRI Management, Crop variety, Agronomy.

That the System of Rice Intensification (SRI) was developed inductively from observations and experimentation without hypotheses or *a priori* assumptions has been both a strength and a weakness for this agroecological innovation in rice crop management. On the plus side, Henri de Laulanié's empirical, thinking-outside-the-box construction of SRI in Madagascar some four decades ago is benefiting tens of millions of rice-producing households in over 60 countries, and it has produced important new knowledge for producing rice, some of which is rather counter-intuitive.[1]

For example, through observation and in-field experimentation with farmers, Laulanié established that: .

- ***Transplanting very young rice seedlings*** *enables the resulting plants to produce more tillers, panicles, and grains* than if they are transplanted at an older age.[2]
- ***Reducing plant density****, by as much as 80-90%, can increase grain yield per unit area,* if the remaining plants are managed with complementary practices designated by SRI.

[1] Laulanié referred to the rice plant as his teacher ('mon maître' -- my master), to suggest that he learned mostly from observation rather than from textbooks or journal articles (although he had earned a university degree in agriculture before he entered a Jesuit seminary in 1941). See the technical paper (Laulanié, 1992) from which he wrote his only published paper on SRI (Laulanié, 1993/2011).

[2] This effect can be explained morphologically by analyzing rice plant growth in terms of phyllochrons (Nemoto et al., 1995), as summarized on pages 154-160 of Uphoff (2016).

- ***Rice plants should not be kept continuously flooded*** because this widespread practice suffocates their root systems, and thereby constrains their yield.

These conclusions contradicted what was accepted scientific knowledge at the time (e.g., Sinclair, 2004). For example, recommendations from leading rice research institutions included transplanting seedlings more than 20 days old, not seedlings younger than 15 days; planting rice crops optimally densely rather than optimally sparsely; and keeping rice paddies always inundated so that the plants would never experience any water stress (De Datta, 1981). This 'common knowledge' is no longer tenable, however, because of SRI performance and research.

On the other hand, taking an inductive approach has meant that explanations have to be constructed *post hoc*, and theory has to catch up with practice rather than informing and leading practice. Persons who were skeptical about SRI, scientists as well as farmers, would probably have had less difficulty in accepting SRI's novel ideas and recommendations if these could have been better explained in scientific terms when SRI was introduced into the literature some 20 years ago (Stoop *et al.,* 2002).

There are now reasonably robust scientific explanations for SRI success, e.g., Toriyama and Ando (2010), Stoop *et al.,* (2011), Thakur *et al.,* (2016); and there is a large published literature on SRI.[3] However, it is clear in retrospect that it would have been beneficial to distinguish from the outset between the agronomic *principles* that account for the impact of SRI methodology and the respective agronomic *practices* that operationalize SRI in the field, indeed in millions of diverse fields.

Principles are formulated to be general, while practices are expected to be specific and varying. Keeping the soil in rice paddies in mostly aerobic condition rather than continuously flooded (hypoxic), for example, is a basic *principle* for SRI, that can be accomplished by a variety of *practices* which can provide active and/or passive soil aeration. Unfortunately, SRI was not understood well enough at the outset to make a clear delineation between principles and practices. After some introductory comments, this paper addresses this ambiguous area in SRI theory and undertakes to sort out this important distinction.

1. SRI as an Innovation

SRI was called a *system* rather than a technology by Fr. Laulanié because it depends more on knowledge and skill than on introducing a new variety or certain material inputs. It was not specified as a 'technology' because it was and is still evolving (Uphoff, 2023). We consider SRI to be rather a *methodology*, because it is something to be learned and adapted, not something to be 'transferred' like a technology. Basically, SRI represents a paradigm shift, a new and better way of thinking and proceeding. This differentiates SRI from what most people think of as a technology. The following statements characterize SRI simply and summarily:

- ***SRI crop management modifies the environment in which rice plants are grown,*** creating more favorable conditions for their health and growth above and below ground.
- ***SRI practices mobilize biological processes and potentials that already exist,*** within rice plants and within the soil systems in which they grow.
- ***SRI capitalizes on capacities and resources that are readily available to farmers,*** rather than requiring them to buy new inputs or to utilize new plant varieties.[4]

[3] See SRI website for a listing of publications: http://sri.cals.cornell.edu/research/index.html.

[4]This statement needs to be qualified because having access to and using a mechanical weeder for weed control increases crop yield from SRI (see graphs shown below). Use of such a weeder, which aerates the soil, is highly recommended, but it is not required. A study done at ANGRAU concluded that using such mechanical weeders can cut the labor time that women spend in weeding SRI rice paddies by three-quarters (Mrunalini and Ganesh, 2008).

All organisms, not just rice, begin with a certain genetic potential that is incorporated in their DNA. As they develop and interact with their environment, becoming actual, unique plants (or animals or micro-organisms), they achieve some or most but almost never all of this potential. Rather than creating and utilizing new genetic potentials, SRI crop management evokes the fuller expression of genetic potential that already exists.

In some ways, this puts SRI at odds with scientists and commercial interests that have promoted a 'Green Revolution' strategy for agricultural development. This approach makes improvements in crops' genetic resources and then utilizes more inputs - synthetic (inorganic) fertilizers, agrochemical protectants, and more water to benefit from the increment in potential. It is often forgotten that increased irrigation has been a major part of Green Revolution successes, and this is an increasingly scarce, costly, or unreliable resource.

SRI methods enable farmers who want to use hybrid or improved varieties to get even greater yields from these HYVs or hybrids (e.g., Diwakar *et al.,* (2013), with less expenditure for new and costly seeds, so this further raises farming income. On the other hand, SRI management can also improve the performance and profitability of so-called 'traditional' varieties (Dwiningsih 2023), which makes these unimproved varieties competitive economically with modern varieties. So, SRI can help conserve rice biodiversity as well as benefit farmers.

2. Pictures Each Worth More Than a Thousand Words

An understanding of SRI is best communicated by two pictures that shaped my own comprehension of this agronomic innovation methodology. The first was sent to me in 2004 by a colleague in Cuba, Dr. Rena Perez; the other I took myself during a visit to Indonesia in 2009. These are, admittedly, not average or typical rice plants grown with SRI methods; they are, indeed, some of the best. But they show how much *potential for growth* there is in rice (and other) plants if their genetic potential is capitalized upon more fully by creating favorable conditions for them to grow in, not just improving their physical circumstances but also enriching biological elements and concomitants in their environment.

The two rice plants in the picture below are held by Luis Romero, one of the first farmers in Cuba to try out SRI methods. While it may be hard to believe, these plants are both *the same age* (52 days after seeding) and *the same variety* (VN2084), so they are the same genotype, like twins starting life with the same genetic resources. The SRI-grown plant on the right was removed from its nursery when only 13 days old and transplanted into a rice field with wide spacing between single plants in a square grid pattern; with intermittent irrigation rather than flooding; and with organic matter added to the soil, not relying mainly on chemical fertilizer.

This picture was taken just after the smaller plant on the left had been removed from its nursery to be transplanted into a typically-managed rice field. at 52 days after sowing. This was a typical age for transplanting rice seedlings in that part of Cuba. Dr. Perez happened to have her camera with her on that day when she visited Romero's farm to observe his transplanting. The SRI-grown plant seen on the right was pulled up from its field at random for comparison. The SRI rice plant has 43 tillers, while the conventionally-grown rice plant on the left has just five.

Both plants started with the same genetic potential, the same DNA, but their conditions for growth were quite different. In addition to comparing the difference in plant canopy size, note also that the root system of the SRI plant was both much larger and also lighter-colored, because its roots had not suffocated and degenerated from being in flooded (hypoxic) soil. Its tillers are more numerous and wide-spread because the plant was not being crowded by other plants. This picture shows how much difference in plant growth can be elicited by giving rice plants in more favorable conditions: no crowding, no continuous flooding, and starting with young seedlings transplanted carefully so that their potential for growth is not diminished.[5]

Below, on the left, is the picture of another rice plant, this one presented to me by Indonesian farmers during a visit to their SRI training school in East Java. This plant grown with SRI methods had *223 tillers emerging from a single seed* (*Ciherang* MV). The farmers acknowledged that this was their best SRI plant from the previous season, but it showed them and others the potential for growth and productivity that SRI methods can elicit. The plant's large canopy of tillers and leaves was supported by a massive root system.

How is such rice plant performance possible? Not just in Cuba and Indonesia, but also in dozens of other countries, including India? The picture above on the right was sent to me from Punjab by Dr. Amrik Singh, ATMA/Gurdaspur. The rice plant on the left with the larger roots and canopy is easily identified as having been grown with SRI practices. The agronomic principles that account for such effects are broadly relevant, across countries and also across numerous crops (Adhikari *et al.,* 2018; Berhe *et al.,* 2017; Dhar *et al.,* 2016; Gujja *et al.,* 2018).

3. The Agronomic Principles that Constitute SRI

SRI has usually been described and presented in terms of certain practices, but it is better understood in terms of certain *principles* that are then implemented by particular practices. It is the practices that can make rice plants more vigorous and more productive, better able to fulfill their genetic potential and capitalize on the potentials of coexisting life in the soil. However, the principles that comprise SRI that should be understood and should guide farmers' practices. The principles remain steady, while the practices can and do vary.

Synergies among the recommended SRI practices contribute to the effectiveness of the system overall, as discussed in section 7. But two factors stand out as the foundations for SRI effects.

- The *increased growth and performance of* ***plant root systems,*** evident in the pictures above, and
- The *abundance, diversity, and activity of the* ***soil biota,*** informally referred to as 'the life in the soil.' This encompasses the many millions of organisms, ranging from miniscule microbes to good-sized earthworms, that live (and die) in the soil.

[5]*Anticipating that some people would be skeptical about this picture because it is so easy to alter digital files, I sent a video camera to Dr. Perez so that during the next season she could document in real time the respective plants' growth, also interviewing Romero about his practices and his results. Anyone with access to the internet can see for themselves how SRI plants' express their genetic potential during a growing season: http://sri.cals.cornell.edu/countries/cuba/SICAenglish.wmv (Spanish with English subtitles, 36 min). In Latin America, 'SICA' is used as an acronym for 'SRI' because literal translation of 'SRI' into Spanish becomes 'SIA,' the Spanish acronym for the American Central Intelligence Agency.*

Although not easily seen or never seen, the soil biota provides a great variety of services both to plants and to the soil system, such as nitrogen fixation, phosphorus solubilization, nutrient mobilization, protection against pathogens, soil aggregation and drainage, circulation of air and water in the soil, and making the soil more amenable for root growth. The microbial component of the soil biota (the plant-soil microbiome) is starting to receive the scientific attention that it deserves (Turner *et al.,* 2013; Tkacz and Poole, 2020; Primavesi *et al.,* 2024). This trend has paralleled the intensification of medical research which investigates and appreciates how pervasively the human microbiome affects our own lives and our health.

SRI can be understood in terms of four broad principles that apply to all kinds of rice production, irrigated and rainfed, with modern or traditional varieties. Because they are good agronomy, they apply also for crops like wheat, millet, and sugarcane, as noted above.

i. ***Establish new plants carefully and well***, avoiding trauma to the roots and ensuring opportunity for roots to grow prolifically because these are essential, the *sine qua non* for plants' success. This and the other three principles listed here are given effect in the field through practices reviewed in the next section, section 4.

ii. ***Minimize competition between plants***, ensuring that all of the plants have access to sunlight, nutrients and water, with no shading and no crowding that will inhibit the growth of each plant's tillers and roots. The distance between plants should be optimized rather than maximized, however. Each plant should achieve as much of its potential as possible.

iii. ***Balance both water and oxygen in the soil,*** with never too much of either as all plants need both of these elements. Because air and water occupy the same pore space in the soil, having more of either one means having less of the other available to plants. Water, soil, and weed management practices should strive to maintain a balance of water and air in the soil. Laulanié's advice was to provide paddy fields with the "minimum of water" (*le minimum de l'eau*) that would meet the needs of both the plants and the soil biota.

iv. ***Enhance and maintain the soil system's fertility***, knowing that this depends on the amount and activity of life in the soil as well as on good structure of the soil and good functioning of the soil system. The soil's fertility is a function not just of the amount of nutrients currently available in it, but also of the abundance and diversity of life in the soil.

These principles are not likely to elicit much controversy among agronomists. However, some of the SRI methods recommended for applying them in the management of plants, soil, water, nutrients and weeds contravene current practices for rice cultivation, either age-old or of modern origin.

4. Practices for Operationalizing these Principles

SRI should not be regarded as a recipe*, i.e.,* a certain fixed set of practices, but more like a menu*, i.e.,* a set of choices, in much the same way that a restaurant patron chooses from the eating establishment's menu a soup, a salad, an entrée, a dessert, etc., according to what he or she considers most suitable for the time and place.

Farmers should function as managers, as decision-makers making choices, not as robotic laborers following instructions. During training for SRI, farmers should be told more than just *<u>what</u> to do*. It should be explained *<u>why</u>* particular practices are recommended, and *<u>how</u>* these practices can be best used and/or adapted to local conditions.

The following practices give effect to the principles enumerated above. The practices discussed below are for irrigated rice production, where the crop is established by transplanting seedlings from a nursery. Alternatively, an SRI crop can be established by direct-seeding using somewhat different practices for the first principle, either by hand or with equipment designed to achieve the same purpose. Some examples shown in section 6. The practices are listed according to their respective principles.

Principle 1: ***Establish new plants carefully and well***

A. **Start with seed selection** so that only well-developed seeds are sown in the nursery. Submerge the seeds in salt water and discard the poor seeds that float to the top, as shown below in a demonstration in a West Bengal village in India. Sow only the good seeds that sink to the bottom. These are put into a bag and kept in a dark, moist, warm place to trigger germination before they are sown in a nursery under one of the options for the next practice.

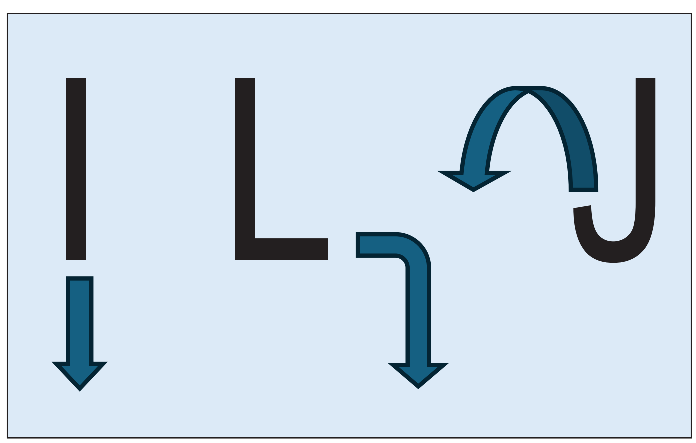
B. **Grow the seedlings in a small garden-like nursery** that is elevated like a raised bed and not flooded. The nursery's size will be only 10-20% as large as previously because with SRI, the seeding rate is reduced so greatly. The nursery should be close to or in the main field, wherever there is a source of water for watering the seedlings as neededas shown in A below. Alternatively, seedlings can be grown on *trays* made of metal or plastic trays that can be easily

(A) SRI seedling nurseries adjacent to a main field in Madhya Pradesh state of India. (B) SRI seedlings in Lombok, Indonesia, being grown on small metal trays that are easily carried to the field. (C) Farmers in Karnataka state showing SRI seedlings being grown in plastic trays, a method made practical because SRI requires only 10-20% as many seedlings as in usual practice. (D) SRI seedlings grown in Costa Rica in a tray filled with soil and planting material that can be rolled up like in a rug for easy transportation and then transplantation by machine.

transported to the field (B); or in the kind of plastic trays that are designed for vegetable setts, which avoid any root disturbance (C); or on *mats of soil and other organic material* that can be rolled up and used in mechanical transplantation (D). There are thus several ways to raise SRI seedlings as shown in the pictures below; and in some places there is the option of direct-seeding with no hand or mechanical transplanting.

C. **Transplant seedlings into the field when they are still at a young age,** usually just 8-14 days old, at the 2-3 leaf stage, before tillering starts. Remove the young plants from the nursery or tray carefully, keeping soil around the roots attached to them. This will minimize trauma to the roots and reduce the 'transplant shock' that will delay the seedlings' resumption of growth. Also, seedlings benefit from shallow transplanting, just 1-2 cm, because deeper placement in the soil reduces the plants' tillering. The pictures below show young seedlings being lifted out of a nursery with a trowel, and a young seedling that is ready for transplanting.

D. **Transplant the young seedlings into the soil quickly and carefully**, never letting their roots dry out. Young seedlings should not be thrust straight downward into the soil unless their tips are held gently so that *the tips do not get turned upward*. Ideally, the plant and root will be vertical, like the letter **I**. But it may be quicker to lay the seedling into the moist soil with a gentle sidewise motion, keeping the root horizontal like in the letter **L**. If after transplanting the tip is pointed *upward* like the letter **J** as seen below, the seedling's resumption of growth can be delayed for a week or more while the tip of the root re-orients itself for *downward* growth.



Principle 2: *Minimize competition between plants*

E. **Seedlings should be spaced widely apart in a square pattern**, one plant per hill (possibly two per hill if the soil is not very fertile). As seen in the pictures below from Indonesia and from India, a grid pattern is marked on the field with a rake or a roller-marker (or possibly with a rope or cord, which is less efficient). This marking establishes equal distances between the plants in all directions and makes possible mechanical weeding in perpendicular directions.

Optimal spacing is most often 25 x 25 cm; but in soil that is less fertile, spacing of 20 x 20 cm may give a higher yield, while in very fertile soil, 30 x 30 cm distance between plants and rows can give better yield. Farmers should determine the optimum distances for their own field by trying different spacings and evaluating the results.

Principle 3: *Maintain both water and oxygen in the soil, with not too much of either*

F. **During transplanting, the soil should be wet and muddy, but not covered with standing water**. Continuous flooding of the field should be avoided because this deprives the soil of oxygen and will suffocate the plants' roots and most soil organisms. The field will then be flooded intermittently when irrigation water is applied, as much as 5 cm depth at a time; this water will be absorbed into the soil and should not keep the soil sealed off from the air.

G. **During the crop season, irrigation water should be provided intermittently** by what is commonly called *alternate wetting and drying* (AWD). Any schedule for flooding the field and then letting the water seep into the soil so that it dries out superficially should be adjusted according to the soil type, topography, and climatic conditions.

Most soils should be allowed to dry until small cracks form on the surface, an indicator that it is time to irrigate again. Note that *heavy clay soils* should NOT be allowed to dry out to the crack-forming stage because then they become too hardened for roots to grow through them easily. Aerobic soil is more hospitable to earthworms and other beneficial organisms in the soil, as seen from the earthworm castings in the picture below on the right. These castings are an indicator that the soil has been kept mostly aerobic.

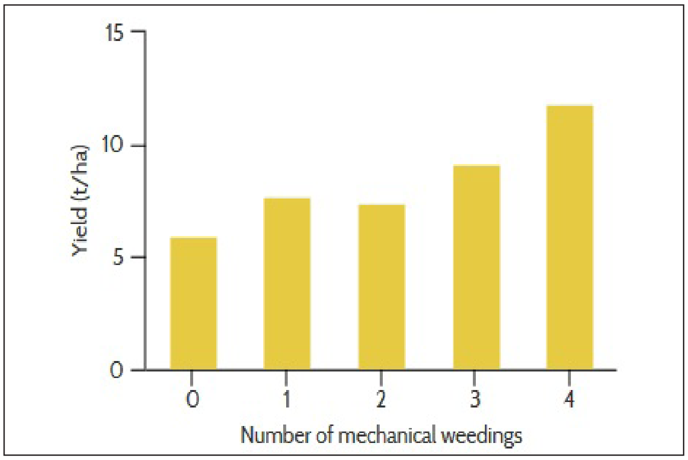
The original recommendation for SRI practice was to practice AWD until the rice plants start to flower and form grains, *i.e.,* until panicle initiation (PI). And thereafter to keep a shallow layer of water on the field (1-2 cm) until 10 days before harvest. However, research at the ICAR-Indian Institute for Rice Research in Bhubaneswar has indicated that with SRI, AWD should continue beyond PI and during the plants' reproductive stage (Thakur *et al.,* 2018). The schedule for a particular field and crop should be determined empirically so that the water needs of plants and the soil biota are being met but not exceeded.

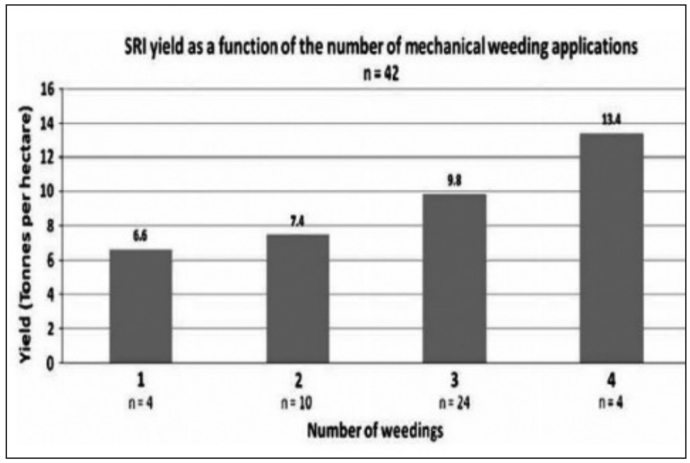
H. **In SRI management, active soil aeration is incorporated into weed control.** When rice paddies are not kept flooded all the time, there will be more growth of weeds, at least until their seeding cycle has been broken. Weeding several times during the season using a simple mechanical weeder, possibly a motorized weeder to make the work easier, is preferable to manual weeding or using herbicides because the mechanical implement aerates the topsoil while churning weeds into the ground (as green manure). This active soil aeration through mechanical weeding complements and intensifies AWD's effect of *passive soil aeration*.

The first mechanical weeding should be done 10-15 days after transplanting and in *perpendicular directions*, as shown in the picture below on the left from Indonesia. The soil should be recently wetted or flooded before weeding to make the task easier and more effective. A second weeding should then be done another 10-15 days later. This may be sufficient to control weeds, but because soil-aerating weeding aerates the soil while it controls weeds, it is recommended that a 3^{rd} and even a 4^{th} weeding be done at 10-15 day intervals, or until the canopy closes and further weeding is no longer possible.

Weeding in two directions is not absolutely necessary, but it has the benefit of breaking up the topsoil all around each plant and enhancing yield, as seen below. A motorized mechanical weeder, shown in the right-hand picture below from Colombia, reduces the time and effort needed for soil-aerating weeding.

Mechanical weeding, manual or motorized, can increase grain harvest by one or more tons per hectare without applying additional fertilizer because of the microbial nitrogen fixation, phosphorus solubilization, etc. associated with active soil aeration. SRI weeding enhances yield as shown in the graphs below, from Madagascar (N = 74 farmers) and Afghanistan (N = 42 farmers). Note that all of the Afghan farmers who did four weedings were second-year SRI users, having gained confidence in the new methods from their first year (Thomas and Ramzi, 2011). This SRI effect of active soil aeration should be studied and documented more widely.





Principle 4 - *Enhance the soil system's fertility*

I. Provide the soil with as much organic matter as possible within the constraints of availability and cost of biomass and labor. All of the practices of plant, soil, and water management recommended above are conducive to greater soil fertility, but it is recommended that at least some biomass be added directly to the paddy soil to build up its soil organic matter (SOM).

The SRI recommendation for nutrient management is to increase SOM through recycling of rice straw into the soil (no burning of straw) and adding organic compost made of weeds, loppings and other vegetative material and/or animal manure. Organic mulches and/or green manures (e.g., *Gliricidia*) are also beneficial. These materials improve the life in the soil as well as the soil's structure, making it easier for rice plant roots to proliferate. Also, soil with higher levels of organic matter will absorb more rainfall, reduce runoff, and increase water retention for subsequent plant use.

Inorganic or synthetic fertilizer can be used together with other SRI practices because SRI is not necessarily or always an 'organic' method of production. But many SRI farmers choose not to use inorganic fertilizer or other agrochemical inputs so that their SRI production is fully organic and may earn a premium price, besides being free of chemical residues. Farmers who use SRI methods generally appreciate the value of the beneficial soil organisms that live around, on, and even inside their rice plants. The SRI recommendation is to rely as much as possible on organic matter to enhance the soil's fertility in preference to using inorganic sources of nutrients.

How much organic matter It is feasible to apply to an SRI field will depend on the availability and cost of *biomass* (composted vegetative matter, straw, mulch, manure, etc.) as well as on the cost and opportunity costs of *labor* to collect, transport, process, and apply this material. SRI farmers are mindful that inorganic fertilization and chemical control of pests and diseases can have some adverse effects on the beneficial organisms that live in the soil, so preference is given to organic materials and methods of pest control.

As noted above, the suite of SRI practices is eco-friendly. When the soil is not kept continuously flooded and when there is more space left between plants, plant root systems grow larger, and there is more plant root exudation of organic compounds into the soil. Also, unflooded aerobic soil is more hospitable for populations of earthworms and beneficial fungi like arbuscular mycorrhizae that require oxygen. When these die and when plant roots decompose, they add to the soil's stock of organic matter. At the same time, soil-aerating weeding enhances the amount of life in the soil.

Some agronomists object that larger populations of organisms living within the soil system will compete with plants, consuming available nutrients. But this is a short-run view. What soil scientists refer to as the 'immobilization' of nutrients within the soil system actually *conserves* nutrients within the soil, keeping them from leaching through it or exiting in water runoff. When soil organisms die, their immobilized nutrients return to the flux and cycling of nutrients within soil systems.

It is well-known that soil with life in it is more fertile than soil that is 'dead.' Soil organisms, both large and small, improve the structure and functioning of soil systems by aggregating soil particles and by facilitating the passage of air and water through the mineral portion of the soil. This makes the soil system itself more stable and sustainable. Building up soil organic matter is imperative in India where SOM levels have been declining disastrously since the mid-1950s.[6]

The highest yields with SRI management have come with some *combination* of nutrient sources (compost and fertilizer) as an effort at optimization, in what is called Integrated Nutrient Management (INM). Whether or not this will give farmers the *greatest net income* will depend on their costs of purchasing inorganic fertilizer vs. producing alternative organic fertilizer. The opportunity costs of labor and the availability of biomass need to be considered when assessing net benefits. There are environmental benefits from relying mostly or entirely on organic fertilization that should be considered, including long-term productivity and the sustainability of the farming system.

J. Complementary practices: There are some other things that should or can be done in connection with SRI rice cultivation that are not particular to SRI. Thus, they are not considered to be part of SRI, although they should be noted here.

- **i. Leveling of the paddy field well before planting** so that water can be evenly distributed to all parts of the field. This is good practice for any irrigated rice cultivation, saving water and benefiting the plants. The most advanced and precise field preparation can be done with laser-leveling and specialized machinery, as has been done as part of the large-scale application of SRI methods in Punjab, Pakistan (Sharif, 2011). Leveling fields should be a one-time operation, and it can be done manually; the smaller the field or plot, the easier it is to make it quite level.
- **ii. Seed priming** has been shown to be beneficial with SRI by research done in Pakistan (Khalid *et al.,* 2015). As this is not uniquely beneficial with SRI, it is considered as an auxiliary practice rather than as something intrinsic for SRI.
- **iii. Crop protection** is a challenge for almost all farmers and crops. One of the reported benefits of SRI management is that damage to rice crops from most insect pests and diseases is less than with conventional rice crop management, particularly with the use of organic inputs (Chintalapati *et al.,* 2023). Chemical means of protection can be used in

[6]*Unfortunately, little attention has been paid to the crucial parameter of SOM. The National Rainfed Areas Authority has started publicizing this degradation of India's soil systems. See 'Soil organic content fell from 1% to 0.3% in 70 years in India: NRAA,' Business Standard, March 26, 2022: https://www.business-standard.com/article/current-affairs/soil-organic-carbon-content-fell-from-1-to-0-3-in-70-years-in-india-nraa-122032600305_1.html*

SRI where pest or disease problems become great enough to make their use economic. In general, SRI farmers practice organic means of pest and disease control such as Integrated Pest Management (IPM) methods or biocontrol. SRI farmers pay more attention than most farmers to the conservation of beneficials, *i.e.,* to insect and other predators that control crop pests (e.g., Karthikeyan *et al.,* 2010; Kakde and Patel, 2018).

iv. **Intercropping:** With wider spacing between rice plants, some experimentation has been done in Kashmir, planting pulse crops between the rows of SRI rice. Beans, for example, when intercropped with SRI rice have been found to fix nitrogen in the soil and reduce the need for weeding between the rice rows, reducing the costs of production while bringing in income from a supplementary cash crop (Shah *et al.,* 2021). This underscores that SRI is not a fixed technology or a recipe as SRI farmers are expected to make adjustments and adaptations of various sorts once they understand the principles and their purposes.

v. **Irrigation should be stopped about 10 days before the crop has become mature enough to harvest.** This will let the soil dry out. It has been observed that SRI rice crops frequently mature about 5-15 days sooner than when the same variety of rice is grown under conventional crop management. This means that SRI methods are producing their higher yield in a shorter period of time.

K. **Monitoring:** Monitoring the progress of the crop during the growing season is important, adjusting the amount and timing of water issues, or the timing of weeding, or taking steps to protect the crop against pests or disease if necessary, preferably with organic (IPM) practices.

- The simplest gauge of a crop's progress and health is to periodically pull up a typical plant (or a struggling plant) and inspect its roots, to see if these are growing well and have good white or light coloration. Roots that are dark-colored are suffocating and will eventually turn black.
- Simply observing the color of the lower portion of the plants' *tillers*, their lower 3-4 cm, is an indicator of whether the plant is getting enough oxygen. The bottom lengths of rice tillers will turn brown and then black when deprived of oxygen, while healthy plants will have dark green coloration.

At present, farmers seldom monitor and inspect their crop's roots and tillers in this way, but neither do technicians. Tillers are easier to observe, but they do not reveal as much as do the roots. Uprooted plants resume their growth when they are replanted in the soil.

5. Distinguishing between principles and practices: Relevance for the mechanization of SRI

SRI was developed to improve irrigated rice production where the crop is established by transplanting seedlings from a nursery, but its principles can similarly inform and improve rice production when the crop established by direct-seeding rather than by transplanting. And the practices for direct-seeding will be different whether done by hand or, more efficiently, with equipment designed for the same purpose. Practices differ, but the principles stay the same.

Direct-seeding saves farmers the labor needed to make and manage a nursery, and it takes less time than transplanting. The critical consideration is whether, under the given soil, water, temperature, and other conditions, the rate of seed germination will be satisfactory. Transplanting has the advantage of ensuring that rice plants will all grow and will grow evenly across the field, especially important where landholdings are small and labor is relatively more abundant than land.

Fr. Laulanié determined that having optimally more spacing between plants was beneficial for plant performance, giving all of them access to enough space for their root and tiller growth, and to sunlight, nutrients, and water so they can express their genetic potential more fully. He also concluded that roots should be treated with care when seedlings are transplanted, to minimize trauma and 'transplant shock' as discussed above. The principle is to *protect and nurture plant roots*, not to plant seeds or seedlings in a certain way. Practices can and will vary, but the principle of nurturing roots is of general importance. Direct-seeding avoids transplant shock altogether, so it can offer some advantages for crop growth provided that spacing is optimized, and there is a sufficiently high rate of seed germination.

The machinery used for direct-seeding can range widely, from simple to complex. On the left below is a drum-seeder developed in Andhra Pradesh, India, and on the right, a tractor-mounted planter designed and used in Arkansas state of USA for a mechanized version of SRI. The US machine places rice seeds into the soil through pneumatic tubes with precise spacing and at desired shallow depth. The seeds are implanted through a cover-crop mulch that enhances nitrogen in the soil as it suppresses weeds.

Various mechanization opportunities for SRI have been reviewed in Uphoff (2021), and more are being developed all the time. Mechanical transplanters for rice seedlings have been developed for conventional rice production in Asian countries for many years. See the evaluation of MSRI (modified or mechanized SRI) done by researchers in the ICAR-Indian Institute for Rice Research on the incorporation of mechanical transplantation into SRI methodology (Kumar *et al.*, 2023). With appropriate adjustments for spacing and with modifications for handling smaller/younger seedlings, existing mechanical transplanters can be used for SRI cropping, as done by Oscar Montero in Costa Rica. The crop that he planted with a Yanmar

transplanter that he modified for SRI use, shown below on the left, gave him a yield of 8 tons ha^{-1} with greatly reduced expenditures for labor (Montero, 2008).

A novel approach was devised in Pakistan by Asif Sharif, who fabricated a multi-task machine that punches holes in the surface of machine-made, laser-leveled raised beds. Laborers riding on this machine, seen below on the right, drop 10-day-old seedlings into the holes 22.5 x 22.5 cm apart, to which water plus compost and a little fertilizer are added as the machine passes over the holes. Sharif's paddy yield from an 8-hectare 'test plot' averaged 12 tons ha^{-1}, with 70% less water and 70% less labor than is required with usual farmer practices (Sharif, 2011).

As discussed above, for SRI the practice of weeding is preferably mechanized at least to the extent of using a mechanical rotary weeder or a cono-weeder that can be pushed between the rows of plants in perpendicular directions to aerate the soil as it controls weeds. Having a mechanical weeding implement that is *motorized* greatly reduces the time and effort needed to perform this operation, and the soil aeration can be greater. There are now even some prototypes of solar-powered weeders that avoid the costs and emissions of fossil-fuel engines (e.g., Saha and Raheman, 2022). But this concerns SRI practices, not principles.

For any method of SRI crop establishment, whether, for example, by transplanting or by direct-seeding, as for weeding, the principles that guide rice production remain the same while the respective practices and implements will vary. As discussed above, SRI is not a usual kind of technology with a set of material things or certain practices. Rather, SRI represents *a change in thinking* about how to get the most benefit from the resources used in agricultural production, informed by an agroecological understanding crop performance rather than by industrial models.

6. The Importance of Eliciting Better Phenotypes from given Genotypes: Promoting Climate-Change Resiliency

The principles and practices of SRI that induce better expression of rice plants' genetic potentials offer an additional benefit for farmers and consumers, over and above raising yield, reducing costs of production, saving water and seed, and minimizing agrochemical expense and impacts. They enable resulting rice crops to *resist climatic and other stresses*: drought, water stress, flooding, storm damage, and pests and diseases, hazards that are growing in most countries and are expected to increase in the years ahead. This advantage comes from rice plants growing larger, deeper root systems as well as stronger tillers that have better architecture (Thakur *et al.,* 2010). An additional reason for reduction of storm damage is the wider spacing between plants, which allows wind to pass through crops with less resistance; this is a result of management practices and not of phenotypic differences.

Below are pictures of Vietnamese farmers who learned about SRI through their farmer field school supported by the Ministry of Agriculture and Rural Development and the FAO/IPM Program. The differences shown between rice crops are in plant phenotype, not plant genotype. The farmers' village and their rice paddies had been struck by the wind and rain of a tropical storm that passed over the area a few days before the pictures were taken.[7]

On the left are two adjacent rice fields with a farmer holding up representative rice plants removed from their respective fields. The SRI field and an SRI plant are on the left, while the field and rice plant on the right were managed with farmers' usual methods. On the right are this farmer with three other members of her farmer field school group giving a closer view of the plants. These women took it upon themselves to

[7] *The pictures were taken and shared by Elske van de Fliert, FAO/IPM program, Hanoi. I was subsequently able to visit the village of Dông Trù where these farmers live and to talk with them about their SRI experience; see pages 2-6 of http://sri.cals.cornell.edu/countries/vietnam/vnntutr106.pdf.*

carry these plants to other villages in the district to show their neighbors what could be achieved with SRI crop management.

Then below is another picture, this one from East Java in Indonesia, taken by the farmer who managed the organic SRI field seen on the right, Miyatti Jannah. Her neighbor's field on the left had been planted with a modern variety (*Ciherang*) and then managed with fertilizer and agrochemical inputs, while Miyatti's field on the right was growing a traditional aromatic variety of rice (*Sinantur*) without synthetic fertilizer or chemical inputs. This picture was taken after both

fields had been hit by a brown planthopper pest attack and then by a tropical storm. From her paddy field of 1000 m^2, Miyatti got a yield of 800 kg (8 tons ha^{-1}), while her neighbor despite his greater expenditure on inputs had little marketable harvest.

These pictures show the kind of protection against biotic and abiotic stresses that SRI management can give to rice plant phenotypes. Larger root systems and stronger tillers make SRI plants better able to resist lodging. Also, deeper root systems give them access to water reserves in lower horizons of the soil, buffering them against water stress and drought. Their increased uptake of silicon from soil that is more aerobic makes for tougher leaves and tillers that can resist insect damage.

Better plant phenotypes are more resilient to the stresses that are escalating due to climate change in most countries. As a bonus, SRI crop management, particularly its AWD water management, *reduces the net emissions of greenhouse gases from rice paddies*. SRI practices can thus help to mitigate the dynamics that drive climate change while enabling farmers to cope with the constraints imposed by climate change (Dahlgreen and Parr, 2024).

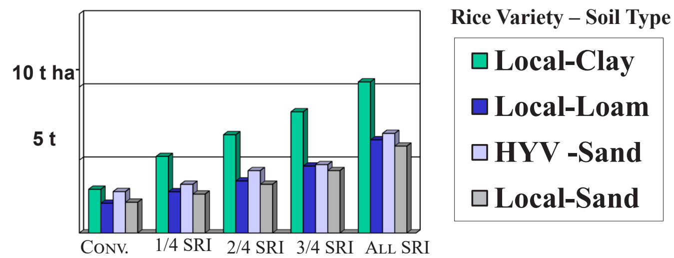
7. SRI is a Matter of Degree

Understanding SRI in terms of complementary principles and practices makes the methodology more a matter of degree than of kind. Asking whether a certain rice crop **is SRI** or **is not SRI?** misdirects attention. It is more informative to ask instead: **to what extent** is the crop grown according to (and benefiting from) SRI principles and practices? This is another reason why SRI should be regarded as a system rather than as a technology, and why it is better to use the term 'SRI' as an adjective than as a noun. SRI is not a 'thing' but rather a set of ideas and insights that can be applied beneficially when growing rice (as well as other crops – Adhikari *et al.,* 2018).

Also, the care and thoroughness with which SRI practices are employed can vary, and this will affect the crop's performance. For example, seed selection can be done hastily or rigorously; and mechanical weeding can just eliminate most of the weeds or with a little additional care, it can also aerate the topsoil around the plants more thoroughly. So, the quality of crop management has some effect on agronomic results.

The first multi-factorial evaluations of SRI practices done in Madagascar showed that the *extent* of using SRI practices can have a consistent, significant, and cumulative effect on crop performance. In 2000 and 2001, baccalaureate thesis research projects were done by the top students in their respective graduating classes of agronomists at the University of Antananarivo. These trials were conducted on farmers' fields under contrasting agroecological conditions: first, on the west coast of Madagascar near sea level; and then on its central plateau at 1200 m elevation. The first set of trials (N=288) was done on poor sandy soils near Morondava with a tropical climate, also comparing the results with a traditional local variety (*riz rouge*) vs. a modern improved variety (2798). The second set of trials (N=240) were conducted near Anjomakely, with better soils and a temperate climate, also comparing SRI results on clay vs. loamy soils.[8]

The four practices evaluated were: (i) age of seedling [16 or 20 days vs. 8 days];[9] (ii) number of seedlings per hill [3 vs. 1]; (iii) water management [flooded vs. aerobic soil]; and (iv) fertilization [NPK fertilizer vs. compost]. A summary analysis of the results is shown in the figure below, comparing yields in tons ha^{-1} from (a) conventional practices, *i.e.,* older seedlings, 16 or 20 days; 3 per hill; flooded soil; and NPK fertilizer, with (b) just one of these SRI recommended practices: 8-day single seedlings, flooded soil, or compost fertilization, i.e. 25% SRI; (c) two of these practices (= 50% SRI); (d) three practices (= 75%), or (e) all four practices [= 100%]. Detailed results of the respective trials are reported in Randriamiharisoa and Uphoff (2002) and in Uphoff and Randriamiharisoa (2002).



In the data from these multi-factorial evaluations, there is evidence of synergy among the practices.

- Going from all conventional practices to ***just one*** of the SRI practices (any one), going from zero SRI to 25% SRI, raised average plot yields by 35% across the different combinatorial trials.
- Using ***any two*** of the four SRI practices evaluated or using ***any three*** of the practices, *i.e.,* going to either 50% SRI or to 75% SRI, added, respectively, another 24% and then another 26% to yield beyond what resulted from adopting just any single SRI practice.
- Using ***all four*** of the recommended practices, going to 100% SRI, added on average another 37% to yield beyond what was produced when any three of the four practices were used.

Thus, while all of the practices had a positive effect, the greatest increment was achieved by using the full set.

[8] *The research design was the same in both locations evaluated six factors with random bloc distribution and three replications of test plots (2.5x2.5 m), hence the large number of trials. Soil-aerating mechanical weeding vs. hand or chemical weed control was not evaluated because this would have doubled or tripled the number of trials required. Because there was no difference between the spacings (25x25 vs. 30x30 cm), all of the combinations analyzed and compared had six replications, which added to the evaluations' statistical significance.*

[9] *At higher elevations, rice phyllochrons are shorter because of lower temperatures, so the different calendar ages represent equivalent biological ages for seedlings in the two respective areas.*

Unfortunately, the effects of *active soil aeration* through mechanical weeding were not evaluated in these trials, as explained in footnote 8. The data reported in graphs above from Madagascar and Afghanistan show large increments in yield when mechanical weeding (active soil aeration) accompanies the other practices recommended for SRI.

A large evaluation of SRI effects in India undertaken in 2012 by the International Water Management Institute (IWMI) reinforces these findings from Madagascar. A survey of over 2,200 farmers across 13 states found that all of the farmers who had adopted SRI to some extent had benefited from higher yield as well as from lower production costs (Palanasami *et al.,* 2013). Of relevance here is that the 20% of surveyed farmers who had adopted all of the recommended practices reported higher yields than those who had adopted the new methods only partially.

This is consistent also with the findings of a meta-analysis done in China that included all of the studies that had been published through 2013 by Chinese rice researchers who had evaluated SRI vs. best management practices (BMP) (Wu *et al.,* 2015). Both the data base, which covered 26 sets of field trials from seven major rice-producing provinces of China, and the methodology employed were more rigorous than the data base and methodology for a previously published meta-analysis that attempted a similar comparison of SRI vs. BMP methods (McDonald *et al.,* 2006).

The McDonald study calculated from its data set, which excluded all data from Madagascar and was not inclusive, that BMP had a yield advantage of 11% over SRI. The analysis by Wu *et al.,* on the other hand, found that for the whole data set, SRI had an average yield advantage of 11% over BMP.

Because most of the Chinese evaluations had not evaluated the full set of SRI practices – only 20% of the studies had followed an SRI protocol fully – a weighting matrix was developed to quantify the degree to which SRI methods were used (see appendix of that article). Scoring 20 points or above (out of a possible 27 points) was considered to be 'good' use of SRI principles and practices; scoring only 10-14 points or fewer was classified as 'minimal' use.

When considering only cases with 'good' use of SRI methods, the SRI yield advantage was 20%, while with 'poor' (*i.e.,* limited) use of SRI practices, there was a BMP advantage of 4%. This reflects the synergy among practices, e.g., if very young seedlings were used but the field was kept continuously flooded (no AWD) this would stunt the small rice plants; or not having optimally wide spacing of plants would constrain their achievable root growth.

The data base did not contain enough results from full SRI vs. BMP trials to assess the statistical significance of 100% SRI management. Few of the researchers, it turned out, had been willing to rely fully on organic fertilization in their SRI trials. But the published results reported from China showed that SRI had a 30% advantage over BMP.

8. Conclusion

SRI results will always vary because they depend upon the growing environment of rice plants, more than on the seeds (genotype) planted or on exogenous inputs. As noted at the beginning of this paper, by inducing greater root growth and enhancing the life in the soil SRI practices create a much more favorable growing environment for the plants. Increasing organic matter in the soil, for example, makes it better able to absorb and retain rainfall as well as to support an active and diverse soil biota, including the plant-soil microbiome.

Enhancement of the root systems and the soil biota go together as a result of roots' exudation. This creates a positive feedback loop between the plants' root systems and their canopies (leaves and tillers). The better the root system can acquire water and nutrients from within the soil system, the better the canopy will grow and function, and vice versa. The more sunlight (energy) that the canopy can intercept and the more photosynthate that it produces, the more organic compounds can be shared with the root system and with the soil biota. The life in the soil in turn benefits the roots and the canopy through N fixation, P solubilization, mineralization, and other processes.

These processes apply for all kinds of rice and for other plants. But they are becoming more important as farmers are confronted by the challenges of climate change and by the declining levels of carbon (energy) in their soils. I would like to conclude this article with two particular observations.

- For farmers: ***Crop agriculture should be regarded particularly as a matter of growing plant roots*,** rather than just as a task of growing plants, *i.e.,* what can be seen above-ground. This may sound inverted, but if plants are enabled through appropriate practices to grow larger, healthier, longer-lived, better-functioning root systems, then the plants as a whole will be better able to thrive and to deal with most kinds of biotic and abiotic stresses, accordingly giving better yields. Plants with good root systems can take care of themselves.
- For policy-makers: ***Substantial and urgent investments should be made in soil fertility and sustainability.*** This is one of the most crucial and productive investments that can (must) be made for the welfare of both people and country. For example, in India, the MGNREGA program could be utilized on a large scale to get greater amounts of organic matter into its carbon-depleted soils as a purposeful investment in India's future productivity. This is something as important and tangible as roads or bridges for the country's well-being and stability.

These conclusions range beyond the subject of the System of Rice Intensification, but they represent some of the consequential lessons that have been learned from SRI research and experience, reaching beyond rice.

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Ameliorants for the Management of Soil Acidity - A Review

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Abstract

Soil acidity is one of the major yield limiting factors in rice crop production. The H^+ and Al^{3+} ions in the soil must be neutralized by the release of OH^- ions on application of liming materials for the management of soil acidity. Liming material is the substance, which can increase the soil pH by combining with H^+ ions in the soil solution. Lime is the most widely used ameliorant for management of soil acidity. There are alternative products, such as dolomite, rice husk ash, gypsum, phosphogypsum and calcium magnesium silicates having high reactivity than lime in increasing the pH, supply of nutrients like Ca, Mg, Si *etc*., and have the potential to reduce iron and aluminium toxicity and reduce methane emission. Fineness and chemical purity of the liming material are the major factors affecting the ability of the material to neutralise soil pH. Method and timing of application of liming material depend on the place of origin, nutrients and other elements associated with it, and amount of neutralising power. Relative worth of the liming material also depends on the cost of the same.

Key words: Soil acidity, Limestone, Dolomite, Calcium silicate, RHA, Phosphogypsum.

Introduction

Soil pH is the measurement of acidity or alkalinity of the soil pH stands for *potential of hydrogen* and is expressed as number from 0 to 14 and H^+ concentration is expressed in g/l. The term was first proposed by Sorensen, a Danish chemist in 1909, which gives the measurement of the hydrogen (H^+) ion concentration in soil water and is expressed as the negative common logarithm of H^+ concentration in the soil. It is an index of the activity of H^+ as it interacts with soil components, nutrients in the soil solution and plants growing in the soil. It is an important factor in the soil influencing nutrient availability, microbial activity and numerous soil chemical reactions and processes.

Soil acidity

When the concentration of H^+ ions in the soil increases, the soil pH decreases and acidity increases. When the soil pH is lower than a neutral pH, it is said to be acidic. Because of the logarithmic scale, a small decrease in soil pH value denotes a large increase in acidity. The soil with pH of 4 is 10 times more acidic than a soil with pH of 5, hundred times more acidic than a soil with pH of 6 and thousand times more acidic than a soil with pH of 7. The main causes of soil acidity are acidic parent material, high rainfall and leaching of basic cations, decomposition of organic matter, application of acidic fertilizers and removal of basic cations by crops. About 15 Mha of rice soils in India are acidic with toxicity of Fe, Al, Mn and deficiency of K, Ca, Mg, B, Si, and problem of P fixation (Srinivasarao *et al*., 2017).

Soil acidity due to concentration of hydrogen (H^+) in the soil solution is called active acidity (Getaneh and Kidanemariam, 2021). Active acidity is determined by measuring pH of soil water suspension or extract from soil during routine soil test. It is the concentration of H^+ ions in the soil solution when measured in 1:2.5 soil to water ratio mixture. However, all H^+ ions are not released immediately from the soil into solution. Soil acidity due to the portion of the H^+ ions that remains attached or adsorbed to negatively charged exchange sites on clay and organic matter particles is called exchangeable acidity or salt replaceable acidity (Agegnehu *et al.,* 2019). Exchangeable acidity may be defined as the acidity due to hydrogen (H^+) and aluminium (Al^{3+}) ions retained on the exchange complex of the soil, *i.e*., adsorbed on the surface of soil colloids and organic matter, which will supplement the H^+ ions in soil solution when depleted by neutralization. This acidity is also called reserve acidity because H^+ can be released into solution, as soil solution conditions change due to moisture changes and concentrations of dissolved ions and salts (Cihacek *et al.,* 2021). Accurate estimation of lime requirement of a soil is done by the measurement of reserve acidity. Reserve acidity can be measured by the addition of a dilute calcium chloride solution (0.01 M $CaCl_2$) or a buffer to the water pH suspension. The active acidity is in equilibrium with the exchangeable acidity permitting the ready movement from one form to another form and the aluminum and hydrogen that are removed from the soil solution will be replenished by the adsorbed aluminum and hydrogen ions on the exchange sites. The reserve-to-active acidity ratio refers to the soil's buffer potential or the ability to soil to resist pH change as an acid or base is added to the soil. Soils having more cation exchange sites can hold more H^+ ions and thus resist a decrease in pH. Once these soils became acidic, these soils can also resist the pH increase on lime application by releasing the H^+ ions from the soil surfaces into the soil solution. Buffering capacity of sandy soil, or its reserve acidity, is much lower than that of a soil that contains more clay, like silt loam. Soils with high CEC (20% 2:1 type clay and 6% OM) resist acidification better than soils with low CEC (sandy loam with 2% OM and 10% kaolinite) and therefore, lime requirement of clay loam will be higher than that of sandy loam with same pH value (Weil and Brady, 2022). Soils with high CEC will require more lime in order to increase the pH to the desired level.

The acidity associated with non exchangeable aluminum and hydrogen ions that are bound to soil colloids by organic matter and silicate clay, which remains in the soil after active and exchange acidity has been neutralized is called residual acidity. The potential acidity is the sum of exchangeable and non-exchangeable acidity. The potential acidity and the active acidity contribute to total acidity in the soil.

Effect of soil acidity on nutrient availability

According to Tandzi *et al.,* (2018), acid soils are characterized by the presence of toxic heavy metal elements like iron, copper, manganese, zinc, aluminum, lack of essential nutrients like phosphorus, potassium, calcium, magnesium, sodium and low soil pH which can generate excesses of aluminum, iron, and manganese. Primary nutrients *viz*., nitrogen, phosphorus and potassium have low availability at strongly acidic pH values. Nitrogen uptake in the NO_3 form is best at acidic pH, while NH_4^+ is absorbed more efficiently at a neutral pH. Phosphorus becomes insoluble aluminium or iron compounds at low pH. Among the secondary nutrients, Ca and Mg are less available in acid soils, while the SO_4^- ion form of sulfur is retained better by acidic soils. Availability of all the micronutrients decreases as pH rises, except for molybdenum (Mo). Zn, Cu and Mn availability decreases 100-fold in concentration with every one unit increase in pH (Miller, 2016). At high pH, Fe and other micronutrients (except Mo) are rendered unavailable since they are locked up as insoluble hydroxides and carbonates. Iron and aluminum availability increases as soil acidity increases and aluminum become toxic to plants at pH values less than 5. Al, Fe, and Mn become more soluble and can be taken up by roots and thus become toxic to plants at low pH. As pH increases, their solubility decreases and precipitation occur. Plants may suffer deficiencies as pH rises above neutrality (Sparks, 2003). High Al and Fe oxides and hydroxide in low soil pH are responsible for P fixation, making it unavailable to plants Rastija *et al*., (2014) reported that liming with dolomite raised the soil pH, affected soil chemical properties and resulted in great increases of plant available phosphorus. They also observed that potassium availability in the soil was independent of liming. The nutrient availability at different soil pH is given in the **Figure 1**.

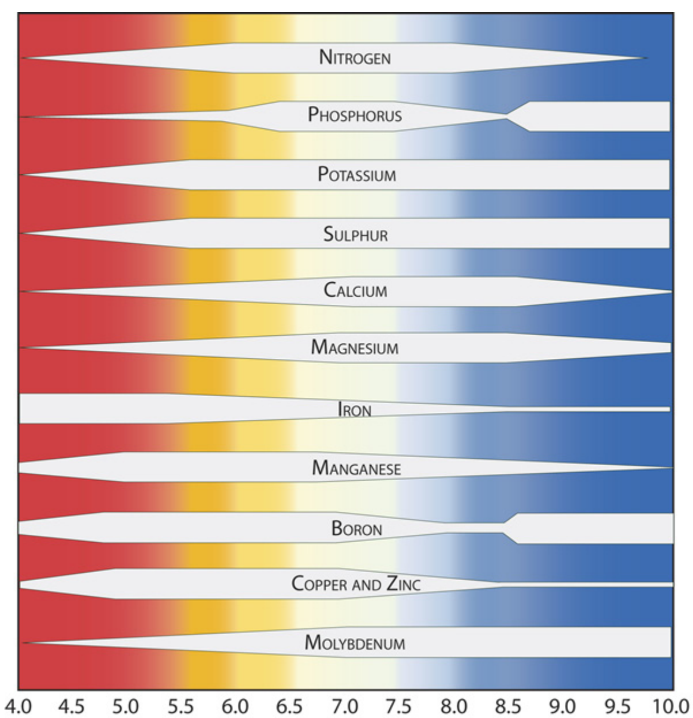

Figure 1: Nutrient availability for plant use at different soil pH (Source: TNAU Agritech Portal)

Management of acidity

H^+ and Al^{3+} ions in the soil must be neutralized for the management of acidity by the release of OH^- ions on application of liming materials. A liming material is the substance which can increase the soil pH by combining with H^+ ions in the soil solution. Acid sulphate soils will be suitable for crop production only by the addition of amendments to correct the acidity. The chemical and physical properties of acid sulfate soils can be improved by adding soil ameliorants for increasing the pH value, increasing nutrient availability, and improving water content and soil permeability (Maftuah *et al., 2023*). Beena *et al.,* (2013) reported that for the amelioration of acid sulphate soils, special management practices such as liming and washing out of water, bunding, providing subsurface drainage *etc*., must be undertaken. Application of liming materials at the rate of 6.0 to 12.5 tha^{-1} and leaching can reduce soil acidity to a great extend in acid sulphate soils of Kuttanad (Neenu *et al.,* 2020). The most economical method of ameliorating soil acidity is liming. Limestone is the widely used ameliorant. However, there are alternative products, such as dolomite, rice husk ash, gypsum, phosphogypsum and silicates. Ananthanarayana and Hanumantharaju, (1993) observed that CaO, $Ca(OH)_2$ and $CaC0_3$ reduced soil acidity at a rapid rate with maximum rate of reaction during the first week, while dolomite, and basic slag neutralize the soil acidity after about two months' time. Common liming materials used for management of acidity and their $CaCO_3$ equivalent are given in **Table 1.**

Table 1: Common liming material and their $CaCO_3$ equivalent

Common name of liming material	Chemical formula	% of $CaCO_3$ equivalent
Calcitic limestone	$CaCO_3$	100
Dolomitic limestone	$CaMg(CO_3)$	95-108
Burnt lime	CaO	178
Hydrated lime	$Ca(OH)_2$	134
Basic slag	$CaSiO_3$	70-90
Marl	$CaCO_3$	40-70
Wood ashes	CaO, MgO, K_2O, K (OH)	40-80

Source: (Weil and Brady, 2022. The Nature and Properties of Soils)

Limestone

Soil acidity can be corrected easily by adding liming materials like calcitic limestone ($CaCO_3$) having neutralizing value of 100, and less frequently used other liming materials like burned lime (CaO), hydrated lime [$Ca(OH)_2$] with neutralizing value of 179 and 136, respectively (Peters *et al*., 1996). Lime which is made from calcium and carbonate in its most pure form, on application to acidic soils, increases availability of calcium (Mohammed *et al*., 2021). According to Christenson *et al.,* (1993) lime applied to soil neutralizes acidity, supplies calcium to the soil and increases the availability of nitrogen, phosphorus, potassium, magnesium, sulfur, boron and molybdenum. According to Fageria and Baligar (2008), the most suitable method for lime application is broadcasting as uniformly as possible and mixing thoroughly through the soil profile. Lime, which is usually broadcasted on the soil surface and mixed with soil at the time of tillage, dissolves in water and hydrolyzes to form OH^- ions that can subsequently react with both H^+ ions formed from hydrolysis of Al^{3+} and exchangeable Al^{3+} (Thakuria *et al.,* 2016). When liming materials such as calcium carbonate is added to the soil, the calcium replaces the H^+ and Al^{3+} on the exchange sites and the carbonates neutralize these H^+ and Al^{3+}. The action of lime applied to soil to neutralize soil acidity and increase crop yields by the improvement of chemical attributes in the soil, is restricted to the topsoil (up to 0-20 cm) due to slow reaction in soil (Amaral *et al.,* 2004). Devi *et al.,* (2017) has reported that application of lime, dolomite or rice husk ash increased the soil pH or reduced acidity along with improvement in soil available P in very strongly acidic soils of Vaikom Kari in Kuttanad region of Kerala. Tang (2004) reported that liming cannot ameliorate subsoil acidity because of the slow movement of lime down soil profiles and deep placement of lime for amelioration of subsoil acidity is not economically feasible. The lime requirement of a soil depends on the change in the pH required, the buffering capacity of the soil and the quality and degree of fineness of the liming material.

Dolomite

Dolomite is a natural sedimentary rock derived ameliorant and pure dolomite minerals contain 45.6% $MgCO_3$ or 21.9% MgO and 54.3% $CaCO_3$ or 30.4% CaO. (Farhati *et al*., 2023). Dolomitic limestone made from rocks containing a mixture of Ca and Mg carbonates is comparatively cheaper liming material imported from the neighbouring states with neutralizing value of 109. Application of dolomite to soil can supply two essential nutrients calcium and magnesium to the plants. According to Devi *et al.,* (2017) dolomite and lime application in very strongly acidic soils of Vaikom Kari in Kuttanad region in two splits, as basal and 30 days after sowing, improved soil available Ca and Mg at both stages.

Dolomite application @ 2 t/ha along with steel slag @ 2.5 t/ha could increase the weight of 1000 grains in rice plants. (Farhati *et al*., 2023). Hartatik *et al*., 2023 reported that improvement of acid sulfate soils can be achieved by application of dolomite @ 4-6 tons ha^{-1} and micronutrients, to increase soil pH or decrease the soil acidity to the optimum level needed for plant growth. Shaaban *et al.,* (2014) observed that in a laboratory study with soil from rice paddy-rapeseed rotation and from rice paddy-fallow-flooded rotation, dolomite application not only counteracts soil acidification but also has the potential to mitigate N_2O emissions in acidic soils. According to Shaaban *et al.,* (2016), dolomite application to the acidic soils has the potential to enhance the CH_4 uptake at low moisture levels and to decrease the emissions of CH_4 at higher moisture levels and N fertilizer application. Dolomite application increased soil pH and increased rate of emission of CO_2 due to the priming microbial decomposition of native organic matter resulting in greater availability of organic C and mineral N (Shaaban *et al*., 2017).

Calcium silicate

Calcium or magnesium silicates (slags) are by-products of various industries like iron and steel. As silicate anions (SiO_3^{2-}) have the same valency as carbonate anions (CO_3^{2-}) from the limestone, slags have the same potential to correct soil acidity as limestone with a neutralizing value of 86% (Korndorfer *et al.,* 2003). Alcarde and Rodella (2003) reported that calcium silicate has higher potential for the correction of soil acidity in the subsurface than lime since it is 6.78 times more soluble than calcium carbonate. Silicates have greater reactivity, thus neutralizes soil pH faster than lime and products from silicate dissociation reach deeper layers of soil than lime and can correct a thicker soil layer further down in the soil improving the possibility of plant deepening the root system and absorbing more nutrients. Nolla *et al.,* (2013) reported that use of slag results in formation of monosilicic acid (H_4SiO_4), which dissociates less than H^+ adsorbed to the exchangeable cation capacity and therefore, soil pH increases.

Silicate is an efficient source for acidity correction because it increases the number of exchangeable bases in the soil equivalent than lime. Calcium and magnesium silicates on application to the soil release calcium, magnesium and silicate ions in the soil solution and thus increase the availability of silicon, calcium, magnesium and phosphorus concentrations for plants and increase the yield. Silicate is more efficient than lime by its efficiency in increasing the phosphorus availability, reducing aluminum toxicity, improving mineral nutrition by supply of Ca and Mg reflecting in higher yield (Castro and Crusciol, 2013). According to Castro *et al.,* (2016), increased soil silicon levels increased the P concentrations in the crop than with the lime application due to the competition of silicon with phosphorus for anion-binding sites on soil colloids, keeping more P in the soil solution for plant uptake. Thus, by the application of silicon, more phosphorus will be taken up by the plant, and less is left in the soil. Application of slags to the soil results in the formation of hydroxy aluminium silicates thus reducing the aluminium phyto toxicity in plants. Khalid and Silva (1980), observed that, due to the formation of insoluble alumino-silicates in the soil or due to precipitation of Si on hydrated aluminium oxides, application of calcium silicate increased the soil pH, exchangeable calcium content, decreases extractable aluminium in the surface soil. Elisa *et al.,* (2016) reported that application of calcium silicate in an acid sulfate soil, increased the soil pH and was effective in alleviating aluminium toxicity and supplied substantial amounts of calcium and silicon. For effectively reducing the aluminium concentration in acid sulphate, rice-cropped soil, calcium silicate should be mixed with the top 30-cm layer. Silicates also supply silicon to the soil solution, increasing silicon availability to the plant and thereby increase the plant resistance to biotic and abiotic stresses by higher tolerance to drought, increased lodging resistance and resistance to pest and diseases. (Nolla *et al.,* 2013 and Elisa *et al.,* 2016). Studies conducted at China on the effects of silicate application on CH_4 and N_2O emissions and global warming potentials in paddy soils revealed that silicate application can reduce the contribution of enhanced UV-B radiation to global warming potentials (Lou *et al*., 2019).

However, use of silicates in agriculture depends on the concentration of the heavy metals present in them. The expensive purification process for removing the heavy metals in products with high levels of heavy metals limits the agricultural use of slags. However, slags derived from the steel industry with low heavy metal concentration can be used in agriculture. (Korndorfer *et al.,* 2003).

Rice husk ash

Rice husk, the yellowish brown outermost layer of paddy grain obtained as a milling by-product of paddy include 37.05% carbon, 35.03% oxygen, 11.06% nitrogen, 9.01% silicon and 8.80% hydrogen (Sarangi *et al.,* 2009; Babaso and Sharanagouda, 2017). Rice husk, which has 75% organic volatile content and 17-20% silica under uncontrolled burning, gets converted into rice husk ash which is 25% by weight of rice husk (**Table 2**). Every tonne of paddy produces about 0.2 t of husk and every tonne of husk produces about 0.18 to 0.2 t of ash depending on the variety, climatic conditions, and geographical location (Kothandaraman *et al.,* 2007; Singh, 2018). Rice husk ash (RHA), one of the major by-products of rice husk burning is obtained when husk is burnt in ambient temperature and pressure condition contains 87-97% silica with small amount of alkalies and other trace elements (Yadav, 2021).

Table 2: Chemical composition of the Rice Husk Ash

Compound / Element (constituent)	Weight (%)
Silica (SiO_2)	91.59
Carbon (C)	4.8
Calcium oxide (CaO)	1.58
Magnesium oxide (MgO)	0.53
Potassium oxide (K_2O)	0.39
Haematite (Fe_2O_3)	0.21
Sodium (Na)	Trace
Titanium oxide (TiO_2)	0.20

Source: (Alaneme and Adewale, 2013)

RHA is a good and cheap source of liming material as it can improve the soil pH and fertility of acidic soils (Masulili *et al.,* 2010). Preetha *et al.,* (2022) reported that rice husk ash is an environmentally favourable agricultural resource, alkaline in nature, which can raise the pH of an acidic soil and also supply nutrients to crops as it contains CO_2-0.10%, SiO_2-89.90%, K_2O-4.50%, P_2O_5-2.45%, CaO-1.01%, MgO-0.79%, Fe_2O_3-0.47%, Al_2O_3-0.46%, MnO-0.14%.

Rice husk ash (RHA) which has an alkaline pH can be used as a potential liming material as it is cheap and environmentally friendly (Devi and Swadija, 2017). Okon *et al.,* (2005) observed that RHA which has low neutralizing value was found to stir up great soil reactions with evidence of increase in effective cation exchange capacity, exchange acidity, soil pH, and rapid growth and yields and can be recommended for adoption by the resource-poor farmers as a high potential and low-external-input material for ameliorating soil acidity. Rice husk ash reacts faster than limestone though it has low effective calcium carbonate equivalent of around 3% and low neutralizing value of around 1% (Islabao *et al*., 2014). Kath *et al.,* (2018) reported that RHA reacts much faster than conventional limestone, as all bases contained in it are dissolved immediately after their incorporation into the soil. Okon *et al.,* (2005) reported that the ability of RHA to reduce soil acidity and raise the pH of the soil to the level needed for the cultivation of most vegetables and arable crops is due to its possession of reasonable quantities of the basic cations like Ca, Mg, K, Na, and other essential elements including P and very little N. Application of combination of humic materials from water hyacinth and silicon from rice husk biochar as soil ameliorants in acid sulphate soils increased the pH and decreased aluminium and sulphate concentration in oxidised conditions, decreased iron concentration under reduced conditions and thus decreased iron, manganese and aluminum toxicity (Maftuah *et al.,* 2023). Teutscherova *et al.,* (2023) reported that the application of RHA could be considered for soil application to recycle nutrients, ameliorate soil acidity, promote plant growth and, ultimately, to reduce losses of applied nitrogen. Preetha *et al.,* (2022) reported that application of rice husk ash @ 48.5 g kg^{-1} registered comparable soil pH with the equivalent $CaCO_3$ level of 5.0 g kg^{-1} confirming the possibility of using rice husk ash as an amendment for acid soil.

Mini and Lekshmi (2020) reported that soil test based RDF + RHA @ lime (based on pH) + foliar spray of 0.5% solution of customized formulation @ 5 kg ha^{-1} as foliar application of 0.5% solution in two splits at maximum tillering and panicle initiation stage increased the yield by 23 per cent in acid sulphate soils of Kuttanad compared to the recommended dose of lime and fertilizer application and the B : C ratio increased from 1.53 to 1.91. Gao *et al.,* (2019) reported that application of RHA to soil increases soil P availability, both by supplying P contained in the ash or indirectly by increasing soil P solubility upon soil pH increase. The application of RHA promoted higher plant biomass production than lime which had no effect on plant growth (Teutscherova *et al.*, 2023). According to Kath *et al.,* (2018), the residual effect of RHA in the pH and on the exchangeable Ca, Mg and K contents, increased with increasing the dose of RHA applied to the soil.

Gypsum

Gypsum is a mineral that is naturally found in the soil and can be mined out from the geological deposits. Gypsum is also obtained as a byproduct from many industries like flue gas desulfurization gypsum (FGD-gypsum) and Phospho gypsum. Gypsum is a good source of calcium and sulphur. Although both are sources of calcium, lime raises the pH of the soil, while gypsum does not. While calcium in gypsum can replace the H^+ ions in the soil, sulphates cannot neutralize the hydrogen ions, these ions will remain in solution and will not adjust soil pH. Zoca and Penn (2017), reported that since gypsum is not an acid-neutralizing or acid-forming substance, depending on soil mineralogy, CEC and competing anions, the sulfate can potentially increase or decrease the pH. Gypsum can act as a soil conditioner that may be used to correct aluminum problems in the subsurface soil layers. Sneller (2011) reported that gypsum dissolution products cannot directly neutralize acidity but it is effective in reducing aluminium toxicity in soils with pH lower than 4.5 as the sulfate may act as a counter ion on soil particles increasing aluminum absorption from the soil solution. Aluminum sulfate is less toxic to plants than the individual aluminum ion. Gypsum applied to the topsoil due to its high solubility, slowly moves down the profile and increases labile calcium levels and decreases aluminium and sodium levels in the subsoil, acts as a soil conditioner, which will improve soil structure to encourage roots to penetrate and proliferate in the subsoil resulting in higher nutrient uptake and yield. (Ritchey *et al*., 1995). Even though the application of gypsum will not change the soil pH, it counteracts the toxic effect of soluble aluminum on root development and thus can promote better root development of crops, especially in acid soils (Dick, 2018). The problem of both deep acid subsoils and shallow acid subsoils in no-till systems where liming material cannot be incorporated can be remediated through, gypsum application due to its high solubility than lime, mobility of gypsum dissolution products, and potential to provide high rates of Ca and sulfate that can decrease Al^{3+} activity in solution (Zoca and Penn, 2017). Rate of application of gypsum depends on the purpose of gypsum application, type of soil, amount of rainfall in the region, cropping system and other potential factors (Kost *et al*., 2014). Continuous application of gypsum can cause magnesium and sodium deficiencies in soil.

Phosphogypsum

Phosphogypsum is a byproduct of phosphate fertilizer industry formed during the production of phosphoric acid from rock phosphate. The phosphogypsum, generated from the phosphoric acid production plants is composed mostly of calcium sulphate ($CaSO_4 \cdot H_2O$). Phosphogypsum is more soluble than limestone, but its addition does not increase the soil pH as it cannot neutralize the replaced H^+ ions. Caires *et al.,* (1999) reported that phosphogypsum applied to the soil surface moves along the profile under the influence of percolating water and thereby increase the supply of calcium and reduce the aluminium toxicity in the subsoil. Phosphogypsum is therefore, an alternative for improving the root environment in the subsoil and can be used in acidic soils as a supplement for liming (Caires *et al.,* 2003). Gypsum and lime when applied together have synergistic effects. Ebimol *et al.,* (2017) observed an increase in soil pH and available calcium content by the application of phosphogypsum along with lime @ 300 kg/ha and was highly effective in lowering the toxic concentration of Fe and Al in the acid sulphate soils of Kuttanad. Costa and Crusciol (2016) observed that superficial liming with or without phosphogypsum increased the Ca^{2+} levels throughout soil profile and reduced the surface and subsurface soil acidity, five years after application in a no till system but had residual effect on the SO_4^- S levels, and high sulphate concentrations were observed in the subsoil after five years. The organic matter content increased with liming with or without phosphogypsum, indicating that in the long term, these practices can increase the carbon accumulation in the system. Application of phosphogypsum along with lime can correct both the surface and subsurface acidity. A major concern about the use of phosphogypsum is its radioactivity. However, the degree of radioactivity dependents on the place from where the phosphate rock was mined (Guimond and Hardin,1989).

Biochar

Biochar, a carbon-rich product is produced by a process known as carbonization, through thermochemical conversion of organic material or biomass materials such as crop residues, forestry waste, industrial by-product, municipal waste and animal manure under limited supply of oxygen and at relatively low temperature. Biochar can be used as a soil amendment to improve nutrient availability, soil productivity, carbon storage, and filtration of percolating soil water and act as stable form of carbon due to its resistance to decomposition and its influence on nutrient dynamics (Lehmann and Joseph, 2009). According to Gao *et al.*, (2019), biochar additions to soil increased available P by 45 per cent, but have negative effect on the accumulation of inorganic N. In highly acidic soils, application of biochar increased the soil pH, P availability, cation exchange capacity and soil organic carbon in a sustainable manner (Bedassa, 2020). Phares *et al.,* (2020) reported that combined biochar and triple superphosphate application increased soil pH, improved soil fertility, nodulation and nitrogen fixation in cowpea grown in a tropical sandy loam soil amended with biochar at 1.5 t ha^{-1} and 2.5 t ha^{-1} solely or together with inorganic phosphate fertilizer (TSP), applied at a rate of 60 kg P/ha. Biochar is a biomass-derived carbonaceous material often alkaline in nature and therefore, when used as a liming agent has the potential to alleviate soil acidity; however, more reliable datasets of its liming and consequent effects are still to be explored (Bolan *et al.*, 2023).

Conclusion

Adverse soil conditions like low pH, iron and aluminium toxicity, low nutrient availability and low fertilizer use efficiency are the factors limiting productivity of rice in extremely acidic soils. Application of lime shell is the most common practice adopted by the farmers for the management of acidity. But the high cost, low quality, reduced availability and evolution of CO_2 during the calcination process recommends the use of various other natural materials like RHA and industrial by-products like calcium silicate and phosphogypsum as an alternative option for the amelioration of acidic soils. These materials are having high reactivity in increasing the pH, supply of nutrients like Ca, Mg, Si *etc*., and also has the potential to reduce iron and aluminium toxicity and reduce methane emission.

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Genetic Gain and Productivity Trend Analysis for the Yield of Rice Varieties in Central India

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Abstract

The genetic gains and productivity trends were estimated for rice varieties developed by Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, India from 1905 to 2021 to assess the improvement in rice breeding programme. During this period (categorized into three different phases - 1, 2 and 3), 90 rice varieties were developed. Twenty-four varieties that became popular in different phases (Seven popular landraces from Phase 1, six varieties from Phase 2 and 11 varieties from Phase 3) were selected and evaluated for yield over five consecutive years (2017 to 2021) under replicated trials. The study revealed highest genetic gain of 1.50% for yield in the varieties that were released in Phase 2 with a yield enhancement of about 51 kg ha^{-1} $year^{-1}$, followed by a genetic gain of 1.03% (43 kg ha^{-1} $year^{-1}$) during Phase 3 and least genetic gain of 0.159% (4 kg ha^{-1} $year^{-1}$) in Phase 1. This increase seems to be a result of planned and strategic research in crop improvement coupled with improved agronomic practices.

Keywords: Genetic gains, IGKV, productivity trend, rice breeding, rice varieties.

Introduction

Rice is the main staple food crop of India with more than 65 per cent of the population depending on it for their livelihood (Singh and Singh, 2020). The major contributors for rice production in India during the year 2018-19 are West Bengal (13.79%), Uttar Pradesh (13.34%), Andhra Pradesh with Telangana (12.84%), Punjab (11.01%), Odisha (6.28%), Chhattisgarh (5.61%), Tamil Nadu (5.54%), Bihar (5.19%), Assam (4.41%), Haryana (3.88%) and Madhya Pradesh (3.86%). In India, rice breeding has made significant contributions in ensuring national food security and supplying of food to its burgeoning 1.35 billion population. India is also a major global exporter of Basmati and Non-Basmati quality of rice. Apart from having a large geographical area (328 m ha), its varied agro-ecological climatic conditions and diverse soil types contribute to its current global status in rice area and production. Further, this achievement is also due to the continuous efforts of breeders and collaborating scientists, appropriate policies and above all, the efforts of millions of rice farmers from diverse parts of the country. Rice breeding in India has significantly contributed towards improving the socio-economic status by ensuring food security along with the commerce of the country. The rice varieties developed from Andhra Pradesh is occupying more then 50% area in eastern Indian states (Reddy *et al.,* 2022).

Indira Gandhi Krishi Vishwavidyalaya (IGKV) was established in 1987 in Raipur city of the Chhattisgarh State of India. It is one of the premier institutes working on rice breeding in the country. It has a dynamic rice-breeding program dedicated to improving rice genotypes for grain yield, nutritional quality, and other traits of economic value along with replicated multi-location testing across different rice growing environments towards the release of potential and stable varieties for commercial cultivation. Rice is also the main food crop of the Chhattisgarh state, and most of its economy depends on rice production and procurement.

It is anticipated that climate change, mainly temperature rise will have a direct impact on the yield of main crops like rice. In this scenario, rice will have a severe impact due to its high-water requirement (Zhao *et al.,* 2017). Further, because of tremendous population growth, consumption of rice is projected to increase to more than 578 million tons and the average consumption is estimated to increase by 1 kg to reach 55 kg per year by 2028. However, the area utilized for rice production is estimated to increase by only 1% (Anonymous, 2019).

Therefore, enhancement in rice production can only be achieved by yield improvement coupled with superior agronomic practices. Therefore, breeding programs must aim to develop new climate-resilient varieties having higher yields under varied climatic conditions and help to get over the evident threats to food security. Yield potential in rice is estimated to be 15–16 t/ha and the yields of 10 t/ha could be realized under assured irrigation (~20 mha) and rainfed shallow lowland (11 mha) ecosystems. The yield gap of approximately 6 t/ha is therefore, needed to be reduced on priority through appropriate technical and policy interventions to sustain the demands of the burgeoning population (Muralidharan *et al.,* 2019). The yield gaps can be enhanced with the introgression of genes for biotic stresses like BLB and blasts (Aleena *et al*., 2023).

Genetic gain, a measure of performance enhancement, achieved through selection (Xu *et al.,* 2017) with respect to important traits, including yield results in improved profitability and sustainability and hence, is crucial for the adoption of new varieties at the field level by the rice farmers.

Estimate of genetic gain realized for yield has been assessed in plant breeding programs of maize and Canola to quantify the progress made in breeding programs by earlier workers (Crespo-Herrera *et al.,* 2018, Laidig *et al.,* 2014). In this context, the assessment of productivity trend of popular varieties developed through breeding programs was undertaken to understand the level of genetic gains achieved in rice breeding programs of IGKV, Raipur.

Materials and Methods

Details of Experiment

The present study was conducted at IGKV, Raipur, Chhattisgarh, India (Lat $21^0$25'14"N, long $81^0$62'96"E, 298 m asl). A set of 24 rice varieties released since 1905 were evaluated for grain yield and other ancillary characters for five consecutive years from 2017 to 2021. The study was undertaken during the *kharif* season in two replications under Randomized Block Design.

Genotypes

Twenty four varieties released during different years were categorized into three different phases. Phase 1 represents the pre-green revolution era, while Phase 2 is the period between 1987-2005 and Phase 3 represents the period between 2005-2021. During Phase 1, seven landraces, namely Bhondu No. 11, Parewa No. 22, Cross 116, Laloo 14, Madhuri, Safri-17 and Pandri Luchai were selected for the study. In Phase 2, six varieties, namely, Kranti, Mahamaya, Purnima, Danteshwari, Bamleshwari and Indira

Sugandhit Dhan-1 and under Phase 3, 11 popular varieties, namely, Samleshwari, Chandrahasini, Karma Mahsuri, Rajeshwari, Durgeshwari, Indira Barani Dhan-1, Maheshwari, Indira Aerobic-1, Chhattisgarh Sugandhit Bhog, Chhattisgarh Devbhog and CG Dhan 1919 were selected for evaluation (**Table 1**). These varieties were sown for five consecutive years from 2017 to 2022 in Randomized Complete Block Design (RCBD) in two replications using standard agronomic practices at Research Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh.

Statistical analysis

Agronomic data of grain yield were separately analyzed for each year using the mixed model:

$$y_{ijklm} = \mu + g_i + s_j + gs_{ij} + b_k + \varepsilon_{ijk(1)}$$

Where y_{ijk} is the grain yield measurement for the i^{th} genotype in the j^{th} year and k^{th} complete block;

μ is the overall mean; g_i is the fixed effect of genotype; s_j is the random effect of the specific season;

gs_{ij} is the random effect of the interaction between the genotype and the specific season;

b_k is the random effect of the complete block, also referred to as replicate; and ε_{ijkl} is the residual error.

All the random effects were assumed identically and independently distributed (i.i.d).

Table 1: Mean yield of varieties released by IGKV, Raipur

S. No.	Rice Varieties	Year of release	Yield (kg/ha)
1.	Bhondu No 11	1913	2101.50
2.	Parewa No 22	1923	2165.45
3.	Cross116	1942	2294.93
4.	Laloo 14	1964	2550.82
5.	Madhuri	1965	3149.55
6.	Safri-17	1966	3096.46
7.	Pandri Luchai	1966	3227.98
8.	Kranti	1987	2905.42
9.	Mahamaya	1996	4297.58
10.	Purnima	1997	2985.55
11.	Danteshwari	2001	2931.88
12.	Bamleshwari	2001	4203.14
13.	Indira Sugandhit Dhan-1	2005	3316.44
14.	Samleshwari	2007	3807.04
15.	Chandrahasini	2007	3532.23
16.	Karma Mahsuri	2008	4215.16
17.	Rajeshwari (IGKV, R1)	2011	4486.82
18.	Durgeshwari (IGKV, R2)	2011	3483.67
19.	Indira Barani Dhan 1	2012	3886.82
20.	Maheshwari (IGKV, R1244)	2012	3666.40
21.	Indira Aerobic-1	2015	4390.93
22.	Chhattisgarh Sugandhit Bhog	2017	4494.69
23	Chhattisgarh Devbhog	2019	4701.52
24.	CG Dhan 1919	2021	5654.78

Software used

Analysis for the current study was done using the R statistical programming language and environment utilizing the packages l me 4 and ls means through R version 3.4.3. (Lenth, 2016).

Results and Discussions

The study was conducted to analyze the genetic gains of the developed varieties and their trends in the productivity of major rice varieties. The period of 100 years of rice research in IGKV has been divided into three phases *i.e.,* Phase I (pre-green revolution era, prior to 1987), Phase II (after the establishment of Indira Gandhi Krishi Vishwavidyalaya, Raipur in the year 1987 up to 2005) and Phase III (after 2005 to 2021). The mean yield data of varieties released by IGKV are provided in **Table 1**. A total of 24 rice varieties were released during the three phases, Phase 1 (seven varieties), Phase 2 (six varieties), and Phase 3 (11 varieties) and their mean yield in kg/ ha has been provided (**Tables 2 to 4**).

Table 2: Yield of rice varieties developed during Phase 1 (1913 to 1966)

S. No.	Name of the variety	Year of release	Yield (kg/ha)
1.	Bhondu No 11	1913	2101.50
2.	Parewa No 22	1923	2165.45
3.	Cross116	1942	2294.93
4.	Laloo 14	1964	2550.82
5.	Madhuri	1965	3149.55
6.	Safri-17	1966	3096.46
7.	Pandri Luchai	1966	3227.98

Table 3: Yield of rice varieties developed during Phase 2 (1987 to 2005)

S. No.	Name of the variety	Year of release	Yield (kg/ha)
1.	Kranti	1987	2905.42
2.	Mahamaya	1996	4297.58
3.	Purnima	1997	2985.55
4.	Danteshwari	2001	2931.88
5.	Bamleshwari	2001	4203.14
6.	Indira Sugandhit Dhan-1	2005	3316.44

Table 4: Yield of rice varieties developed during Phase 3 (2005 to 2021)

S. No.	Name of the variety	Year of release	Yield ($kgha^{-1}$)
1.	Samleshwari	2007	3807.04
2.	Chandrahasini	2007	3532.23
3.	Karma Mahsuri	2008	4215.16
4.	Rajeshwari (IGKV, R1)	2011	4486.82
5.	Durgeshwari (IGKV, R2)	2011	3483.67
6.	Indira Barani Dhan 1	2012	3886.82
7.	Maheshwari (IGKV, R1244)	2012	3666.4
8.	Indira Aerobic-1	2015	4390.93
9.	Chhattisgarh Sugandhit Bhog	2017	4494.69
10.	Chhattisgarh Devbhog	2019	4701.52
11.	CG Dhan 1919	2021	5654.78

Genetic trend estimates for 24 rice varieties

Genetic trend estimates of variety mean yields for 24 varieties of Raipur, Chhattisgarh have been presented in **Table 5**. A considerable variation in yield *per se* among the varieties released during the three phases studied was observed. The multi-year evaluation of rice varieties and their yield data were subjected to analyze the genetic gains and productivity trends in different eras of the rice breeding program at IGKV. A high level of genetic gain for yield was found for the varieties that were released in Phase 2 which was 1.50% along with a yield increase of about 51 kg ha^{-1} $year^{-1}$. During Phase 3, a genetic gain of 1.03% (43 kg ha^{-1} $year^{-1}$) and the least genetic gain of 0.159% (4 kg ha^{-1} $year^{-1}$) in Phase 1 was observed.

Table 5: Genetic Trend Model - Estimate of variety mean yields for IGKV released varieties

Phases	Number of varieties	Baseline yield $\pm$ Standard error	Increase of yield (kg ha^{-1} $year^{-1}$)	Yield gain ($year^{-1}$)	Model R squared
Phase I	7	2655 $\pm$ 187.2	4.23 $\pm$ 0.25	0.159%	0.912
Phase II	6	3440.0 $\pm$ 279.7	51.63 $\pm$ 9.32	1.50%	0.020
Phase III	11	4210.9 $\pm$ 258.5	43.68 $\pm$ 8.58	1.03%	0.485

Productivity trends during three phases

As shown in **Figure 1**, the productivity trend of studied 24 rice varieties shows a regression R^2 value of 0.773 and an incremental yield improvement throughout the released years. During the Phase 1 study of seven varieties (pre-green revolution era) **(Figure 2)**, the productivity trend shows a regression R^2 value of 0.912 with a linear yield increment. In the present study, **Figure 3.** showed a regression R^2 value of 0.020 with a linear increment in yield whereas a regression R^2 value of 0.485 with a linear yield increment is visible in **Figure 4**. Both figures (**Figures 3 and 4**) show productivity trends of rice varieties developed after the establishment of the University in 1987. **Figures 1-4** shows, the IGKV-released varieties over the past 100 years had an increased genetic trend. The regression constant for the baseline grain yield is highest for Phase 1 followed by Phase 3 and least for Phase 2. Whereas an increased yield indicated by the slope of the regression lines was found to be higher in Phase 1 as compared to Phases 2 and 3.

Genetic trend estimates for 24 varieties

The high degree of genetic gain for yield was found in the varieties that were released in Phase 2 (varieties released from 1987 to 2005) which was 1.50% with a yield improvement of about 51 kg ha^{-1} year^{-1}. This is due to the introduction of the dwarfing gene(s) in varieties which were high-yielding and fertilizer responsive, whereas during the pre-green revolution era, rice improvement was done mainly through selection from traditional varieties to release new, locally suitable cultivars.

In the case of rice, genetic gain analysis was conducted very rarely, mainly in Asia where rice is the major food crop. A study in Southeast Asia was conducted by Peng and Khush (2003) at IRRI, Philippines in 1996 and they found 1% yield (75-81 kg ha^{-1}) increase per year. While Breseghello *et al*., (2011) in Brazil analyzed genetic gain for rice breeding of upland for 25 years and found that there was no significant yield improvement annually between 1984 and 1992. Whereas 15.7 kg ha^{-1} year^{-1} (0.53%) yield increased between 1992 and 2002; and approximately three times from 2002 to 2009 at a yield gain of 45.0 kg ha^{-1} year^{-1} (1.44%). Kumar *et al.,* (2020) in India reported genetic gains in rice cultivars cultivated from 2005 to 2014 with 0.68–1.9% for grain yield under different levels of moisture stress regimes.

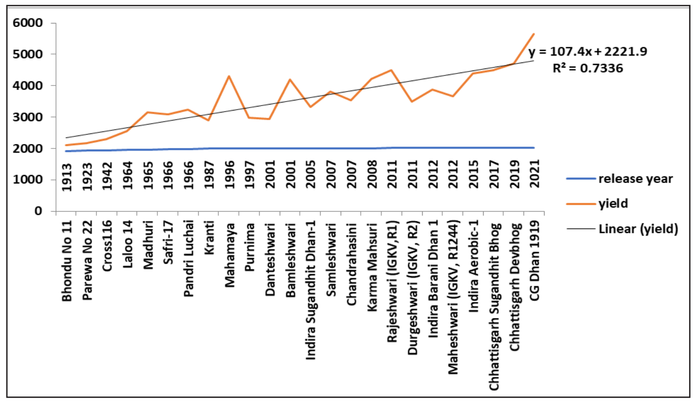

Figure 1: Productivity trend and regression line over the years

Similar results were reported after an assessment of genetic gain performed in a study of maize crop by Crespo-Herrera *et al.,* (2018) who reported a grain yield of 38 kg ha^{-1} year^{-1} (1.8%) under marginal condition, while a yield of 57 kg ha^{-1} year^{-1} (1.4%) in average productivity condition and over all the conditions, observed yield increase was 48 kg ha^{-1} year^{-1} (1.6%). Laidig *et al.,* (2014) in Germany assessed the genetic gain for 12 different crop varieties developed in 30 years by various crop breeding programs. They found yield improvement in all the crops for improved varieties, the highest gain was observed in Winter canola or winter oil seed rape (1.86% yearly) and lowest in Italian ryegrass (0.16% yearly).

Productivity trends during three phases

Comparing the Productivity trend of IGKV-released varieties and estimated genetic gain during the

Phase 1 study, The R^2 value of 0.912 with genetic gain in yield was observed to be about 0.159% (**Figure 2 and Table 5**), where the rice improvement was based on the selection of locally popular landraces. Whereas, during post green revolution era, the hybridization-led crop improvement research was initiated and the development of semi-dwarf, nutrient-responsive cultivars, the yield genetic gains were found to be around 1.5% during Phase 2 with a regression R^2 value of 0.020. During Phase 3 the annual genetic gain comes to be around 1.03% in terms of yield/ year with an R^2 value of 0.485. During post green revolution phase, the rice breeding program mainly focused on the incorporation of polygenes for pest resistance and tolerance to abiotic stresses such as moisture stress by utilizing conventional and molecular breeding approaches, which leads to the development of climate-resilient crop varieties. Varietal development and pyramiding of high yield and superior grain quality traits were also emphasized along with nutritional quality traits.

The yield trends of varieties developed and released by IGKV after its establishment in 1987 is depicted in **Figures 3 and 4**. Rice productivity not only witnessed a continuous increase during both the pre- and post-green revolution phases but more importantly the yield gain has been improved day by day. This is an important achievement because rice is cultivated in the *kharif* (wet season) in the Chhattisgarh state of India, and therefore, it is highly vulnerable to erratic rainfall patterns and quantity. But during phase 3 there was a steep decrease in the genetic gain of 0.47% (from 1.50% to 1.03%) suggesting that there is a scope for improvement in the modernization of the breeding program to shorten the breeding cycle and enhance the genetic gain by adopting speed breeding and smart breeding tools and techniques to increase the selection accuracy and experimental reliability.

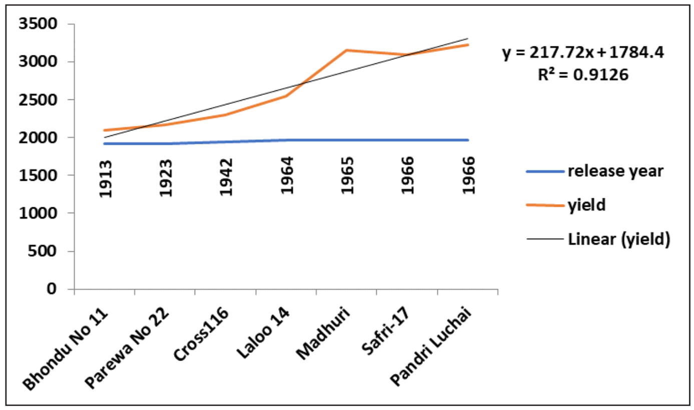

Figure 2: Productivity trend of rice varieties during Phase I (Pre-green revolution)

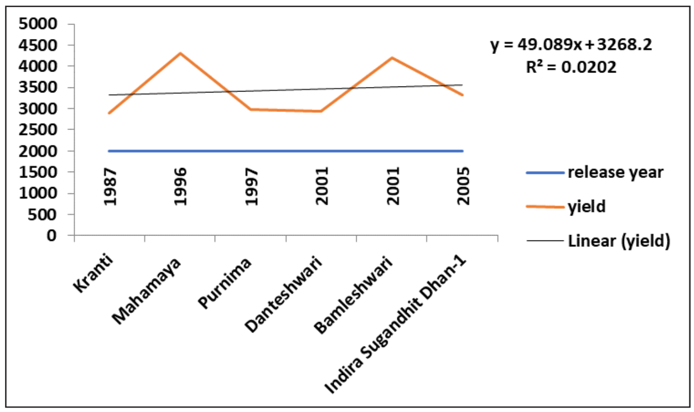

Figure 3: Productivity trend of rice varieties during Phase II (Post green revolution)

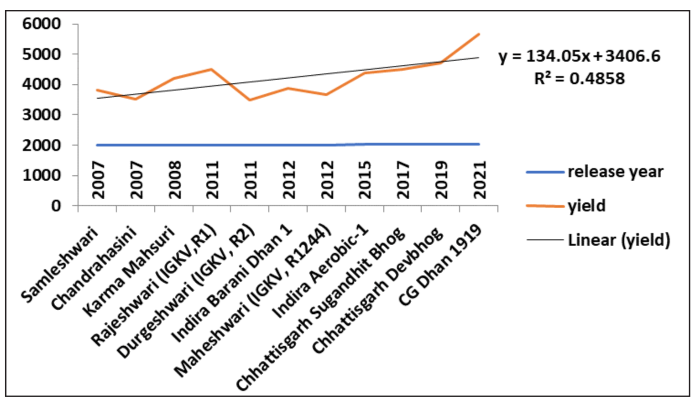

Figure 4: Productivity trend of rice varieties developed during Phase III (after 2005 to 2021)

Analysis of the degree of productivity enhancement in rice varieties since 1911 of the IGKV rice breeding program indicated that there is a consistent increase in productivity from 4 kg ha^{-1} $year^{-1}$ to 51 kg ha^{-1} $year^{-1}$ during all three phases of crop improvement activities. This increase could be due to the planned and applied research in rice improvement and agronomic management practices.

Conclusions

Estimation of genetic gains in terms of yield of the developed varieties to assess the impact of any breeding program through experiments like "Era" studies or historical data sets analysis required to be conducted time to time under multi-location evaluation trials as the varying scenario of climate change is the important impact on rice growing environments. These studies provide directions to the crop improvement programs to plan strategically for the release of enhanced cultivars that could be adopted by the farmers for increased profitability. The assessment of the degree of productivity enhancement of rice varieties since 1911 of the IGKV rice breeding program indicates a consistent increase in productivity from 4 kg ha^{-1} $year^{-1}$ to 51 kg ha^{-1} $year^{-1}$ during three phases of crop improvement activities. This increase seems to be a result of planned and strategic research in crop improvement with improved agronomic practices.

Consumer/market-preferred grain quality characters under multi-environment trials of advanced breeding lines must also be analyzed for the popularization of new varieties. Analysis may provide the targeted genetic gain by breeding programs for planning crossing programs and strategies to achieve objectives with the incorporation of desired variable lines in the breeding programs. Analysis of actual genetic gain at the field level is the critical input, which gives an idea to breeders to make important changes for speeding up the varietal improvement programs while catering to the variable market and consumer preferences. This study will help to decide the investments in different aspects of the breeding program efficiently and in an effective manner. Although a lot of progress has been made in the last decades, the genetic gain from the different crop breeding strategies is plateaued over time and the yield enhancement in present times is contributed more by agronomic interventions.

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Declaration of Competing Interest

The authors declare that there are no known competing interests or personal relationships, which influence the work reported in this paper.

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In silico Identification of Alternatively Spliced Variants from Transcriptome Data of Rice Lines Exhibiting Complete Panicle Exsertion

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Abstract

Alternative splicing is a molecular mechanism governing gene expression, particularly in plants, wherein a single gene can yield multiple mRNA transcripts, thereby diversifying the resulting protein isoforms. Panicle exsertion is an important trait associated with grain yield in rice. We deployed the mRNA sequencing (transcriptome) data from incompletely exserted panicle genotype, BPT-5204 and its ethyl methanesulphonate mutant lines *viz.*, CPE-109 and CPE-110 exhibiting completely exserted panicle for identification of Alternative Splicing events. Our systematic analysis using rMATS package revealed 414 and 368 genes alternatively spliced upon the comparison of CPE-109 with BPT-5204 and CPE-110 with BPT-5204 respectively. We identified alternative 3′ splice site (A3SS) as the predominant AS type upon comparison of CPE-109 with BPT-5204 (51.20% A3SS) and CPE-110 with BPT-5204 (48.91% A3SS) at panicle initiation stage. In total 23 and 19 genes emanated multiple transcripts *via.,* AS. Remarkably, upon comparison of splicing data of CPE-109 with BPT-5204 and CPE-110 with BPT-5204, we found three common genes namely, *Os07g0406600* encoding DDHD domain containing protein, *Os10g0442100* encoding tRNA methyltransferase and *Os04g0675800* encoding H0103C06.10 protein, that generated more than two transcripts *via.,* AS. These genes can be further validated for determining its role in panicle exsertion through gene expression studies, over expression and functional characterization.

Keywords: Alternative splicing, Complete panicle exsertion, Transcriptome, rMATS, DDHD domain

Introduction

Alternative splicing (AS) represents a pivotal post-transcriptional and co-transcriptional mechanism inherent to eukaryotic gene expression. Alternative splicing is a cellular course in which exons from the same gene are joined in different combinations, leading to different, but related, mRNA transcripts. Further, these mRNAs from a single gene can be translated to produce different proteins with distinct structures and functions. This intricate process orchestrates the selective inclusion or exclusion of exonic sequences, as well as variations in noncoding regions within pre-mRNA transcripts. Alternative splicing of pre-mRNAs promotes transcriptome and in turn proteome diversity and plays an important role in a wide range of biological processes in eukaryotes. The regulation through AS is dynamic and depends on the cell type, tissue, environmental condition etc. The pre-mRNAs and interactions of RNA-binding proteins affects the generation of AS isoforms.

The major types of AS events include intron retention (IR), exon skipping (ES), alternative 5′ splice sites (A5SS; alternative donor site), alternative 3′ splice sites (A3SS; alternative acceptor site), and mutually exclusive exons (MXE). The frequency of AS also varies from species to species for example, in rice and Arabidopsis 33% and 42% of intron-containing genes respectively. It has been reported that 51% of intron-containing genes utilize alternative 5′ or 3′ splice sites or exon skipping events.

In plants, AS is integral to the regulation of diverse biological processes, encompassing developmental programs and responses to environmental stimuli. The AS events are well characterized in crops like rice, wheat, maize, etc. under various abiotic and biotic stresses and the isoforms differential expression has been linked to tolerance or resistance in plants (Ganie and Reddy *et al.,* 2021). The NGS methods, notably RNA-Seq, offer a high-throughput and cost-effective means to comprehensively analyse the transcriptome. This allows researchers to identify, quantify, and characterize alternative splicing events on a genome-wide basis. The technology's capacity for large-scale data generation has revealed novel insights into the complexity of AS patterns in plants. The methodology and the identification of AS events depends on the technology deployed, sequences / ESTs/ assemblies etc. (Syed *et al.,* 2012). Various tools, pipelines and softwares are available for analyzing alternative splice variations deploying the RNA-seq data sets (Yu *et al.,* 2021).

The rice genotype exhibiting complete exsertion of panicle from flag leaf results in higher grain yield compared to genotype whose panicle is partially choked in flag leaf sheath. Incompletely exerted panicle from flag leaf results in grain yield loss (Guan *et al.,* 2011; Duan *et al.,* 2012). To avoid such loss, complete panicle exsertion (CPE) is desirable in both hybrids and varieties. Recently, quantitative trait loci (QTL)/ genes/ marker underlying complete panicle exsertion have been mapped (Hake *et al.,* 2023); however, role of alternatively spliced genes in complete panicle exsertion in rice is largely unknown. With a hypothesis that AS variations could have role in CPE, in the present study, we have utilized the RNA-seq data of completely exserted panicle lines, CPE-109 and CPE-110, (stabilized mutants of BPT-5204) and their parent BPT-5204 (exhibited incomplete panicle exsertion) to discern the molecular mechanism underlying panicle exsertion.

Materials and Methods

Identification of alternatively spliced (AS) variants

The cleaned reads of RNA-seq data from NCBI Sequence Read Archive (SRA) database (BioProject ID PRJNA687517 and PRJNA772118) of three rice genotypes, namely BPT-5204 (a popular and widely adapted cultivar but incompletely exserted panicle from flag leaf), CPE-109 and CPE-110, stable mutants of BPT-5204, exhibiting complete panicle exsertion from flag leaf were utilized for identification of alternatively spliced variants (Pottupureddi *et al.,* 2021). The reads were mapped on the rice reference genome, R498 using a splice-aware alignment algorithm, HISAT2 (v 2.1.0) (Kim *et al.,* 2019). Splicing events such as skipped exons (SE), intron retention (IR), alternative 5′ splice site (A5SS), alternative 3′ splice site (A3SS), alternative donor, and acceptor sites were analyzed by utilizing alignment of RNA-Seq data of CPE-109 and CPE-110 with BPT-5204 using the rMATS package 4.1.2, a computational tool to detect differential alternative splicing events from RNA-Seq data (Shen *et al.,* 2014). The graphical representation was executed using the sashimi plot, a tool for RNA-Seq analyses of isoform expression (Kartz *et al.,* 2015).

Results and Discussions

We performed a comprehensive and comparative analysis of AS events using rice transcript (RNA-seq) data from flag leaf at panicle initiation stage of three genotypes namely, BPT-5204 (exhibiting incomplete panicle exsertion), CPE-109 and CPE-110 (both exhibiting complete panicle exsertion). In total, 414 and 368 splicing events were identified from RNA-seq data upon the comparison of CPE-109 with BPT-5204 and CPE-109 with BPT-5204 respectively. Upon comparison of RNA-seq data of CPE-109 with BPT-5204, we found 414 spicing events by alternative 3′ splice site (A3SS; 212 events) followed by alternative 5′ splice site (A5SS; 110 events), retained intron (RI; 64 events) and skipped exons (SE; 28 events) (**Table 1**) observed in 369 genes, off these 22 genes exhibited two or more than two spicing events (**Table 2**). Likewise, upon comparison of RNA-seq data of CPE-110 with BPT-5204, we found 368 splicing events by alternative 3′ splice site (180 events) followed by alternative 5′ splice site (105 events), retained intron (RI; 56 events) and skipped exons (SE; 27 events) (**Table 3**) in 329 genes, off these 19 genes exhibited two or more than two splicing events (**Table 4**)

Table 1: Study of splicing events for CPE upon comparison of RNA seq data of CPE-109 with BPT-5204

Splicing Type	Chromosome number												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
Alternative 3′ splice site	31	21	28	29	18	12	18	18	9	10	9	9	212
Alternative 5′ splice site	15	15	12	10	7	5	13	5	7	8	9	4	110
Retained Intron	9	9	5	7	5	6	8	3	4	0	5	3	64
Skipped Exon	4	3	5	1	2	1	3	1	3	2	1	2	28
Total	59	48	50	47	32	24	42	27	23	20	24	18	414

Table 2: Multiple transcripts generated by alternate splicing events for CPE upon comparison of RNA seq data of CPE-109 with BPT-5204

Gene (MSU_ID)	Gene (RAP_ID)	Description of gene	Splicing Events			
			A3SS	A5SS	RI	SE
Os01g0720600	LOC_Os01g52250	Starch synthase	✓	✓	×	×
Os08g0451700	LOC_Os08g35050	ARID/BRIGHT DNA-binding domain containing protein	✓	✓	×	×
Os03g0286200	LOC_Os03g17730	P-protein	✓	✓	×	✓
Os01g0113600	LOC_Os01g02334	Expressed protein	✓	✓	×	×
Os10g0436800	LOC_Os10g30054	ENT domain containing protein, expressed	✓	✓	×	×
Os07g0406600	LOC_Os07g22390	DDHD domain containing protein	✓	✓	×	×
Os03g0811900	LOC_Os03g59740	ADP-ribosylation factor	✓	×	✓	×
Os03g0219200	LOC_Os03g11960	Copper/zinc superoxide dismutase, putative, expressed	✓	×	✓	×
Os03g0219900	LOC_Os03g12020	50S ribosomal protein L15, chloroplast precursor, putative, expressed	✓	×	✓	×
Os02g0321000	LOC_Os02g21570; LOC_Os02g21580	PPR repeat containing protein, expressed	✓	×	×	✓
Os03g0156700	LOC_Os03g06090	High-affinity nickel-transport family protein, putative, expressed	✓	×	×	✓
Os09g0513400	None	Hypothetical protein	✓	×	×	✓
Os08g0430300	LOC_Os08g33350	Expressed protein	✓	×	×	✓
Os10g0442100	LOC_Os10g30550	tRNA methyltransferase	✓	×	×	✓
Os04g0675800	LOC_Os04g57920	Similar to H0103C06.10 protein	×	✓	✓	×

Gene (MSU_ID)	Gene (RAP_ID)	Description of gene	Splicing Events			
			A3SS	A5SS	RI	SE
Os05g0519200	LOC_Os05g44290	Protein kinase domain containing protein	×	✓	✓	×
Os06g0102750	LOC_Os06g01304	Spotted leaf 11	×	✓	✓	×
Os11g0434000	LOC_Os11g24630	Magnesium-dependent phosphatase 1	×	✓	✓	×
Os04g0278200	LOC_Os04g20960	Expressed protein	×	✓	×	✓
Os06g0659200	LOC_Os06g44870; LOC_Os06g44880	Type II intron maturase protein	×	✓	×	✓
Os02g0326700	LOC_Os02g22100	OsRhmbd6 - Putative Rhomboid homologue, expressed	×	✓	×	✓
Os07g0139500	LOC_Os07g04700	MYB family transcription factor	×	✓	×	✓

***A3SS**: Alternative 3' splice site; **A5SS:** Alternative 5' splice site; **SE:** Skipped Exon; **RI:** Retained Intron*

With the advent of next-generation sequencing technologies, newer aspects of AS events are unfolded (Barbadikar *et al.,* 2024). The AS events creates new combination of transcripts and thus contributes to expanding of the proteome. The AS isoforms are involved in the regulation of post-transcriptional gene expression (Campbell *et al.,* 2006). Interestingly, during panicle initiation stage, most of the genes transcribed by alternative 3′ splice site mechanism (212 events in CPE-109 vs BPT-5204 and 180 events CPE-109 vs BPT-5204) signifies its role in panicle exsertion. The isoforms of genes resulted due to splicing events represented by the Sashimi plot (**Figure 1**). Upon comparison of the splicing data of CPE-109 with BPT-5204, out of 369 alternatively spliced genes, 21 revealed two types of transcripts while one gene namely, *Os03g0286200* encoding P-protein produced three transcripts *via* alternative spicing by alternative 3′splice site, alternative 5′splice site and skipped exon (**Table 2**). Likewise, upon comparison of splicing data of CPE -110 with BPT-5204, out of 329 alternatively spliced genes, 18 revealed two types of transcripts while gene *Os07g0406600*, encoded to DDHD domain containing protein produced three transcripts *via* alternative spicing by alternative 3′ splice site, alternative 5′ splice site and skipped exon.

Table 3: Number of splicing events for CPE upon comparison of RNA seq data of CPE-110 with BPT-5204

Splicing Type	Chromosome number												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
Alternative 3′ splice site	21	26	26	20	9	9	12	14	7	10	14	12	180
Alternative 5′ splice site	15	13	13	9	9	6	11	3	8	6	7	5	105
Retained Intron	11	5	8	5	2	2	5	4	6	2	4	2	56
Skipped Exon	3	1	4	2	1	1	5	3	2	2	3	0	27
Total	50	45	51	36	21	18	33	24	23	20	28	19	368

Table 4: Multiple transcripts generated by alternate splicing events for CPE upon comparison of RNA seq data of CPE-110 with BPT-5204

Gene (MSU_ID)	Gene (RAP_ID)	Description of gene	Splicing Events			
			A3SS	A5SS	RI	SE
Os07g0406600	*LOC_Os07g22390*	DDHD domain containing protein	✓	✓	✓	×
Os01g0178200	*LOC_Os01g08290*	Similar to integral membrane family protein	✓	✓	×	×
Os01g0757800	*LOC_Os01g55300*	DNA polymerase eta domain containing protein	✓	✓	×	×
Os03g0210400	*LOC_Os03g11200*	RNA-processing protein, HAT helix domain containing protein	✓	✓	×	×
Os05g0588800	*LOC_Os05g51119*	Expressed Protein	✓	✓	×	×

Gene (MSU_ID)	Gene (RAP_ID)	Description of gene	Splicing Events			
			A3SS	A5SS	RI	SE
Os06g0691000	*LOC_Os06g47580*	DNA-repair protein, UmuC-like domain containing protein	✓	✓	×	×
Os01g0102900	*LOC_Os01g01340*	Light-induced protein 1-like	✓	×	✓	×
Os02g0740300	*LOC_Os02g50680*	AAA-type ATPase family protein	✓	×	✓	×
Os03g0284100	*LOC_Os03g17570*	Similar to Two-component response regulator-like PRR73	✓	×	✓	×
Os06g0564500	*LOC_Os06g36840*	O-acetylserine (thiol) lyase	✓	×	×	✓
Os11g0112900	*LOC_Os11g02159*	Hypothetical conserved gene	✓	×	×	✓
Os10g0442100	*LOC_Os10g30550*	tRNA methyltransferase	✓	×	×	×
Os11g0526900	*LOC_Os11g32369*	Non-protein coding transcript	✓	×	×	×
Os03g0562000	*LOC_Os03g36419*	Expressed protein	×	×	×	✓
Os07g0203950	*None*	Non-protein coding transcript	×	×	✓	×
Os07g0676200	*None*	Non-protein coding transcript	×	×	✓	✓
Os12g0137200	*LOC_Os12g04260*	Similar to Saccharopine dehydrogenase family protein, expressed	×	×	✓	✓
Os04g0675800	*LOC_Os04g57920*	Similar to H0103C06.10 protein	×	×	✓	✓

A3SS: Alternative 3′ splice site; **A5SS:** Alternative 5′ splice site; **SE:** Skipped Exon; **RI:** Retained Intron

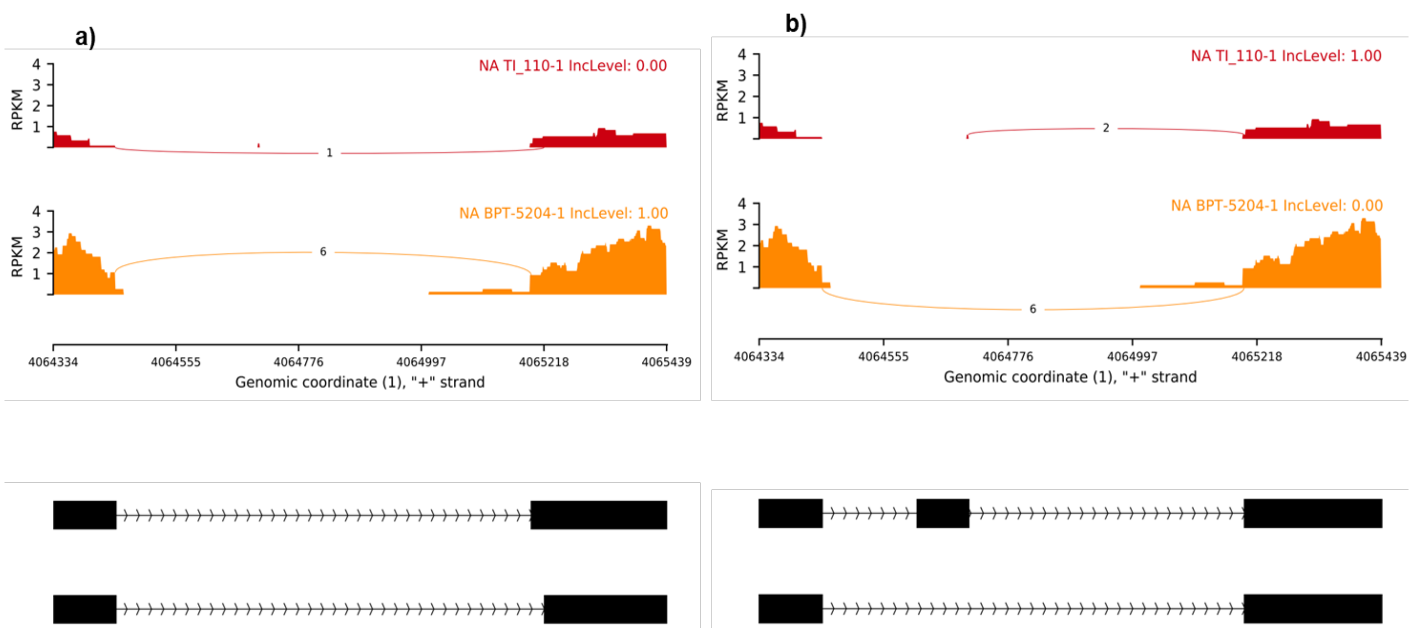

Figure 1: Two transcripts of gene, *Os01g0178200* produced by alternative splicing a) by alternative 3′ splice site and b) by skipped exon mechanism

Remarkably, upon comparison of splicing data of CPE-109 with BPT-5204 and CPE-110 with BPT-5204, we found three common genes namely, *Os07g0406600* encoded to DDHD domain containing protein, *Os10g0442100* encoded to tRNA methyltransferase and *Os04g0675800* encoded to similar to H0103C06.10 proteins (**Table 2 and 4**), generated more than two transcripts *via* alternative splicing, determining its crucial role in complete panicle exsertion. Further, evaluating the data of these three differentially genes, we found DDHD domain containing protein (*Os07g0406600*) upregulated in both CPE-109

(log_2FC=+1.69) and CPE-110 (log_2FC=+1.79) while similar to H0103C06.10 protein (*Os04g0675800*) was down regulated in both CPE-109 (log_2FC=-0.80) and CPE-110 (log_2FC=-0.64). The gene *Os10g0442100* revealed genotype dependent expression response, it was downregulated in CPE-109 (log_2FC=-0.24) while upregulated in CPE-110 (log_2FC=+0.89). In rice, Dong *et al.,* (2012) reported alternatively spliced genes encoding to SR proteins (critical regulators of Zn, Mn, and P nutrition) regulates P uptake and remobilization between leaves and shoots of rice. Thus, in our study, alternatively spliced genes, *Os07g0406600* (DDHD domain containing protein), and *Os04g0675800* (similar to H0103C06.10 proteins) determining its crucial role in complete panicle exsertion.

Alternative splicing has been thoroughly studied in rice for various traits. Yu *et al.,* 2018 studied grain size related parameters and executed characterization of a QTL for grain length *OsLG3b*, encoding a MADS-box transcription factor 1 (*OsMADS1*). Candidate gene association revealed six SNPs in *OsLG3b* region responsible for AS and associated with the levels of gene expression during panicle and seed development. Lui *et al.,* 2022 identified that AS is involved in grain size 3 *GS3* isoforms. *GS3.1* accounting for 50% total transcripts encodes the full-length protein and *GS3.2*, 40% of total transcripts, generate truncated proteins due to a 14 bp intronic sequence retention. Grain size is observed to be decreased in overexpressed lines for *GS3.1* but in *GS3.2*, no significant effect was observed. Also, due to the competitive binding to intermediate gene, *GS3.2* disrupts *GS3.1* signaling. So, it is evident that AS has regulatory role for maintaining the transcripts spatiotemporally. Deep rooting, a crucial parameter for nutrient use efficiency for climate resilience in rice has been studied for AS regulation through RNA-seq. The Intron Retention (IR) in *OsPIN1* contributes to increased root depth in response to drought stress by altering the polar transport of auxin (Wei *et al.,* 2020). Additionally, AS in the 3' untranslated region (UTR) of Rice Nutrition Response and Root Growth (NRR) pre-mRNA modifies gene expression in roots during macronutrient deficiency, thereby influencing root architecture (Zhang *et al.,* 2012). The variations in pre-mRNA splicing has been recently analyzed genome-wide in rice for salinity tolerance. Under the salt stress conditions, two candidate genes with splice variants, *OsNUC1* and *OsRAD23* exhibited differences between the variants for shoot growth in rice (Yu *et al.,* 2021).

In our study, first time we have reported the role of AS in panicle for CPE. We report highly differential expressed alternatively spliced variants commonly expressed in two mutant lines exhibiting complete panicle exertion as compared to BPT-5204. These genes may be involved in the regulation or molecular mechanism of CPE. The results can be further confirmed through gene expression studies. Accordingly, the differentially expressed AS isoforms can be associated with CPE by using functional characterization techniques like overexpression or genome editing. Additionally, functional characterization efforts can be complemented by downstream analyses, including transcriptomic and proteomic profiling, to unravel the molecular pathways and networks influenced by the identified AS isoforms. These comprehensive analyses will provide a holistic understanding of the regulatory mechanisms underlying complete panicle exertion and the intricate interplay between alternative splicing and gene expression in this context.

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Assessment of the Effects of Gamma Radiation on Qualitative and Quantitative Traits of Red Rice (*Oryza sativa* L.) Variety MO 4

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Abstract

Healthy seeds of red rice variety (Bhadra-MO 4) were exposed to different doses of gamma radiation at 15, 25, 35 and 45kR at Bhabha Atomic Research Centre, Mumbai, India. In M_1 generation, 15kR and 25kR doses did not reduce the seed germination and its percentage. LD_{50} was found at 35kR dose, where seed germination was 51%, while at 45kR dose killed most of the seeds and the plant survival rate was reduced drastically (27%) as compared to the control (97%). Increased mean and variability were noticed in the number of productive tillers per plant, number of grains and filled grains per panicle and grain yield per plot at 15 and 25kR doses, meanwhile at 35kR dose exhibited reduced mean and increased quantitative variability and at 45kR dose showed decreased mean and variability for all the traits. Lower doses (15 and 25kR) of gamma radiation could be effectively used in mutation breeding for red rice crop improvement, which induces the stimulatory effect on grain yield.

Key words: Red rice, Gamma irradiation, LD_{50}, Genetic variation, Quantitative traits

Introduction

India is the world's second largest producer of rice and the largest exporter of rice in the world. In coastal region of Karnataka, red rice with medium/long bold grain type varieties are very popular and people still prefer red rice varieties for their daily consumption because of excellent cooking and eating qualities in addition to the nutritional values. Many traditional rice varieties along with improved red rice varieties are being cultivated in the farmer's fields. Because of growing the same variety in the same region over 25 years farmers are not getting profitable yield due to fluctuating trends in rainfall, temperature, humidity and observed genetic variability in base population in the coastal zone.

Most crop improvement programmes on rice are generally focused on breeding for higher yield. But in recent decades, development of nutrient enriched rice varieties with improved cooking qualities has become the most important objective, next to yield enhancement (Krishnamrutha *et al.,* 2023). The induction of mutations has been accepted as a useful tool in the plant breeding programmes. One of the chief advantages of mutation breeding is its ability to improve a single feature in a variety without significantly altering desirable genetic makeup of agronomic traits. Gamma rays were effectively utilized to develop semi-dwarf mutants of cultivars such as Basmati 370 (Deus *et al*., 2020) and in Japan, rice variety *Reimei* (gamma ray mutant) was one of the first allele sources used for the development of dwarf rice cultivars (Futsuhara *et al*., 1967). T-DNA insertion (Chern *et al*., 2007), RNA interference (Qiao *et al*., 2011) and recently CRISPR/ Cas9 (Han *et al*.,

2019) induced mutations were used to develop semi-dwarf cultivars in rice.

High doses induce physiological injuries which cause the death of a plant and therefore, most effective dose that induces high variability at morphological as well as genetic level needs to be identified. Therefore, the experiment was conducted to determine the effects of different doses of gamma radiations on seed germination, plant survival and also to find out LD_{50} in M_1 generation of red rice variety. The present investigation was also aimed to assess the genetic variability in M_4 generation for further selection of superior mutants with beneficial variation in advanced generation.

Materials and Methods

Bhadra (MO 4) is semi dwarf high yielding (45-50q/ha), medium bold red rice variety that matures in 130-135 days. 200 healthy seeds of this variety were irradiated at 4 doses of gamma rays *viz.* 15, 25,35 and 45kR using ^{60}CO source at Bhabha Atomic Research Centre, (BARC) Mumbai, India.

Plant Material

M_1 generation

200 irradiated seeds of each treatment of red rice variety were sown in their respective nursery beds along with untreated parent seeds as Check to raise the M_1 generation at Zonal Agricultural and Horticultural Research Station, Brahmavar in *kharif* 2019. Seed germination was recorded right from the emergence of the first shoot and the it's percentage was calculated by counting the germinated seedlings emerged in each nursery bed per total number of seeds sown, multiplied by hundred and seedling survival was assessed based on number of plants that reached transplanting age (25 days after sowing). After 25 days of sowing, healthy seedlings of M_1 Mutants along with untreated parent as a check were transplanted separately in the main field with 15 cm × 10 cm spacing in 2 meter square area. Data on plant height (cm), number of productive tillers per plant, panicle length (cm), number of grains per panicle and grain yield per plot (gm) were collected on each plant in each treatment including parent MO 4.

M_4 generation

Plant to progeny method was followed to forward the individual plants from M_1 (2019**)** to M_2 (2020). Plants with semi-dwarf, earliness and medium bold red grain type that were primarily selected and forwarded to M_3 (2021**)** from each treatments (15, 25, 35 and 45 kR) and mutants showing severe diseases incidence like false smut, blast, brown leaf spot, lodging type were rejected. Healthy plant attributing good agronomic traits compared with the parent were selected and forwarded to M_4 generation. For the present study 37, 43, 36 and 31 superior M_4 (2022**)** mutants were selected from each treatment 15, 25, 35 and 45kR respectively and utilised to estimate the Genetic Variability for yield and yield attributing traits in superior mutants. All the above said healthy superior mutants based on the yield and yield attributing traits were transplanted in Randomized Complete Block Design with two replications along with untreated parent Check following 15 cm between rows 10cm between plant spacing during *kharif* 2022 in $2mt^2$ areas. Data on plant height (cm), number of productive tillers per plant, number of filled grains per panicle, panicle length (cm) and grain yield per plot (gm) were collected from 10 randomly selected plants of each replication.

Results and Discussions

Effect of gamma radiations on germination and plant survival in M_1 mutants:

Gamma rays influence plant growth and development by inducing cytological, genetical, physiological and morphogenetic changes in cells and the higher doses of gamma rays will usually inhibit the seed germination and plant survival in rice (Soriano, 1961). The impact of gamma radiation on red rice seed germination and plant survival percentages drastically reduced with increasing doses, maximum decrease in seed germination (38%) was noted at 45kR followed by 35kR where germination percentage was 51 and the lower doses affected least on seed germination percentage (93.5 and 90 at 15kR and 25kR dose respectively). Similarly, majority of the seedlings from the seeds irradiated with 15kR (82.5%) and 25kR (77%) survived, but there was marked decrease in plant survival at 35kR (44.5%) and only 27% plant survived at 45kR as compared with control (97%) (**Table 1 and Figure 1**). Similar results were also seen by Mohammed Jiya *et al.,* (2018) who reported that the decrease in seed germination percentage with increasing doses might be attributed to the disturbance at cellular as well as physiological levels. Mushtaq *et al.,* (2015) observed the consistent decrease in survival percentage with the increasing intensity of gamma radiations. In the present investigation, LD_{50} was found at 35kR dose, where seed germination recorded 51%.

Table 1: Effect of gamma radiations on germination and plant survival in M_1 mutants

Varieties	Gamma rays treatments	M_0-All treated seeds were sown in nursery bed	Germination		M_1-Indiviusal plants transplanted in main field	
			No.	%	No of Plant survival	Plant survival%
Parent MO 4	untreated	200	200	100	194	97
MO 4	15Kr	200	187	93.5	165	82.5
	25Kr	200	180	90	154	77
	35Kr	200	102	51	89	44.5
	45Kr	200	76	38	54	27

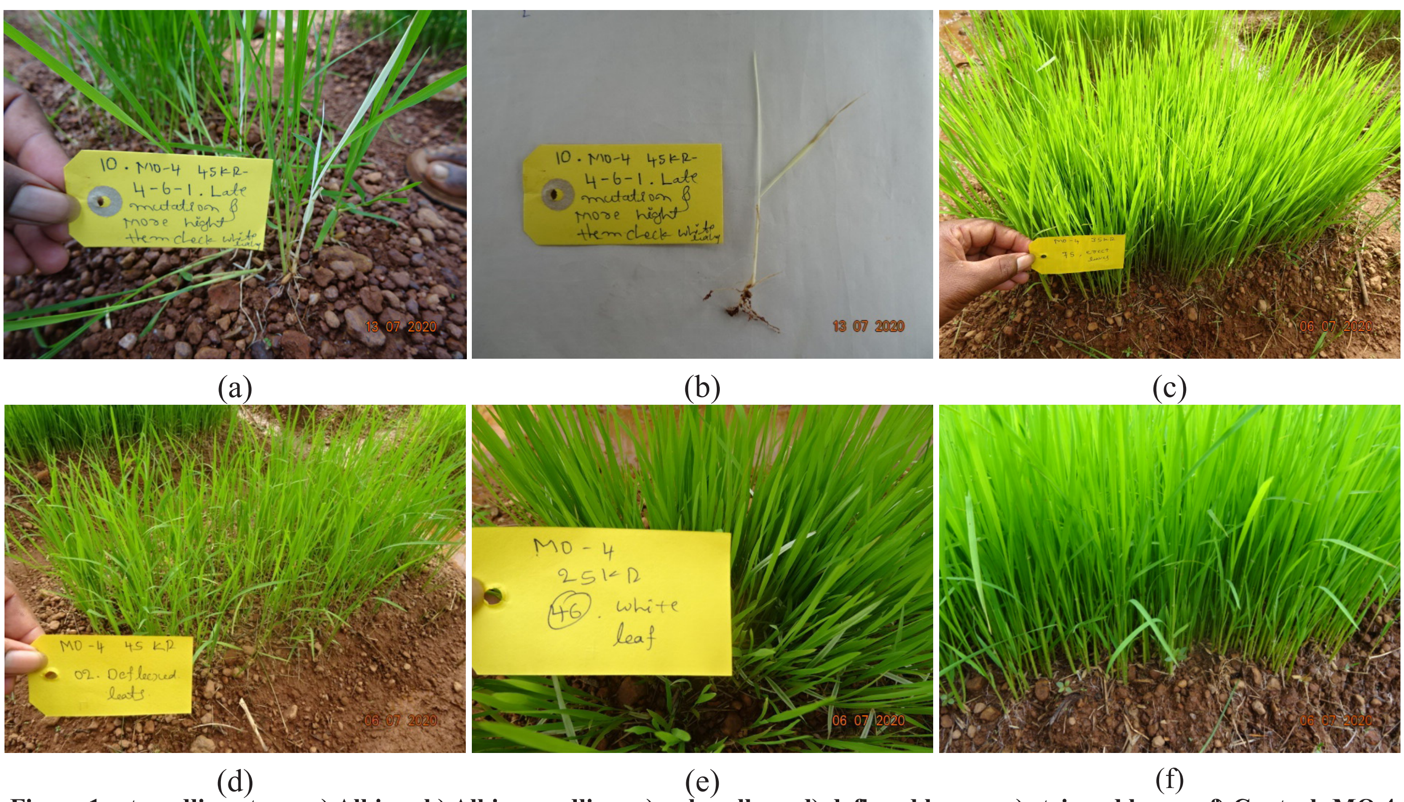

Figure 1: at seedling stage: a) Albino; b) Albino seedling; c) pale yellow; d) deflexed leaves; e) stripped leaves; f) Control- MO 4

Induced variations in M_1 generation

All the doses of gamma radiations exhibited wide range of variations for plant height, number of productive tillers per plant, panicle length, number of filled grains per panicle and grain yield per plot as compared to the untreated parent **(Table 2)**, indicating gamma radiation induces wide of variation in all the treatments in red rice variety.

Table 2: Range values of qualitative and quantitative traits in M_1 generation after different doses of gamma radiations

Characters	Control	15kR	25kR	35kR	45kR
Plant height (cm)	78-83	70-95	61-98	53-84	53-80
Panicle length (cm)	18-22	12-21	16-27	12-25	8-15
No. of Productive tillers/plant	18-20	8-19	4-25	2-24	2-8
No. of grains/ panicle	126-160	108-162	103-165	71-171	36-98
No. of filled grains/ panicle	93-150	55-158	42-162	22-170	8-49
Grain yield/2 mt^2 (gm)	960-1270	800-1298	780-1297	685-1270	540-850

Retardation of growth process is one of the most common responses of plants subjected to ionizing radiation. Mean value of plant height was reduced (72.41 cm) at higher (35kR) doses of irradiation, but a slight stimulating effect was observed at the lowest dose of irradiation *i.e.,* some of the plants at 15kR responded positively to gamma irradiation and showed a slight increase in average plant height (80.54 cm) in comparison to the control plants (80.18 cm). Lesser plant height (Dwarf plants) was observed at higher dose of irradiation (45 kR) (67.33 cm) **(Table 3).** The adversely affected plant height was also reported by Tabasum *et al.,* (2011) and Mushtaq *et al.,* (2015) who opined that the irradiation of seeds with high doses of gamma rays might have disturbed the synthesis of proteins, hormone balance, leaf gas-exchange, water exchange and enzyme activity to cause adverse effects on plant height.

Plants exposed to at 15kR and 25kR gamma irradiation significantly produced highest average mean (18.39, 18.21, 153.15, 144.27, 132.42 and 129.32) and decreased variability (8.83, 26.18, 7.44 and 11.13) for number of productive tillers per plant, number of grains and filled grains per panicle than the control, but decreased mean (12.46, 107.23 and 114.88) and increased variability (39.70, 22.70 and 41.18) was observed for these above traits at 35kR. Higher dose (45kR) of gamma radiation caused marked decreased in average mean and variability in number of productive tillers per plant, number of grains and filled grains per panicle **(Table 3)**. The lowest dose furthermore offered maximum potential for increasing the number of productive tillers/ plant and number of grains/panicle which can be an economically useful character. The present results are in agreement with Jiya *et al.,* (2018) who observed gamma irradiated plants significantly ($P \leq 0.05$) produced higher number of tillers.

In the present study, average mean of panicle length was not affected by lower doses (15, 25 and 35kR) of gamma radiation and the negative effect of gamma rays on panicle length was noticed at higher dose and it's mean was decreased (11.33cm) with the increasing (at 45kR) intensity of gamma radiations **(Table 3)**. The present findings are in accordance with Degwy (2013) and Ramchander *et al*., (2015) who reported that M_4 irradiated mutants had shorter panicle length than control.

Average mean values and variability of grain yield per 2 square meter shown improvement over control (1036.10gm/ ($2mt^2$). The mean grain yield per 2 square meter at 15kR (1131.19 gm), 25kR (1141.80 gm) and at 35kR (1131.21 gm). The maximum decrease in the average values of grain yield per 2 square meter was

Table 3: Mean, Standard deviation, coefficient of variation of qualitative and quantitative traits in M_1 generation after different doses of gamma radiations

Treat-ments	Plant height (cm)			Panicle length (cm)			No. of Productive tillers/plant			No. of grains/panicle			No. of filled grains/ panicle			Grain yield/2 mt^2 (gm)		
	Mean	±SD	CV	Mean	±SD	CV	Mean	±SD	CV	Mean	±SD	CV	Mean	±SD	CV	Mean	±SD	CV
Control	80.18	1.83	2.28	20.73	1.48	7.16	18.15	0.53	2.90	149.50	10.38	6.94	127.00	15.92	12.53	1036.10	77.48	7.48
15kR	80.54	6.58	8.17	20.04	1.85	9.23	18.39	1.62	8.83	153.15	11.39	7.44	132.42	23.46	17.72	1131.19	116.64	10.31
25kR	76.26	8.37	10.98	20.03	1.46	7.28	18.21	4.77	26.18	144.27	16.06	11.13	129.32	33.02	25.54	1141.80	128.63	11.27
35kR	72.41	7.59	10.49	20.08	2.04	10.18	12.46	4.95	39.70	107.23	24.34	22.70	114.88	41.18	35.85	1131.23	126.77	11.21
45kR	67.33	6.06	9.00	11.33	1.01	8.92	5.91	1.52	25.81	89.13	8.77	9.84	44.04	6.21	14.09	627.16	49.76	7.93

observed at 45kR of radiation dose (627.16 gm) with respect to the control **(Table 3)**. The present results are in agreement with the findings of Iqbal *et al.,* (1975). The little increase in rice seed yield occurred mainly in lower dose treatments which enhanced tillering. The reduction in seed yield may be in terms of small sized panicle, reduced number of grains/ panicle, reduced the number of weight of individual seeds and sterile grains occurred more due effect of gamma doses.

Gamma radiation induced variations

Most treated M_1 plants exhibited retarded growth (lanky and twisted plant) at early seedling stage due to the effects of gamma rays used, but majority of them recovered and reached maturity as the parent type. Most common variations observed in M_2 and M_3 generation were albino, xantha, striped, bushy plant, thin leaves, light yellowish leaves, striped leaves in seedling stage, node/internodes pigmentation and stunted growth, difference in plant height, lodging, erect and spreading type, pale green and drooping/ vertical leaves, clustered spikelet, awned, seed tip pigmented and sterile seed were observed in different stages (**Figure 1 and 2)**.

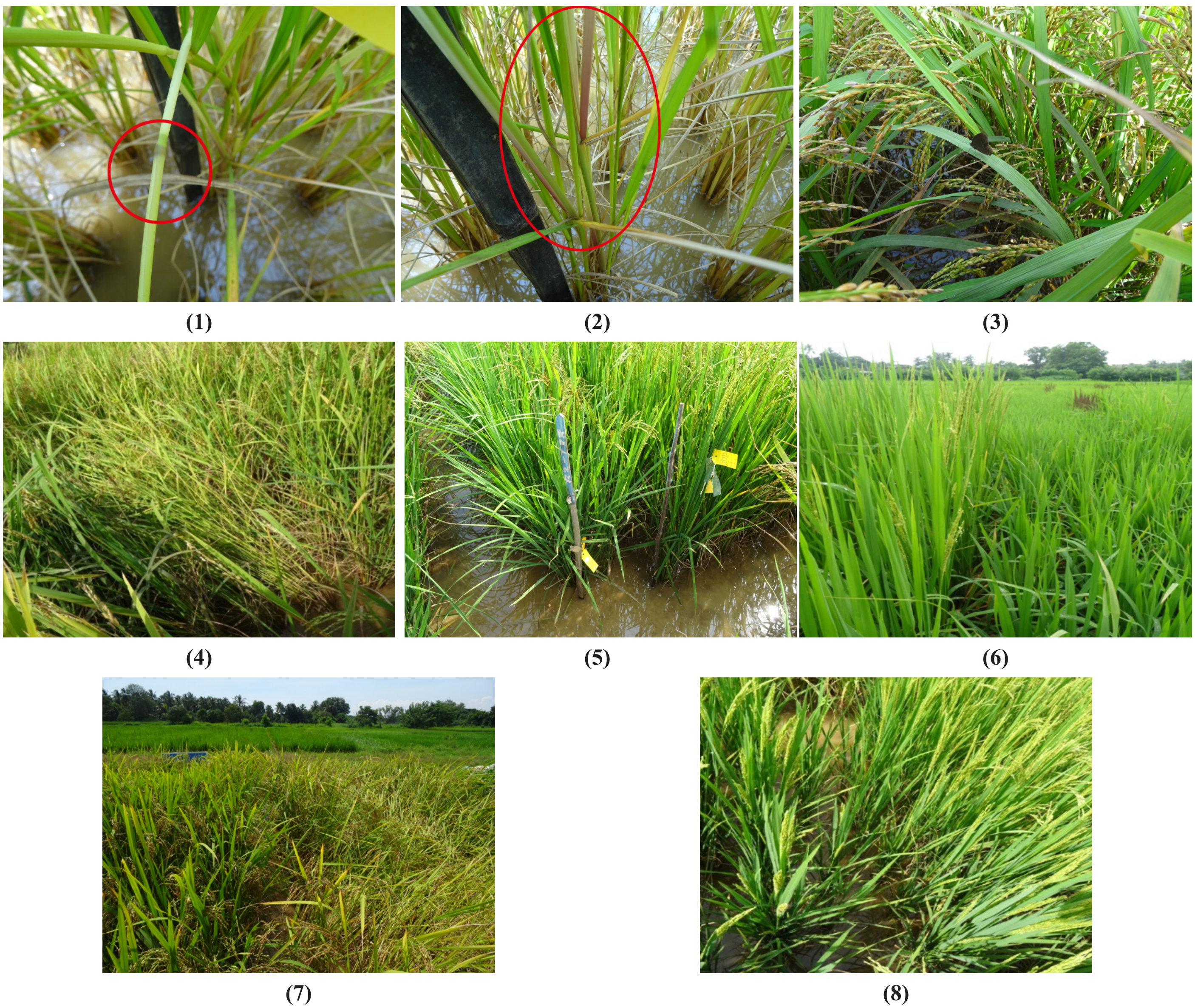

Figure 2: at main field: 1) Nodal Pigmentation; 2) Internode pigmentation; 3) Broad leaves; 4) Thin stem; 5) Spreading; 6) Early maturity and height difference; 7) lodging; 8) Stunted growth

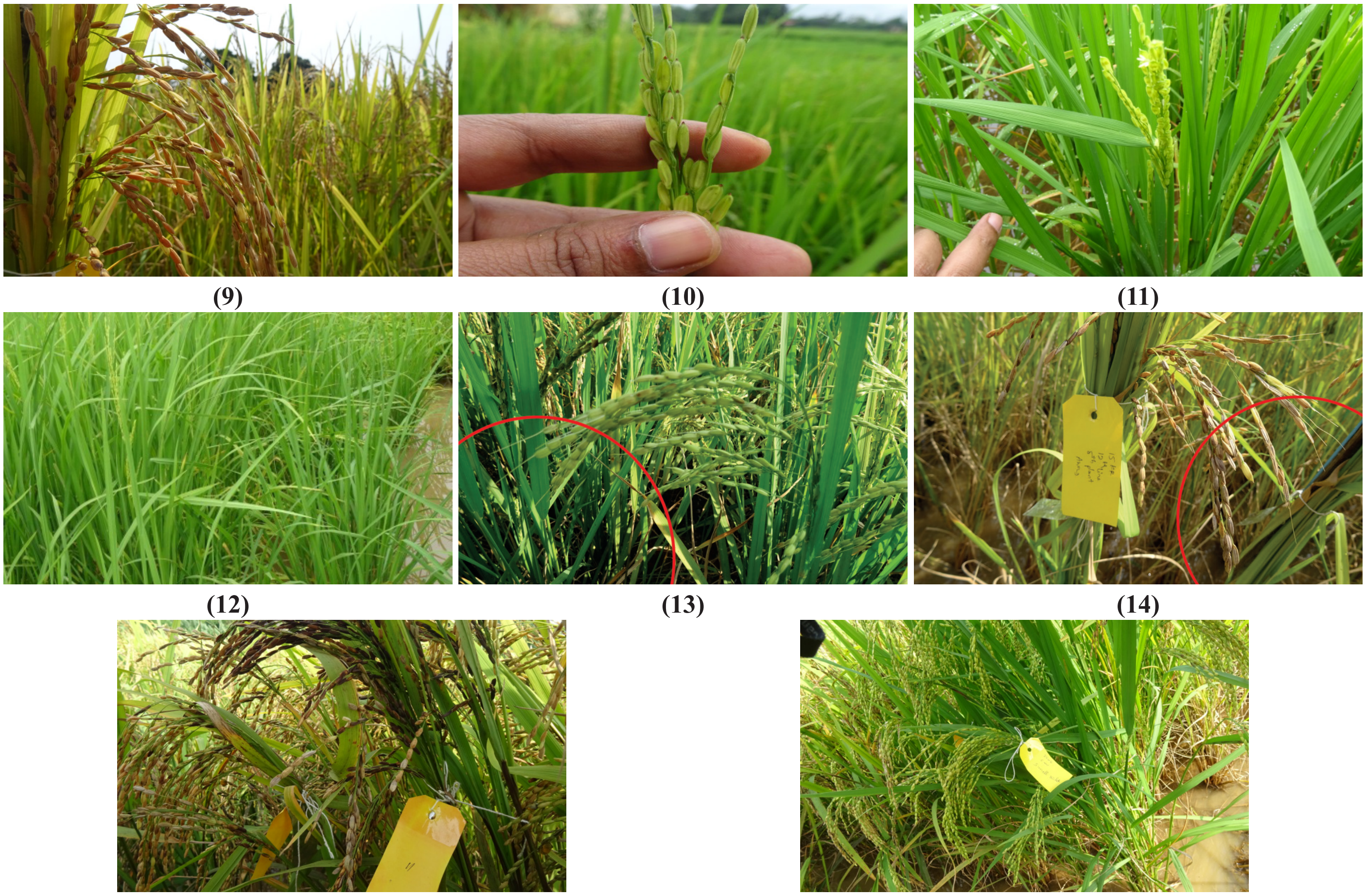

Figure 2: at main field: **9) Long and seed husk colour change; 10) seed tip pigmented; 11) clustered spikelet; 12) drooping leaves; 13 & 14) Awns; 15) Change in seed husk colour; 16) Small seeds**

The genetic variations of thin leaves, striped leaves, node/internode pigmentation and pale green and drooping/ vertical leaves and the mutants observed in the M_4 generation are shown in **Figure 3**.

Figure 3: A) early maturity; B) semi erect/ semi Spreading; C) Difference in plant height compared with control; D) Field view in M_4 generation

Induced variations in M_4 generation

Mean sum of squares due to different gamma radiations treatments were significant for all the traits studied indicating existence of considerable variability in the treatments imposed for the study **(Table 4)**. A wide range was observed for all the traits studied, indicating the scope for selecting the high yielding mutants from these different treatments **(Table 5)**.

Table 4: Mean sum of squares for qualitative and quantitative traits in M_4 mutants

Source of variation	Treatment	Df	Plant height (cm)	Panicle length (cm)	Productive tillers/ plant	No. of filled grains/ panicle	Grain yield/ 2 mt^2plot (gm)
Replication	15kR	2	78.01	0.33	1.59	393.80	299380.26
	25kR	2	88	0.73	1.92	441.01	50688
	35kR	2	66.22	1.63	0.86	24.99	27479.40
	45kR	2	107.64	3.51	6.89	102.51	14400
Mutants	15kR	38	5373.85**	1223.28**	1146.91**	25302.49**	16803660.11**
	25kR	44	9916.09**	598.09**	465.49**	60622.21**	13656076.82**
	35kR	37	6740.78**	448.54**	686.05	82238.49**	13893283.59**
	45kR	32	5438.86**	433.61**	845.23**	22555.73**	6529572.44**
Error	15kR	37	1608.49	51.17	76.91	2820.70	471257.74
	25kR	43	1781	66.27	42.58	4025.49	837179
	35kR	36	1216.78	92.86	95.14	4813.51	503251.59
	45kR	31	1165.86	66.98	128.61	1896.98	245588

**- Significant at 5% probability level

The differences between genotypic coefficient of variation and phenotypic coefficient of variation were found narrow for panicle length (19.82 and 18.94) (12.69 and 11.32), number of productive tillers per plant (21.88 and 20.42) (14.57 and 13.26), number of filled grains per panicle (25.85 and 24.15) (38.57 and 36.15) and grain yield per plot (2mt^2) (38.87 and 37.76) (31.35 and 30.09) at 15 and 25kR treatment respectively **(Table 5)** indicating that these traits were least affected by environment and selection based on phenotype would be rewarding. Similar trend was noticed for all traits observed at 35 and 45kR treatments. The findings were also in accordance with the observations of Teja *et al.,* (2023).

Table 5: Mean, range and genetic variability for qualitative and quantitative traits in M_4 mutants

Sl. No.	Characters	Treatment	Mean ± SEm	Range	Coefficient of variation (%)		GA	GAM (%)	h^2 broad sense (%)
					PCV	GCV			
1	Plant height (cm)	15kR	81.59±4.66	61-95.5	11.78	8.58	10.49	12.86	53
		25kR	76.68±4.55	57-93.5	15.06	12.51	16.40	21.39	69
		35kR	80.95±4.11	62-95.5	12.84	10.64	14.71	18.17	69
		45kR	79.80±4.34	62-95	12.77	10.19	13.38	16.77	64
2	Panicle length (cm)	15kR	20.67±0.83	9.5-29	19.82	18.99	7.74	37.47	92
		25kR	21.68±0.88	14.5-25	12.69	11.32	4.51	20.81	80
		35kR	19.28±1.14	14-24	14.06	11.33	3.63	18.80	65
		45kR	18.33±1.04	11-22	15.29	13.02	4.19	22.84	72

3	No. of productive tillers/ plant	15kR	18.36±1.02	11-27	21.88	20.42	7.21	39.27	87
		25kR	16.51±0.70	12-21	14.57	13.26	4.11	24.87	83
		35kR	16.84±1.15	11-24	19.33	16.75	5.03	29.88	75
		45kR	15.36±1.44	8-24	25.45	21.72	5.87	38.19	73
4	No. of filled grains/ panicle	15kR	113.49±6.17	83-162	16.97	15.13	31.53	27.78	79
		25kR	104.94±6.84	57-161	25.85	24.15	48.76	46.47	87
		35kR	88.99±8.18	39-157	38.57	36.32	62.68	70.44	89
		45kR	59.39±5.53	29-113	32.95	30.21	33.88	57.04	84
5	Grain yield/ 2 mt^2 plot (gm)	15kR	1227.16±79.80	349-2325	38.87	37.76	927.48	75.58	94
		25kR	1325.33±82.74	383-2205	31.35	30.09	788.79	59.47	92
		35kR	1045.27±83.60	371-2043	42.22	40.67	843.80	80.73	93
		45kR	738.34±62.94	280-1355	44.09	42.41	620.51	84.04	93

GCV- Genotypic coefficient of variation; PCV- Phenotypic coefficient of variation

GA-Genetic advance; GAM- Genetic advance as per cent of mean; h^2 b.s- Heritability in broad sense

High heritability coupled with moderate to high genetic advance for all the traits in all the treatments indicated predominance of additive gene action controlling these characters and the selection based on phenotypic performance would be effective against above traits.

High heritability along with high genetic advance as percent over mean was recorded for panicle length, number of productive tillers per plant, number of filled grains per panicle and grain yield per plot ($2mt^2$) in all the treatments (15, 25, 35 and 45kR) of gamma radiation, reflecting the presence of additive gene action for the expression of above traits which is fixable for next generations. At 15, 25, 35 and 45kR radiation doses plant height exhibited high values of heritability coupled with moderate genetic advance as percent of the mean suggests that the selection for improvement of these characters may be rewarding.

Conclusion

Higher gamma radiation dose (45kR) has affected much on seed germination, plant survival rate, qualitative and quantitative traits than the lower dose (15kR). Hence, one has to understand the fact that plant lethality and morpho-genetical damage often increase with increasing doses, and that the intermediate dose has to be taken for good results. From the present study 15 and 25kR doses of gamma radiation are most suitable for inducing variation in red rice.

In M_4 generation, mutants from 15, 25 and 35kR treatments exhibited high heritability coupled with genetic advance as percent of the mean for plant height (cm), panicle length (cm), number of productive tillers per plant, number of grains/filled grains per panicle and grain yield per plot (gm) which revealed that the selection based on phenotypic performance of these traits would be ideal for identification of superior mutants in next generation.

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Genetic Parameters and Association Studies for Yield and Grain Quality Traits in Rice Genotypes Derived from Distant Crosses

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Abstract

In the current study, 49 rice genotypes were studied for thirteen yield and grain quality traits to estimate the variability parameters and character associations. Number of filled grains per panicle and grain yield/plant recorded high phenotypic and genotypic coefficients of variation and most of the characters studied manifested high heritability estimates except for ear bearing tillers/plant and kernel breadth. Grain yield/plant exhibited high estimates for all genetic parameters indicating the predominance of additive gene action in the inheritance of this trait. The results of correlations revealed that, days to 50% flowering, plant height, ear bearing tillers/plant, number of primary branches/panicle, number of filled grains/panicle and test weight exhibited positive and significant correlation with grain yield. The outcome of path coefficient analysis concluded that days to 50% flowering, plant height, ear bearing tillers/plant, number of primary branches/panicle, number of filled grains/panicle and test weight manifested positive direct effects as well as significant positive association with grain yield, and hence direct selection of these traits would improve grain yield/plant.

Key words: Rice, variability, correlation, distant crosses, yield components

Introduction

Rice is the world's most important staple food crop, accounting for nearly half of the global population's dietary intake. Rice is grown on 44.16 million hectares in India, with an annual production of 118.87 million tons and an average productivity of 2.65 tons of milled rice per hectare (Ministry of Agriculture, 2019-20). Modern rice cultivars have limited genetic base which is becoming a major bottleneck for crop improvement efforts. Utilization of crop wild relatives (CWRs) is a promising approach to enhance genetic diversity in cultivated crops for yield and other important characteristics. To address food insecurity, particularly in developing countries, immediate attention must be paid to break the yield plateau. To date, majority of the increased yields have come from manipulating traits to meet future demands, which will necessitate the use of novel genetic resources. Many traits have been identified as possessing the potential to improve yield and high expression of these traits has been found in germplasm collections. For planning and execution of a successful breeding programme, the most essential pre-requisite is the availability of desirable genetic variability. Knowledge of the relationship between grain yield and its component characters will be useful for improving the grain yield.

Materials and Methods

The present investigation was conducted at Agricultural College Farm, Bapatla of Acharya N. G. Ranga Agricultural University (ANGRAU) during *kharif,* 2021. The experimental material comprised of 49 advanced rice genotypes derived from multiple crosses and back cross breeding material involving popular rice varieties and some wild rice genotypes. The details of the designation and the parentage of the genotypes used in the study are presented in **Table 1.** The experiment was laid out in Simple Lattice Design with two replications. Each genotype was raised in five rows of three-meter length with a spacing of 20 x 15 cm between and within the rows, respectively. Standard agronomic practices and recommended fertilizer doses were adopted for normal crop growth. Data was collected on five plants per replication on 13 yield components and grain quality traits *viz.*, days to 50% flowering, plant height (cm), ear bearing tillers/ plant, flag leaf length (cm), flag leaf width (cm), panicle length (cm), number of primary branches/ panicle, number of fertile grains/panicle, kernel length (mm), kernel breadth (mm), L/B ratio, test weight (g) and grain yield per plant (g) by following standard procedures. Mean data was utilized for statistical

Table 1: Details of the rice genotypes studied in the present investigation

S. No	Genotype	Cross combination	S. No	Genotype	Cross combination
01	BPT 2782	NLR145/MTU2077- released variety used as check			
02	BPT 2841	Swarna / IRGC18195 // MTU1081	26	BPT 3234	BPT5204/Ramappa
03	BPT 2848	RPBio226*1 / IRGC48493	27	BPT 3263	MTU7029 / IRGC18195// MTU1081
04	BPT 2858	RPBio226*1 / IRGC48493	28	BPT 3269	RPBIO226*1 / IRGC23385 // Nidhi / MTU1081
05	BPT 2955	MTU1010/IR50	29	BPT 3270	RPBIO226*1/IRGC23385//Nidhi/MTU1081
06	BPT 3111	MTU7029/ IRGC18195// MTU1081	30	BPT 3276	Cult.011120305 /cult.0910025-7
07	BPT 3136	RPBio226*1/ IRGC48493	31	BPT 3278	RPBio226*1/IRGC48493
08	BPT 3137	RPBio226*1/ IRGC48493	32	BPT 3279	RPBio226*1 /Jarava
09	BPT 3140	MTU7029/IRGC18195 //MTU1081	33	BPT 3281	Cult.01120305/ cult.0910025-7
10	BPT 3141	RPBio226*1/ IRGC30983	34	BPT 3286	Cult.01120305/cult.0910025-7
11	BPT 3143	RPBio2268*1/IRGC48493	35	BPT 3391	Cult.01120305/cult.0910025-7
12	BPT 3145	RPBio226*1/IRGC48493	36	BPT 3401	Cult.01120305/cult.0910025-7
13	BPT 3149	RPBIO226*1/IRGC23385//Nidhi/MTU1081	37	BPT 3409	RPBIO226*1/IRGC23385//Nidhi/MTU1081
14	BPT 3151	RPBio226*1/Jarava	38	BPT 3415	MTU7029/IRGC18195//MTU1081
15	BPT 3152	BPT5204*2/ *O. longistaminata*// B-95-1/SwarnaSub-1	39	BPT 3520	Cult.01120305/Cult.0910025-7
16	BPT 3157	MTU7029/IRGC18195//MTU1081	40	BPT 3521	Cult.01120305/Cult.0910025-7
17	BPT 3158	BPT5204*2/ *O. longistaminata*// B-95-1/SwarnaSub-1	41	BPT 3522	MTU7029/IRGC18195//MTU1081
18	BPT 3159	Cult.0910023/ RPBio226*1// Cult. 09100238// BPT5204/Tetep	42	BPT 3523	Cult.01120305/Cult.0910025-7
19	BPT 3164	B-95-1/RPHR1005//B-95-1	43	BPT 3524	MTU7029/ IRGC18195// MTU1081
20	BPT 3166	BPT5204*2/*O. longistaminata*// B-95-1/SwarnaSub-1	44	BPT 3525	RPBIO226*1/ IRGC30983
21	BPT 3167	RPBio226*1/ IRGC18195//MTU1081	45	BPT 3526	Cult.01120305/ Cult.0910025-7
22	BPT 3178	Cult.01120305/ cult.0910025-7	46	BPT 3527	MTU7029/ IRGC18195// /MTU1081
23	BPT 3217	Cult.01120305/ cult.0910025-7	47	BPT 3528	MTU7029/ IRGC18195//MTU1081
24	BPT 3220	Cult.01120305/ cult.0910025-7	48	BPT 3529	MTU7029 /IRGC18195//MTU1081
25	BPT 3227	(RPBio226*1/IRGC23385) // (Nidhi/MTU1081)	49	BPT 3530	MTU7029 /IRGC18195//MTU1081

analysis. The genotypic and phenotypic variance was calculated as per the formulae of Singh and Chaudhary (1977) and classified as described by Sivasubramanian and Madhava Menon (1973). Estimate of heritability inbroad sense (h^2(b)) and genetic advance as percent of mean were calculated by the formulae given by Johnson *et al.,* (1955). Phenotypic and genotypic correlations were calculated by using the formulae given by Falconer (1964). Path coefficient analysis proposed by Wright (1921) and developed by Dewey and Lu (1959) was used to compute the direct and indirect contribution of various traits to yield.

Results and Discussions

Analysis of variance (ANOVA) for morphological, yield attributing and grain quality traits revealed highly significant mean squares due to genotypes for all traits, indicating the existence of sufficient variation among the genotypes for morphological and yield component traits studied. Estimates of mean, range, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (h^2 broad sense) and genetic advance as percent of mean (GAM) for morphological and yield component traits studied in the current study were depicted in **Table 2.** Results on performance *per se* for morphological and yield related traits of the rice varieties studied, genotypes BPT 3276, BPT 3137, BPT 3151, BPT 3152, BPT 2841, BPT 3523 and BPT 3525 exhibited high grain yield accompanied by better yield attributing traits. All these entries recorded more flag leaf length, panicle length, more number of filled grains/panicle and test weight resulting in production of higher grain yield.

Table 2: Mean, range and variability parameters for morphological and yield related traits in rice

S. No	Character	Mean	Range		Coefficient of variation		Heritability (%)	Genetic advance as percent of mean
			Minimum	Maximum	GCV (%)	PCV (%)		
1	Days to 50% flowering	95.8	87	113.0	7.6	7.9	91.2	15.0
2	Plant height (cm)	134.4	105.3	169.0	10.9	11.5	90.5	21.5
3	Ear bearing tillers/ plant	8.24	6.0	10.5	7.8	9.9	15.6	3.2
4	Flag leaf length (cm)	40.0	24.6	56.6	19.9	19.9	99.4	40.9
5	Flag leaf width (cm)	2.63	2.2	4.2	15.2	16.1	89.0	29.4
6	Panicle length (cm)	25.7	22.1	32.3	8.1	9.1	80.0	15.0
7	Number of primary branches/ panicle	13.5	10.0	18.0	12.9	13.5	92.5	25.7
8	Number of filled grains/ panicle	198	142.9	293.0	21.0	21.6	94.4	12.7
9	Kernel length (mm)	5.71	4.88	6.4	8.6	8.6	99.2	17.6
10	Kernel breadth (mm)	1.98	1.69	2.51	19.6	21.1	13. 1	7.4
11	L/B ratio	2.91	2.6	3.36	13.6	16.5	68.1	23.1
12	Test weight (g)	16.3	12.5	20.0	10.9	11.4	93.2	21.8
13	Grain yield/ plant (g)	24.4	17.1	40.8	21.8	22.0	98.6	44.7

The estimates of phenotypic coefficient of variation for all the characters under study were higher than the estimates of genotypic coefficient of variation. Minimum phenotypic and genotypic coefficient of variations were observed for days to 50% flowering (7.9% and 7.6%) while maximum phenotypic and genotypic coefficient of variation was manifested by grain yield/plant (22.0% and 21.8%) indicating the existence of sufficient variation among the genotypes for potential yield improvement through selection. Other traits *viz.,* number of filled grains/panicle (21.6% and 21.0%) and kernel breadth (21.1% and 19.6%) also recorded high PCV and GCV. Similar findings were previously reported by Singh *et al.,* (2020) and Priyanka *et al.,* (2023) for days to 50% flowering and grain yield/plant.

Heritability is the measure of transmission of characters from generation to generation and estimates of heritability are helpful to the breeder in selecting superior individuals and successfully utilizing them in breeding programme(s) (Bharathi *et al.,* 2017). Except ear bearing tillers/plant (15.6%) and kernel breadth (13.1%), all other characters under study recorded high heritability estimates. Maximum heritability estimates were recorded for kernel length (99.2%) followed by flag leaf length (99.2%), grain yield/plant (98.6%), number of filled grains/panicle (94.4%), test weight (93.2%), number of primary branches/panicle (92.5%) and days to 50% flowering (91.2%). Similarly, high genetic advance as percent over mean, was manifested by grain yield per plant (44.7) followed by flag leaf length (40.9), flag leaf width (29.4) and number of primary branches per panicle (25.7) whereas ear bearing tillers (3.2) and kernel breadth (7.4) manifested low genetic advance as per cent over mean. These findings are in consonance with earlier reports of Babu (2020) for flag leaf length and flag leaf width; Islam *et al***.,** (2019) for number of primary branches/panicle; Nath and Kole (2021) and Sindhura *et al.,* (2022) for grain yield/plant, test weight and days to 50% flowering. Based on the results of variability parameters, it may be concluded that grain yield/plant exhibited high genotypic and phenotypic coefficients of variation along with high heritability and high genetic advance as per cent of mean whereas the characters *viz.,* flag leaf length, flag leaf width, number of primary branches/panicle and test weight manifested moderate PCV and GCV along with high heritability as well as high genetic advance as per cent of mean suggesting the predominance of additive gene action in the inheritance of these traits. Hence, simple selection will be highly rewarding for improving these characters.

Grain yield exhibited positive and significant correlation with days to 50% flowering (0.208*, 0.225*), plant height (0.201*), ear bearing tillers/plant (0.248*, 0.657**), number of primary branches/panicle (0.241*, 0.572**), number of filled grains/panicle (0.654**, 0.777**) and test weight (0.286**, 0.298**) indicating that grain yield will be improved simultaneously along with these characters **(Table 3)**. As a result, these traits should be prioritized when making selections for increased grain yield. These findings are in harmony with earlier findings of Kavitha *et al.,* (2020) and Nath and Kole (2021) for days to 50% flowering, plant height, number of primary branches/panicle and test weight; Saha *et al.*, (2019) for number of fertile grains/panicle. Further, studies on inter-character association between yield components and quality traits revealed significant and positive correlation of days to 50% flowering with number of primary branches/panicle (0.241*, 0.266**) suggesting that the genotypes possessing late duration manifested more number of primary branches/panicle. Hossain *et al.,* (2018) also reported similar association between the flowering duration and number of primary branches/panicle. Plant height manifested positive correlation with flag leaf length (0.473*, 0.500*), flag leaf width (0.351*, 0.418**), panicle length (0.435**,0.552**), number of filled grains/panicle (0.275**, 0.378**) and kernel length (0.199*, 0.203*) indicating that the genotypes with tall plant stature manifested more flag leaf length and width which produced longer panicles and more number of filled grains per panicle. Similar relationship was earlier reported by Ramya (2021). Flag leaf length and flag leaf width also inter-correlated with each other and both these traits exhibited significant and positive relationship with panicle length, number of filled grains/panicle, kernel breadth and test weight suggesting more flag leaf area of the plant aids in improvement of all these traits. Aditya and Bhartiya (2013) also found similar associations in their studies. Number of ear bearing tillers/plant manifested significant and negative relationship with panicle length (-0.299**), kernel length (-0.331**), L/B ratio (-0.211*) and test weight (- 0.222*) at genotypic level suggesting that the genotypes with less number of tillers possessed longer panicles, slender grains and more test weight. It is interesting to note that number of primary branches/panicle manifested negative correlation with test weight (-0.435**) and significant negative relationship was recorded by kernel breadth with L/B ratio (-0.754**). These results suggest that the genotypes which possessed more number of primary branches/panicle manifested low test weight (slender grain type) and genotypes which possessed bolder grains (more kernel breadth) had less L/B ratio indicating the need for balanced selection while simultaneously improving these traits. Studies by Kumar *et al.,* (2017) and Herawati *et al*., (2021) revealed similar findings for number of ear bearing tillers per plant with panicle length and for number of primary branches/panicle with test weight respectively.

Selection based on characters with positive direct effect along with positive correlation with grain yield/ plant are needed to achieve fruitful results for yield improvement in breeding programmes. The results of path coefficient analysis revealed that number of

Table 3: Phenotypic and genotypic correlation coefficients for morphological and yield related traits in rice

Character		DFF	PH	EBT	FLL	FLW	PL	NPB/P	NFG/P	KL	KB	L/B	TW	GY/P
DFF	rp	1.000	0.059	0.059	-0.101	0.120	0.008	0.241*	0.092	-0.067	0.025	-0.054	0.108	0.208
	rg	1.000	0.067	0.387**	-0.107	0.124	-0.014	0.266**	0.168	-0.070	-0.028	-0.040	0.120	0.225*
PH	rp		1.000	-0.018	0.473**	0.351**	0.435**	0.162	0.275**	0.199*	0.078	0.082	-0.144	0.196
	rg		1.000	0.024	0.500**	0.418**	0.552**	0.178	0.378**	0.203*	0.226*	0.099	-0.133	0.201*
EBT	rp			1.0000	0.037	0.054	-0.186	0.213*	0.215*	-0.140	0.033	-0.108	-0.098	0.248*
	rg			1.0000	0.077	-0.083	-0.299**	0.580**	0.611**	-0.331**	-0.126	-0.211*	-0.222*	0.657*
FLL	rp				1.0000	0.195	0.509**	-0.088	0.204*	-0.033	0.098	-0.063	0.216*	0.044
	rg				1.0000	0.210*	0.575**	-0.092	0.266**	-0.035	0.284**	-0.080	0.222*	0.049
FLW	rp					1.0000	0.395**	0.197	0.110	-0.047	0.164	0.006	0.209*	0.012
	rg					1.0000	0.453**	0.220*	0.179	-0.038	0.488**	0.003	0.232*	0.030
PL	rp						1.0000	0.068	0.177	0.215*	0.091	0.168	-0.112	0.122
	rg						1.0000	0.091	0.193	0.243*	0.215*	0.249*	-0.156	0.141
NPB/P	rp							1.0000	0.264**	-0.115	0.060	-0.030	-0.435**	0.241*
	rg							1.0000	0.316**	-0.118	0.174	-0.037	-0.234*	0.572**
NFG/P	rp								1.0000	0.153	-0.038	0.133	0.018	0.654**
	rg								1.0000	0.198	0.620**	0.001	-0.020	0.777**
KL	rp									1.0000	-0.001	0.543**	0.278**	-0.025
	rg									1.0000	-0.000	0.654**	0.291**	-0.053
KB	rp										1.0000	-0.754**	0.217**	0.060
	rg										1.0000	-0.782**	0.348**	0.084
L/B	rp											1.0000	0.145	-0.033
	rg											1.0000	0.189	-0.050
TW	rp												1.0000	0.286**
	rg												1.0000	0.298**
GY/P	rp													1.0000
	rg													1.0000

***Significant at1 percent level of probability *Significant at5* per cent level of probability

DFF=Daysto50%flowering, **PH:** Plant height (cm), **EBT:** Ear bearing tillers, **FLL:** Flag leaf length (cm), **FLW:** Flag leaf width (cm), **PL:** Panicle length (cm), **NPB/P:** No. of primary branches/panicle, **NFG/P:** No. of fertile grains/panicle, **KL:** Kernel length (mm), **KB:** Kernel breadth (mm), **L/B:** Length/breadth ratio, **TW:** Test weight(g)**, GY/P:** Grain yield/plant (g) filled grains/panicle manifested high positive direct effect (0.679 and 0.607) on grain yield followed by panicle length (0.369 & 0.154), ear bearing tillers/ plant (0.346 & 0.145), plant height (0.197 and 0.293) at both phenotypic and genotypic levels **(Table 4).** Number of primary branches/panicle (0.455) and test weight (0.199) exhibited high positive direct effects at genotypic level. Devi *et al.,* (2017), Saha *et al.,* (2019) and Nath and Kole (2021) also reported similar findings in their studies. High positive direct effects of these traits appeared to be the main factor for their strong association with grain yield per plant. Hence, these traits should be considered as important selection criteria in rice improvement programmes.

Table 4: Direct and indirect effects of morphological and yield related traits on grain yield in rice

Character		DFF	PH	EBT	FLL	FLW	PL	NPB/P	NFG/P	KL	KB	L/B	TW
DFF	G	-0.056	0.023	0.259	0.052	-0.023	-0.005	-0.128	0.126	-0.001	-0.021	0.004	-0.003
	P	0.129	0.014	0.024	0.020	-0.013	0.001	-0.062	0.105	0.002	-0.001	-0.005	-0.004
PH	G	-0.004	0.293	-0.034	-0.236	-0.077	0.202	-0.087	0.137	0.011	0.015	0.007	-0.024
	P	0.009	0.197	-0.005	-0.096	-0.042	0.066	-0.043	0.105	-0.007	-0.001	0.015	0.009
EBT	G	-0.042	-0.029	0.346	0.025	0.019	-0.061	-0.297	0.431	-0.038	0.104	-0.032	0.230
	P	0.026	-0.007	0.145	0.009	-0.004	-0.020	-0.062	0.168	0.005	-0.006	0.004	-0.007
FLL	G	0.006	0.151	-0.019	-0.457	-0.035	0.219	0.037	0.111	-0.004	-0.027	0.013	0.054
	P	-0.013	0.093	-0.007	-0.202	-0.022	0.079	0.018	0.109	0.009	-0.006	0.069	-0.014
FLW	G	-0.007	0.122	-0.036	-0.088	-0.183	0.168	-0.104	0.072	0.002	0.002	0.015	0.066
	P	0.016	0.069	0.005	-0.038	-0.116	0.060	-0.048	0.069	-0.002	-0.008	0.003	-0.005
PL	G	0.008	0.161	-0.058	-0.270	-0.083	0.369	-0.049	0.077	0.009	-0.070	0.024	0.029
	P	0.009	0.085	-0.019	-0.104	-0.046	0.154	-0.019	0.074	0.002	-0.002	-0.062	-0.008
NPB/P	G	-0.016	0.057	0.226	0.037	-0.042	0.040	0.455	-0.191	-0.003	-0.046	0.019	0.036
	P	0.044	0.044	0.127	0.028	-0.012	0.032	-0.219	0.202	0.009	-0.002	0.009	-0.022
NFG/P	G	-0.012	0.066	0.246	-0.084	-0.022	0.047	-0.143	0.607	0.012	0.029	0.029	0.006
	P	0.019	0.030	0.036	-0.032	-0.012	0.017	-0.074	0.679	0.004	0.005	-0.013	-0.007
KL	G	0.002	0.059	-0.245	0.035	-0.007	0.066	0.022	0.131	-0.055	0.212	-0.143	-0.129
	P	-0.005	0.028	-0.014	0.004	-0.005	-0.007	0.011	-0.053	-0.032	0.005	0.029	0.019
KB	G	0.004	0.015	0.124	0.041	-0.001	-0.089	0.071	0.062	0.039	-0.291	0.154	-0.047
	P	-0.003	-0.003	-0.014	0.002	0.002	-0.005	0.017	0.055	-0.003	0.033	-0.029	0.007
L/B	G	-0.001	0.002	-0.051	-0.027	-0.014	0.042	-0.039	0.084	-0.036	0.208	-0.216	-0.003
	P	-0.005	0.016	0.005	-0.001	-0.003	-0.007	-0.002	-0.064	-0.010	-0.014	0.049	-0.002
TW	G	-0.009	0.083	-0.429	0.132	0.106	-0.039	0.098	-0.002	0.004	0.099	0.049	0.199
	P	-0.005	0.009	-0.005	0.029	0.087	-0.001	0.090	-0.022	-0.004	0.009	-0.004	0.099
GY/P	G	0.225*	0.201*	0.657*	0.049	0.030	0.141	0.572*	0.777*	-0.053	0.084	-0.050	0.298*
	P	0.208*	0.196	0.248*	0.044	0.012	0.122	0.241*	0.654*	-0.025	0.060	-0.033	0.286*

Residual effect: 0.2632(G), 0.4461(P); *Significantat1%level, **Significant at5%level

DFF: Days to 50% flowering, **PH**: Plant height (cm), **EBT**: Ear bearing tillers, **FLL**: Flag leaf length (cm), **FLW**: Flag leaf width (cm), **PL**: Panicle length(cm), **NPB/P**: No. of primary branches/panicle, **NFG/P**: No. of fertile grains/panicle, **KL**: Kernel length (mm), **KB**: Kernel breadth (mm), **L/B**: Length/breadth ratio, **TW**=Test weight(g), **GY/P**=Grain yield/plant (g)

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Character Association Studies for Yield, Nutritional and Cooking Quality Characters in Coloured Rice (*Oryza Sativa* L.)

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Abstract

In the present study 35 coloured rice genotypes along with three checks were evaluated in Randomized Complete Block Design for yield, nutritional and cooking quality traits to study association between the yield, nutritional and cooking quality traits. Correlation studies showed positive and significant correlation of grain yield per plant with yield contributing characters like ear bearing tillers per plant, panicle length, test weight, number of filled grains per panicle and some nutritional characters like protein content and anthocyanin content. The path analysis revealed that traits like ear bearing tillers per panicle, test weight, number of filled grains per panicle, alkali spreading value and anthocyanin content showed not only positive direct effect but also positive correlation with grain yield suggesting the importance of direct selection for above characters. The residual effect in the present study was 0.3696 and 0.2348 at phenotypic and genotypic levels respectively, indicating that the characters included in the present study clearly explained the direct and indirect effects on the dependent variable to some extent.

Keywords: Correlation coefficient, Direct selection, Path analysis, Nutritional and Cooking Quality, Residual effect

Introduction

Rice (*Oryza sativa* L.) is the predominant staple food crop for more than half of the world's population and is playing a pivotal role in providing human nutrition, energy supply and food security. It is not only the major source of carbohydrates, but also source of essential micronutrients. It is the only cereal, cooked and consumed as a whole grain. Hence quality considerations are much more important in rice than for any other food crops (Hossain *et al*., 2009). India is the second largest producer of rice but pigmented rice is restricted to some parts of Northeast and in Western Uttar Pradesh, Punjab and Gujarat. India produces majorly three different pigmented rice - black rice, red rice and purple rice. All three are unique in their functional properties. Eleven different colours of rice varieties are known to exist ranging from the commonly seen white to dark purple or black coloured rice. (Richa Sati and Shweta Singh, 2019). Currently, demand for highly nutritious and healthier food is the norm as people today are more concerned about maintaining a healthy lifestyle. In this regard, coloured rice genotypes have higher content of antioxidant compounds, such as polyphenols, tocochromanols and oryzanols, which have been shown to have a significant effect on human health. Furthermore, these genotypes also contain high micronutrient content, such as iron and zinc. The iron and zinc content of red rice is 2 - 3 times higher than that of white rice. Hence, rice consumers are showing great interest for coloured rice varieties due to their potential health benefits.

To carry out any breeding programme, it is necessary to understand the genetic variability of yield contributing characters, along with their interaction with yield. The genotypic correlation coefficient indicates the genetic proportion of a character that is heritable in nature and hence is used to assist breeding programmes. The existence of this association may be attributed due to linkage, pleiotropic effects of genes, physiological and developmental relationships or due to environmental impacts (Oad *et al*., 2002). Path analysis along with correlation provides a better understanding of the cause and effect link between various pairs of characters (Jayasudha and Sharma, 2010). The association between predictor factors and responder variables has been established using path analysis and this imparts profound knowledge to plant breeders in increasing yield *via* direct and indirect effects (Meena *et al*., 2020).

Materials and Methods

The present investigation was carried out using 35 coloured rice genotypes grown in Randomized Complete Block Design with two replications during *kharif*, 2022 at Agricultural College Farm, Bapatla (**Table 1**). Each genotype was grown in a five rows of 3.0 m length with a spacing of 20 cm between rows and 15 cm between plants, within the row. The data was recorded on ten competitive plants taken from each replication on 18 traits *viz.,* days to 50 per cent flowering, plant height (cm), ear bearing tillers per plant, panicle length (cm), test weight (g), number of filled grains per panicle, grain yield/plant (g), L/B ratio, water uptake, alkali spreading value, amylose content (%), protein content (%), Zn content (ppm), Fe content (ppm), total phenol content (mg/100 g), antioxidant activity (mgAAE/100 g), flavonoid content (mg QE/100 g) and anthocyanin content (mg/100 g). Correlations were worked out using the Formula suggested by Falconer (1964) and partitioning of correlation coefficients into direct and indirect effects was carried out by procedure suggested by Wright (1921) and elaborated as suggested by Dewey and Lu (1959).

Table 1: List of landraces including checks used in the study

S. No.	Black pericarp genotypes	S. No	Red pericarp genotypes
1.	Baasalamaati black	15	Talangur
2.	Ikaladas	16	Aasudhi
3.	Burma black	17	Apputhokalu
4.	Chakhaoamubi	18	Baaludhudiya
5.	Chattisgarh black	19	Bairodlu
6.	**Kalabatti (check)**	20	Barhanaahi
7.	Krishna vrihi	21	Budamalu
8.	Karapukavuni	22	Chittiga
9.	Manipur black	23	Dasumali
10.	Safari	24	Ganga red
11.	SS-56	25	Rakthasaali
12.	Taiwan black	26	Hallabatti
13.	Nalladhanyam	27	Jaajudaan
14.	**BPT 2841 (check)**	28	Talangur
		29	Basumathi
		30	Jethu
		31	Kaantamaguni
		32	Mapilai Samba
		33	Kempusanna
		34.	Poohali
White rice genotype			
35.	**BPT 5204 (check)**		

Results and Discussions

The correlation study (**Table 2**) revealed that grain yield per plant had strong positive association with ear bearing tillers per plant (r_g=0.7601** and r_p=0.5941**), panicle length (r_g=0.8863** and r_p=0.7596**), test weight (r_g=0.7218** and r_p=0.6854**) and number of filled grains per panicle (r_g=0.3832* and r_p=0.3681**) at both genotypic and phenotypic levels. The results are in accordance with the previous findings of Bhargavi *et al.,* (2022), Deepthi *et al*., (2022), Kiran *et al*., (2023), Teja *et al.,* (2023) and Heera *et al*., (2023). Protein content (r_p=0.2937*) and anthocyanin content (r_p=0.3271**) were positively correlated with grain yield per plant at phenotypic level only.

From the correlation studies it can be concluded that yield contributing characters like ear bearing tillers per plant, panicle length, test weight, number of filled grains per panicle and some nutritional characters like protein content and anthocyanin content were positively correlated with grain yield/plant indicating that the above traits can be considered for selection process. Characters like L/B ratio and plant height are correlated negatively with grain yield. It was also observed from the present study that simultaneous selection for all yield and quality traits may not be possible and balanced selection criteria has to be followed. Further breeding programmes should be refined in such a way to break undesirable linkages between traits for simultaneous improvement of both yield and quality traits.

The path coefficient analysis (**Tables 3 and 4**) revealed that traits like ear bearing tillers per panicle (G= 0.1913 and P= 0.2197), test weight (G= 1.2128 and P= 0.6667), number of filled grains per panicle (G= 0.6574 and P= 0.3123), alkali spreading value (G= 0.0873 and P= 0.0370) and anthocyanin content (G=0.5541 and P=0.3829) showed not only positive direct effect but also positive correlation with grain yield suggesting the importance of direct selection for above characters. Traits like plant height, water uptake, amylose content, Zn content, Fe content, total phenol content and flavonoid content showed negative direct effect with positive correlation indicating indirect effects can be the cause of positive correlation. In such situations, the indirect causal factors are to be considered simultaneously for selection. These results were similar with the previous findings of Archana *et al*., (2018), Deepthi *et al*., (2022) and Heera *et al*., (2023).

Further, the residual effect in the present study was 0.3696 and 0.2348 at phenotypic and genotypic levels respectively, indicating that the characters included in the present study clearly explained the direct and indirect effects on the dependent variable to some extent. The residual effect permits precise explanation about the pattern of interaction of other possible components with yield.

Table 2: Correlation coefficients (Phenotypic and Genotypic) for grain yield and yield contributing characters in 35 genotypes of rice (*Oryza sativa* L.)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
D50%F	**G**	1.0000	-0.1691	0.2428	-0.1121	-0.3843*	0.5520**	-0.1376	0.5878**	0.2677	0.1490	0.0644	-0.0957	-0.1548	-0.0207	-0.6524**	0.0605	0.1503	-0.0686
	P	1.0000	-0.1280	0.1792	0.0428	-0.330**	0.4258**	-0.0124	0.4158**	0.2386*	0.1463	0.0575	-0.0433	-0.1394	-0.0257	-0.5001**	0.0562	0.1169	-0.0460
PH	**G**		1.0000	0.0602	0.0709	0.3293	-0.0915	-0.0069	-0.1707	0.1097	-0.1303	0.3546*	0.1492	0.2635	-0.0299	0.2897	0.1341	0.1049	0.1717
	P		1.0000	-0.0069	0.0780	0.2881*	-0.0805	-0.0801	-0.1463	0.0762	-0.1205	0.3184**	0.1247	0.2316	-0.0279	0.2654*	0.1226	0.0974	0.1642
EBT	**G**			1.0000	0.6737**	0.2326	0.7242**	0.2259	0.3303**	0.1526	0.0433	0.4254*	0.2843	0.1290	0.1308	-0.1291	0.3338	0.5636**	0.7601**
	P			1.0000	0.5733**	0.1284	0.5307**	0.3169**	0.2817*	0.1260	0.0468	0.3230**	0.2275	0.1051	0.1091	-0.1038	0.2641*	0.4598**	0.5941**
PL	**G**				1.0000	0.5747**	0.4202*	0.0666	0.1413	0.2351	0.1111	0.3954*	0.0924	-0.0514	0.0486	0.1153	0.2710	0.3676*	0.8863**
	P				1.0000	0.4573**	0.3530**	0.0605	0.1567	0.2037	0.0994	0.3517**	0.0830	-0.0320	0.0374	0.0945	0.2346	0.3196**	0.7596**
TW	**G**					1.0000	-0.1937	-0.2884	-0.0104	-0.0065	-0.1102	0.1653	0.0406	0.1272	-0.1110	0.1043	-0.0460	-0.0590	0.7218**
	P					1.0000	-0.1809	-0.2797*	-0.0064	-0.0149	-0.1074	0.1723	0.0484	0.1196	-0.1082	0.0967	-0.0465	-0.0556	0.6854**
NFGPP	**G**						1.0000	0.0705	0.4032**	0.2976	0.2029	0.3669*	0.2560	0.1943	0.3913*	-0.2708	0.4845**	0.6423**	0.3832*
	P						1.0000	0.0372	0.3563**	0.2786**	0.2115	0.3432**	0.2182	0.1923	0.3728**	-0.2496*	0.4616**	0.6131**	0.3681**
L/B R	**G**							1.0000	-0.0350	-0.0166	-0.1654	0.0940	0.2809	0.3260	0.0341	0.1754	0.0150	0.1027	-0.0927
	P							1.0000	-0.0495	-0.0291	-0.1382	0.0550	0.2109	0.2431*	0.0262	0.1274	0.0057	0.0832	-0.0925
WU	**G**								1.0000	0.3745*	0.0327	0.1531	0.3347*	0.0064	0.0738	-0.2364	0.1614	0.2077	0.1412
	P								1.0000	0.3649**	0.0307	0.1619	0.3066**	0.0053	0.0711	-0.2335	0.1570	0.2052	0.1399
ASV	**G**									1.0000	0.0920	0.2487	0.3173	-0.1785	0.2373	-0.1598	0.3453*	0.3683*	0.1512
	P									1.0000	0.0953	0.2488*	0.2931*	-0.1764	0.2311	-0.1539	0.3389**	0.3613**	0.1467
AC	**G**										1.0000	0.0348	0.0710	-0.0133	0.0180	0.2402	-0.0014	0.0973	0.0151
	P										1.0000	0.0343	0.0684	-0.0085	0.0177	0.2311	-0.0053	0.0959	0.0170
PC	**G**											1.0000	0.2609	0.2191	0.5878**	0.1594	0.6310**	0.7099**	0.2959
	P											1.0000	0.2451*	0.2018	0.5761**	0.1527	0.6137**	0.6993**	0.2937*
Zn	**G**												1.0000	0.1440	0.2718	0.2998	0.3272	0.3570*	0.1020
	P												1.0000	0.1252	0.2603*	0.2890*	0.3116**	0.3409**	0.1081
Fe	**G**													1.0000	0.2136	0.3150	0.1665	0.1929	0.1195
	P													1.0000	0.2094	0.3048	0.1622	0.1867	0.1120
TPC	**G**														1.0000	0.0468	0.7488**	0.7882**	0.0503
	P														1.0000	0.0481	0.7441**	0.7872**	0.0498
AA	**G**															1.0000	0.1415	0.0001	0.0138
	P															1.0000	0.1432	0.00001	0.0188
FC	**G**																1.0000	0.8825**	0.2251
	P																1.0000	0.8786**	0.2196
ANC	**G**																	1.0000	0.3315
	P																	1.0000	0.3271**
GY/P	**G**																		1.0000
	P																		1.0000

* Significant at 5% level; ** Significant at 1% level

D 50%F -Days to 50 per cent flowering, **PH** -Plant height (cm), **EBT** -Ear bearing tillers per plant, **PL**-Panicle length (cm), **TW** -Test weight (g), **NFGPP**-Number of filled grains per panicle, **L/B R**-L/B ratio, **WU**-Water uptake, **ASV**-Alkali spreading value, **AC** -Amylose content (%), **PC**- Protein content, **Zn**-Zn content (ppm), **Fe**-Fe content(ppm), **TPC**-Total phenol content(mg/100g), **AA**-Antioxidant activity(mg AAE/100g), **FC**-Flavonoid content (mg QE/100g), **ANC**-Anthocyanincontent(mg/100g), **GY / P**-Grain yield/plant; **P**- Phenotypic; **G**-Genotypic

Table 3: Direct and indirect effects of different traits on grain yield at genotypic level in 35 genotypes of rice (*Oryza sativa* L.)

	D 50%F	PH (cm)	EBT	PL (cm)	TW (g)	NFGPP	L/B R	WU	ASV	AC (%)	PC (%)	Zn (ppm)	Fe (ppm)	TPC (mg/100g)	AA (mgAAE/100	FC (mgQ-E/100g)	ANC (mg/100g)	GY/P (g)
D 50% F	**0.2401**	-0.0406	0.0583	-0.0269	-0.0922	0.1325	-0.0330	0.1411	0.0643	0.0358	0.0155	-0.0230	-0.0372	-0.0050	-0.1566	0.0145	0.0361	-0.0686
PH	0.0214	**-0.1263**	-0.0076	-0.0089	-0.0416	0.0116	0.0009	0.0216	-0.0139	0.0165	-0.0448	-0.0188	-0.0333	0.0038	-0.0366	-0.0169	-0.0133	0.1717
EBT	0.0465	0.0115	**0.1913**	0.1289	0.0445	0.1385	0.0432	0.0632	0.0292	0.0083	0.0814	0.0544	0.0247	0.0250	-0.0247	0.0639	0.1078	0.7601**
PL	0.0324	-0.0204	-0.1944	**-0.2886**	-0.1699	-0.1213	-0.0192	-0.0408	-0.0679	-0.0321	-0.1141	-0.0267	0.0148	-0.0140	-0.0333	-0.0782	-0.1061	0.8863**
TW	-0.4660	0.3993	0.2821	0.6970	**1.2128**	-0.2349	-0.3497	-0.0126	-0.0079	-0.1337	0.2005	0.0493	0.1543	-0.1346	0.1265	-0.0558	-0.0715	0.7218**
NFGPP	0.3628	-0.0601	0.4761	0.2762	-0.1273	**0.6574**	0.0463	0.2651	0.1966	0.1334	0.2412	0.1683	0.1277	0.2573	-0.1780	0.3185	0.4222	0.3832*
L/B R	-0.0372	-0.0019	0.0610	0.0180	-0.0779	0.0190	**0.2701**	-0.0095	-0.0045	-0.0447	0.0254	0.0759	0.0881	0.0092	0.0474	0.0040	0.0277	-0.0927
WU	-0.0282	0.0082	-0.0159	-0.0068	0.0005	-0.0194	0.0017	**-0.0480**	-0.0163	0.0026	-0.0033	-0.0141	0.0036	0.0063	0.0174	0.0030	0.0001	0.1412
ASV	0.0234	0.0096	0.0133	0.0205	-0.0006	0.0260	-0.0014	0.0296	**0.0873**	0.0080	0.0217	0.0277	-0.0156	0.0207	-0.0139	0.0301	0.0321	0.1512
AC	-0.0215	0.0188	-0.0063	-0.0160	0.0159	-0.0293	0.0239	0.0077	-0.0133	**-0.1444**	-0.0050	-0.0102	0.0019	-0.0026	-0.0347	0.0002	-0.0141	0.0151
PC	-0.0154	-0.0846	-0.1015	-0.0943	-0.0394	-0.0875	-0.0224	-0.0163	-0.0593	-0.0083	**-0.2386**	-0.0622	-0.0523	-0.1402	-0.0380	-0.1505	-0.1694	0.2959
Zn	0.0324	-0.0505	-.0962	-0.0312	-0.0137	-0.0866	-0.0950	-0.0992	-0.1073	-0.0240	-0.0883	**-0.3382**	-0.0487	-0.0919	-0.1014	-0.1107	-0.1207	0.1020
Fe	0.0526	-0.0895	-0.0438	0.0175	-0.0432	-0.0660	-0.1107	0.0254	0.0606	0.0045	-0.0744	-0.0489	**-0.3397**	-0.0726	-0.1070	-0.0565	-0.0655	0.1195
TPC	0.0019	0.0028	-0.0123	-0.0046	0.0104	-0.0368	-0.0032	0.0123	-0.0223	-0.0017	-0.0552	-0.0255	-0.0201	**-0.0939**	-0.0044	-0.0703	-0.0740	0.0503
AA	-0.3822	0.1697	-0.0756	0.0675	0.0611	-0.1587	0.1027	-0.2121	-0.0936	0.1407	0.0934	0.1756	0.1845	0.0274	**0.5859**	0.0829	-0.0005	0.0138
FC	-0.0147	-0.0325	-0.0808	-0.0656	0.0111	-0.1173	-0.0036	0.0153	-0.0836	0.0003	-0.1528	-0.0792	-0.0403	-0.1813	-0.0343	**-0.2421**	-0.2136	0.2251
ANC	0.0833	0.0581	0.3123	0.2037	-0.0327	0.3559	0.0569	-0.0015	0.2041	0.0539	0.3933	0.1978	0.1069	0.4367	-0.0004	0.4890	**0.5541**	0.3315
GY/P	-0.0686	0.1717	0.7601**	0.8863**	0.7218**	0.3832*	-0.0927	0.1412	0.1512	0.0151	0.2959	0.1020	0.1195	0.0503	0.0138	0.2251	0.3315	1.0000
Partial R^2	-0.0165	-0.0217	0.1454	-0.2558	0.8754	0.2519	-0.0250	-0.0068	0.0132	-0.0022	-0.0706	-0.0345	-0.0406	-0.0047	0.0081	-0.0545	0.1837	

Diagonal bold values indicate direct effect, Off-diagonal values-indirect values * Significant at 5% level, ** Significant at 1% level

Residual Effect= 0.2348 R^2=0.9449

D 50%F -Days to 50% flowering, **PH** -Plant height (cm), **EBT** -Ear bearing tillers per plant, **PL**-Panicle length (cm), **TW** -Test weight (g), **NFGPP**-Number of filled grains per panicle, **L/B R**-L/B ratio, **WU**-Water uptake, **ASV**-Alkali spreading value, **AC** -Amylose content (%), **PC** -Protein content, **Zn**-Zn content (ppm), **Fe**-Fe content(ppm), **TPC**-Total phenol content(mg/100g), **AA**-Antioxidant activity (mgAAE/100g), **FC**-Flavonoid content (mgQE/100g), **ANC**-Anthocyanin content(mg/100g), **GY / P**-Grain yield/plant.

Table 4: Direct and indirect effects of different traits on grain yield at phenotypic level in 35 genotypes of rice (*Oryza sativa* L.)

	D 50% F	PH (cm)	EBT	PL (cm)	TW (g)	NFGPP	L/B R	WU	ASV	AC (%)	PC (%)	Zn (ppm)	Fe (ppm)	TPC (mg/100g)	AA (mgAAE/100	FC (mgQE/100g)	ANC (mg/100g)	GY/P(g)
D50%F	**0.0679**	-0.0087	0.0122	0.0029	-0.0224	0.0289	-0.0008	0.0282	0.0162	0.0099	0.0039	-0.0029	-0.0095	-0.0017	-0.0340	0.0038	0.0079	-0.0460
PH	0.0014	**-0.0108**	0.0001	-0.0008	-0.0031	0.0009	0.0009	0.0016	-0.0008	0.0013	-0.0034	-0.0014	-0.0025	0.0003	-0.0029	-0.0013	-0.0011	0.1642
EBT	0.0394	-0.0015	**0.2197**	0.1259	0.0282	0.1166	0.0696	0.0619	0.0277	0.0103	0.0709	0.0500	0.0231	0.0240	-0.0228	0.0580	0.1010	0.5941**
PL	0.0084	0.0153	0.1127	**0.1965**	0.0899	0.0694	0.0119	0.0308	0.0400	0.0195	0.0691	0.0163	-0.0063	0.0073	0.0186	0.0461	0.0628	0.7596**
TW	-0.2200	0.1921	0.0856	0.3049	**0.6667**	-0.1206	-0.1865	0.0043	-0.0099	-0.0716	0.1148	0.0323	0.0798	-0.0721	0.0645	-0.0310	-0.0370	0.6854**
NFGPP	0.1330	-0.0251	0.1658	0.1103	-0.0565	**0.3123**	0.0116	0.1113	0.0870	0.0661	0.1072	0.0682	0.0601	0.1165	-0.0779	0.1442	0.1915	0.3681**
L/B R	0.0002	0.0014	-0.0055	-0.0011	0.0049	-0.0006	**-0.0174**	0.0009	0.0005	0.0024	-0.0010	-0.0037	-0.0042	-0.0005	-0.0022	-0.0001	-0.0014	-0.0925
WU	-0.0092	0.0032	-0.0062	-0.0035	-0.0001	-0.0079	0.0011	**-0.0221**	-0.0073	0.0012	-0.0019	-0.0058	0.0016	0.0028	0.0078	0.0014	0.0000	0.1399
ASV	0.0088	0.0028	0.0047	0.0075	-0.0006	0.0103	-0.0011	0.0121	**0.0370**	0.0035	0.0092	0.0108	-0.0065	0.0086	-0.0057	0.0125	0.0134	0.1467
AC	-0.0140	0.0115	-0.0045	-0.0095	0.0103	-0.0202	0.0132	0.0050	-0.0091	**-0.0955**	-0.0033	-0.0065	0.0008	-0.0017	-0.0221	0.0005	-0.0092	0.0170
PC	-0.0108	-0.0596	-0.0605	-0.0658	-0.0322	-0.0642	-0.0103	-0.0157	-0.0466	-0.0064	**-0.1872**	-0.0459	-0.0378	-0.1078	-0.0286	-0.1149	-0.1309	0.2937*
Zn	0.0050	-0.0143	-0.0261	-0.0095	-0.0055	-0.0250	-0.0242	-0.0299	-0.0336	-0.0078	-0.0281	**-0.1146**	-0.0143	-0.0298	-0.0331	-0.0357	-0.0391	0.1081
Fe	0.0089	-0.0149	-0.0068	0.0021	-0.0077	-0.0123	-0.0156	0.0046	0.0113	0.0005	-0.0130	-0.0080	**-0.0642**	-0.0134	-0.0196	-0.0104	-0.0120	0.1120
TPC	0.0018	0.0019	-0.0075	-0.0026	0.0074	-0.0257	-0.0018	0.0089	-0.0159	-0.0012	-0.0396	-0.0179	-0.0144	**-0.0688**	-0.0033	-0.0512	-0.0542	0.0498
AA	-0.1201	0.0542	-0.0212	0.0193	0.0198	-0.0510	0.0260	-0.0720	-0.0314	0.0472	0.0312	0.0590	0.0622	0.0098	**0.2042**	0.0293	0.0000	0.0188
FC	-0.0094	-0.0206	-0.0444	-0.0394	0.0078	-0.0775	-0.0010	0.0106	-0.0569	0.0009	-0.1031	-0.0523	-0.0272	-0.1250	-0.0241	**-0.1680**	-0.1476	0.2196
ANC	0.0448	0.0373	0.1761	0.1224	-0.0213	0.2348	0.0319	-0.0006	0.1384	0.0367	0.2678	0.1305	0.0715	0.3014	-0.0001	0.3364	**0.3829**	0.3271**
GY/P	-0.0460	0.1642	0.5941**	0.7596**	0.6854**	0.3681**	-0.0925	0.1399	0.1467	0.0170	0.2937*	0.1081	0.1120	0.0498	0.0188	0.2196	0.3271**	1.0000
Partial R^2	-0.0031	-0.0018	0.1305	0.1493	0.4570	0.1150	0.0016	-0.0031	0.0054	-0.0016	-0.0550	-0.0124	-0.0072	-0.0034	0.0038	-0.0369	0.1253	

*Diagonal bold values indicate direct effect, Off-diagonal values-indirect values * Significant at 5% level, ** Significant at 1% level*

Residual Effect= 0.3696 R^2=0.8634

D 50% F -Days to 50% flowering, **PH** -Plant height (cm), **EBT** -Ear bearing tillers per plant, **PL**-Panicle length (cm), **TW** -Test weight (g), **NFGPP**-Number of filled grains per panicle, **L/B R**-L/B ratio, **WU**-Water uptake, **ASV**-Alkali spreading value, **AC** -Amylose content (%), **PC**-Protein content, **Zn**-Zn content (ppm), **Fe**-Fe content(ppm), **TPC**-Total phenol content(mg/100g), **AA**-Antioxidant activity(mgAAE/100g), **FC**-Flavonoid content (mgQE/100g), **ANC**-Anthocyanin content(mg/100g), **GY / P**-Grain yield/plant

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Development of High Yielding Deep Water Rice Variety MTU 1184 Suitable for Semi-Deep Flooded Ecosystem of South Eastern Region of India

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Abstract

In recent years due to heavy and intense rainfall and cyclonic storms, paddy crop is experiencing damage due to flooding. If the flood water stagnation remains for more than a week the varieties are unable to sustain and there by the yield levels are drastically reduced. Hence, there is a need to develop submergence tolerant variety to minimize the yield losses. Acharya NG Ranga Agricultural University (ANGRAU), Regional Agricultural Research Station, Maruteru has developed flood tolerant variety MTU 1184 through conventional plant breeding using PLA 1100 and BM 71 as parents. The flood tolerant rice culture was extensively evaluated for yield in semi deep water ecosystem at RARS, Maruteru over the years of *kharif*, 2012 to *kharif*, 2016 in Station yield trials. The variety recorded superior grain yield (4370 kg/ha) against check PLA 1100 (3811 kg/ha) and yield advantage over check was 14.67%. The entry was tested in AICRIP trials from 2014 to 2017 at RARS, Maruteru and the results revealed that MTU 1184 registered 4650 kg/ha and found to be significantly superior over the national check, Sabitha (3703 kg/ha) and the per cent increase over check was 25.57. The variety recorded a mean grain yield of 4281 kg/ha and found to be significantly superior over the national check, Sabitha (3011 kg/ha) and yield advantage was 1270 kg/ha and per cent increase over national check was 42.17 and zonal check Poornendu in 8 locations of six states of south eastern region. Multi location testing of the variety from 2015 to 2017 revealed that the variety has out yielded (5370 kg/ha) and found superior over the best check PLA 1100 (4290 kg/ha) and the per cent increase over check was 25.18. Minikit testing in 890 locations for a period of three years from 2016 to 2018 revealed that the average mean yield of the variety over three years was 6039 kg/ha against local popular check PLA 1100 (5700 kg/ha) and per cent increase over check was 6.0 when tested in Andhra Pradesh.

Key words: Deep water rice variety, MTU 1184, Stagnant flooding, High yield, Late duration

Introduction

Deep water rice ecosystem represents the flood-prone rice ecosystem where rice plant requires elongation ability to reach the surface with a certain amount of plant height to withstand in stagnant flood water condition. Low yield potentiality of locally adapted deep water cultivars limits the total rice production in the country (Hossain, 1996). Rice crop is being cultivated in varied ecologies to feed increasing population. Coastal rice ecosystems, covering more than 16% of rice areas worldwide (20×10^6 ha) are adversely affected by annual flooding (Krishnaiah *et al.,* 1996). Paddy fields in these flood-prone lowlands are subjected to either flash floods (few days to two weeks) or long-term flooding *i.e.*, semi-deep water (30-50 cm). Rice is the staple food for more than three billion people in Asia, where more than 90% of the world's rice is produced and consumed (Li and Xu, 2007). In recent years, climate change is increasing the incidence of both types of floods and yield loss due to floods ranges from 10 to 100% depending on the cultivated variety, flood duration, depth and floodwater conditions. Continuous high rainfall in a short span leading to water logging causes inundation of paddy fields and lodging of the crop at grain filling and maturity stages causes huge losses to the farmer. Deep water rice ecosystem represents the flood-prone rice ecosystem where stagnant flood water occurred in a depth usually exceeds 100 cm and continues for longer period of time ranging from more than 10 days to five months (Maclean *et al.,* 2002). Further, flood is a recurrent phenomenon in coastal areas of Andhra Pradesh, Assam, Orissa, West Bengal, Kerala, Karnataka and South Gujarat. The problem is accentuated due to poor drainage and topography of the land which impedes fast drainage from crop lands (Yamuna and Ashwini, 2016) In general, the submergence exists up to 15 days which coincides with the vegetative stage of the crop at 30 days after transplanting and recedes later. If the flood water stagnation remains for more than a week, the varieties are unable to sustain and there by the yield levels are drastically reduced. Apart from improving drainage and other preventive measures, farmers can adopt flood tolerant varieties that can withstand inundation for an extended period and reduce the risk from flood damage (Bhuiyan, 2004). Deep water ecosystem has been classified into two types based on stature and depth of water, traditional tall and floating cultivars. Traditional tall cultivars are tall with long leaves and grown at water depths between 50 and 100 cm while floating rice is grown in 100 cm or deeper situations (Shalahuddin *et al.,* 2019). However, this rice required elongation ability to reach the surface, such as the one found in floating rice up to 5 m length (Bouman *et al.,* 2007) Deep water rice is cultivated in the flood plains and deltas of rivers such as the Ganges and Brahmaputra of India and Bangladesh, Myanmar, Vietnam and Cambodia, the Chao Phraya of Thailand, and the Niger of West Africa of these types requires specific adaptive traits, which require the development of unique varieties (Lafitte *et al.,* 2006). Though deep water rice is cultivated in small areas with low yield, attention should be given to develop high yielding deep water rice to maintain stable rice production (Ahmed *et al.,* 2016). Rice is grown in diverse ecologies from submerged lowland in Assam to the coastal saline regions of Kerala (Sreelakshmi *et al.,* 2023).

Materials and Methods

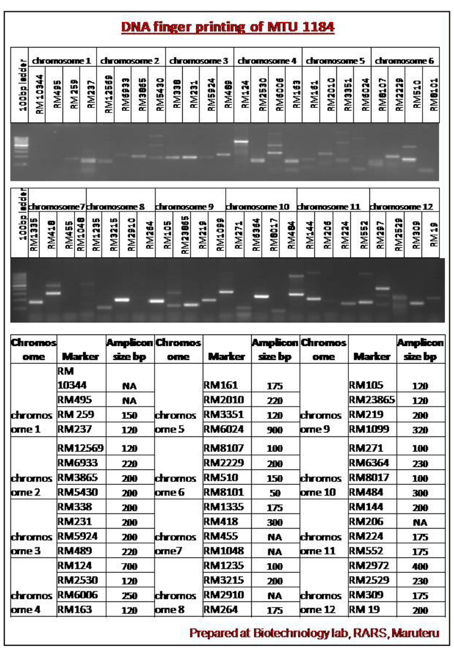
Many advanced breeding lines were developed by Acharya NG Ranga Agricultural University, Regional Agricultural Research Station (RARS), Maruteru. Among them flood tolerant genotype, MTU 1184 is an outcome of single cross between PLA 1100 and BM 71 with an objective to develop a semi deep water submergence tolerant rice variety. The pedigree of MTU 1184 is MTU 2060-1-1-1-1-1. Crossing was done in 2008 and developed through hybridization followed by pedigree selection. The local popular variety PLA 1100 was used as check for this study. The new variety, MTU 1184 with 150 days duration is tolerant to flash floods for 15 days at the tillering stage and suitable for stagnant flooding (50-60 cm) with good elongation ability possessing two weeks dormancy and good grain quality characteristics. It is a medium slender, brown glume, semi-tall plant type of 140-150 cm depending on water depth. The morphological description of the variety is given in **Annexure** and DNA finger printing was carried out by using different markers in **Plate 1** and field view in **Plate 2**.

Annexure: Description of the Variety MTU 1184

S. No	Characteristics	Description
1	Coleoptile: Colour	White
2	Basal Leaf: Sheath Colour	Green
3	Leaf: Intensity of Green Colour	Dark green
4	Leaf: Anthocyanin Colouration	Absent
5	Leaf: Distribution of Anthocyanin Colouration	Absent
6	Leaf Sheath: Anthocyanin Colouration	Absent
7	Leaf Sheath: Intensity of Anthocyanin Colouration	Absent
8	Leaf: Pubescence of Blade Surface	Weak
9	Leaf: Auricles	Absent
10	Leaf: Anthocyanin Colouration of Auricles	Absent
11	Leaf: Collar	White
12	Leaf: Anthocyanin Colouration Of Collar	Absent
13	Leaf: Ligule	Present
14	Leaf: Shape Of Ligule	Acute
15	Leaf Colour Of Ligule	White
16	Leaf: Length Of Blade	59
17	Leaf : Width Of Blade	1
18	Culm: Attitude(For Floating Rice Only)	Not applicable
19	Culm: Attitude	Erect
20	Time Of Heading(50% Of Plants With Panicles)	120
21	Flag Leaf: Attitude of Blade (Early Observation)	Erect
22	Spikelet: Density of Pubescence Of Lemma	Weak
23	Male Sterility	Absent
24	Lemma: Anthocyanin Colouration Of Keel	Absent
25	Lemma: Anthocyanin Colouration Of Area Below Apex	Absent
26	Lemma: Anthocyanin Colouration Of Apex	Absent
27	Spikelet: Colour Of Stigma	White
28	Stem: Thickness	Thick
29	Stem: Length (Excluding Panicle; Excluding Floating Rice)	118
30	Stem: Anthocyanin Colouration of nodes	Absent
31	Stem: Intensity Of Anthocyanin Coloration Of Nodes	Absent
32	Stem: Anthocyanin Coloration Of Internodes	Absent
33	Panicle: Length Of Main Axis	28.2 cm
34	Flag Leaf: Attitude Of Blade (Late Observation)	Erect
35	Panicle: Curvature Of Main Axis	Erect
36	Panicle: Number Per Plant	10
37	Spikelet: Colour Of Tip Of Lemma	Brown
38	Lemma And Palea: Colour	Brown
39	Panicle: Awns	Absent
40	Panicle: Colour Of Awns	Absent

S. No	Characteristics	Description
41	Panicle: Length Of Longest Awn	Absent
42	Panicle: Distribution Of Awns	Absent
43	Panicle: Presence Of Secondary Branching	Present
44	Panicle: Secondary Branching	Strong
45	Panicle: Attitude Of Branches	Semi erect
46	Panicle: Exertion	Well exerted
47	Maturity	150
48	Leaf Senescence	Moderate
49	Sterile Lemma colour	Present
50	Grain: Weight of 1000 Fully Developed Grains	16.19
51	Hulling (%)	77.5
52	Milling (%)	66.5
53	Head rice recovery (%)	67.0
54	Kernal length (mm)	4.91
55	Kernal width (mm)	1.97
56	L/B ratio	2.49
57	Grain type	Short bold
58	Chalkiness	Absent
59	Alakali spreading value	5.0
60	Gel Consistency	43
61	Amylose content (%)	24.55

Plate 1: DNA fingerprinting of MTU 1184



Chromosome	Marker	Amplicon size bp	Chromosome	Marker	Amplicon size bp	Chromosome	Marker	Amplicon size bp
chromosome 1	RM 10344	NA	chromosome 5	RM161	175	chromosome 9	RM105	120
	RM495	NA		RM2010	220		RM23865	120
	RM 259	150		RM3351	120		RM219	200
	RM237	120		RM6024	900		RM1099	320
chromosome 2	RM12569	120	chromosome 6	RM8107	100	chromosome 10	RM271	100
	RM6933	220		RM2229	200		RM6364	230
	RM3865	200		RM510	150		RM8017	100
	RM5430	200		RM8101	50		RM484	300
chromosome 3	RM338	200	chromosome7	RM1335	175	chromosome 11	RM144	200
	RM231	200		RM418	300		RM206	NA
	RM5924	200		RM455	NA		RM224	175
	RM489	220		RM1048	NA		RM552	175
chromosome 4	RM124	700	chromosome 8	RM1235	100	chromosome 12	RM2972	400
	RM2530	120		RM3215	200		RM2529	230
	RM6006	250		RM2910	NA		RM309	175
	RM163	120		RM264	175		RM 19	200

Barcode: A3B7C5D7E7F6G9H7I3J5K6L15 Unique allelles: RM

Field trials were performed under semi-deep water ecosystem in Randomized Block Design with three replications in three consecutive seasons from 2012 to 2014 in 50-60 cm deep water. The entry was tested in flash floods with a stagnant flooding of 60-65 cm for a period of 15-20 days from 2015-2017. All India Coordinated trials were conducted from 2014 to 2017 in seven states of Orissa (Bhuvaneswar, Cuttuck), West Bengal (Chinsurah), Uttar Pradesh (Ghaghraghat), Assam (Gerula), Bihar (Pusa), Karnataka (Sirsi) and Andhra Pradesh (Maruteru). Based on the superior performance of the entry in the Multi location testing when compared to best check PLA 1100 from *kharif*, 2015 to *kharif*, 2017, the culture was tested in minikit testing from *kharif*, 2016 to *kharif*, 2018 and per cent increase of yield over check was estimated. Land was well prepared in semi-dry condition. Sowing was done in second week of June and transplanting was done in the second week of July in each year. All recommended package of practices were followed as per schedule. When flood water or stagnant water

MTU 1184 (MTU 2060-1-1-1-1-1)

Field view at maturity **Field view at grain filling** **Paddy, brown rice and rice kernel after cooking**

Plate 2: Field view of MTU 1184 and paddy brown rice and rice

depth was more than 50 cm, urea application was avoided.

Evaluation of Agronomic traits: The data on plant height, days to 50% flowering, days to maturity, number of panicles/m^2, grain yield, grain type and test weight were recorded in accordance with Standard Evaluation System (SES., 2002). Growth duration was counted from the date of sowing to grain maturity. Grain yield was estimated from eight to ten square meter sample plot for each replication.

Screening for submergence and other important adaptability traits: The seed material was raised in raised bed nurseries and 30 days old seedlings were submerged in submergence ponds for 15 days. Then the water was drained out and the plants were kept for recovery. The plants were scored for submergence tolerance and survival per cent was recorded as per standard evaluation system for rice. The genotype was scored for adaptability parameters of elongation ability, kneeing ability, grain shattering and phenotypic acceptability based on SES system (SES., 2002).

Results and Discussions

The flood tolerant rice variety was extensively evaluated for yield in semi-deep water ecosystem at RARS, Maruteru over the years of *kharif*, 2012 to *kharif*, 2016 in station yield trials The variety recorded superior grain yield (4370 kg/ha) against check PLA 1100 (3811 kg/ha) and yield advantage over check was 14.67 percent (**Table1**).

The culture was tested in AICRIP trials from 2016 to 2017 at RARS, Maruteru and the results revealed that the culture registered 4650 kg/ha and found to be significantly superior over the national check, Sabitha (3703 kg/ha) and the per cent increase over check was 25.57 (**Table 2**).

Table 1: Performance of MTU 1184 in Station trials at RARS, Maruteru

Name of the Trial	Code/ IET No	Year of testing	Entry	Check (PLA 1100)	Percentage increase over check	Remarks
			Grain yield (kg/ha)	Grain yield (kg/ha)		
OYTSDW	ADW 59	*Kharif,* 2012	5330	4988	6.86	Yield under Water depth 20-50 cm
PYT SDW	BDW 55	*Kharif,* 2013	4105	3878	5.85	
AYT SDW	CDW 69	*Kharif,* 2014	3968	3680	7.83	
AYT submergence	CSB 16	*Kharif,* 2016	4077	2697	51.16	Flash floods+ Stagnant flooding 60-65 cm
Mean under stress			**4370**	**3811**	**14.67**	

Table 2: Performance of MTU 1184 (IET 24486) in AICRIP trials at RARS, Maruteru

AICRIP trials						
Name of the Trial	Code/ IET No	Year of testing	Entry MTU 1184	Sabitha National Check	Percentage increase over check	Remarks
			Grain yield (kg/ha)			
AVT 1 SDW	IET No 24486	*Kharif* 2016	5994	4185	43.22	4820 kg/ha over all mean across the locations under semi deep water situation
AVT2 SDW	24486	*Kahrif* 2017	4881	4295	13.64	Performed well in AP
Mean yield under stress			**4650**	**3703**	**25.57**	**Under floods**

The culture was tested in AICRIP trials in six states and the results revealed that the entry registered 3818 kg/ha and was found to be significantly superior over the national check, Sabitha (2852 kg/ha) and zonal check Purnendu (2871 kg/ha). Per cent increase over National check was 33.87 and zonal Check was 32.99 (**Table 3**).

Table 3: Performance of MTU 1184 (IET 24486) in AICRIP trials across locations (2014) in National Semi Deep Water Screening Nursery

State	Location	IET 24486	NC Sabitha	ZC Purnendu	CD (0.05)	CV (%)
Orissa	BBN	5185	1235	2531	858	15.8
Orissa	CRR	2403	2963	3628	1223	17.78
WB	CHN	2924	4971	3728	439	5.38
UP	GGT	2800	2320	1120	742	13.5
ASSAM	GAR	4851	4386	4417	881	10.41
AP	MTU	4746	1235	1802	621	12.97
	Mean	3818	2852	2871		
	Yield advantage		**967**	**947**		
	% increase over checks		**33.87**	**32.99**		

The entry was tested in AICRIP trials in six states and the results revealed that the entry registered 4113 kg/ha and found to be significantly superior over the national check, Sabitha (3210 kg/ha) and zonal check Purnendu (3146 kg/ha). Per cent increase over national check was 28.13 and zonal check was 30.73 (**Table 4**).

Table 4: Performance of MTU 1184 (IET 24486) in AICRIP trials across locations 2015 in IVT

State	Location	IET 24486	NC	ZC	CD (0.05)	CV (%)
Orissa	BBN	6173	2099	2593	589	8.42
Orissa	CTK	4019	2908	1623	754	14.01
Bihar	PSA	2000	2357	2929	833	22.56
Up	GGT	3267	2567	2233	543	11.25
Assam	GAR	3427	3468	3049	618	12.41
Assam	NLP	4103	3977	4387	897	12.68
AP	MTU	4114	3211	3146	286	13.23
KA	SRS	5807	5100	5208	820	9049
	Mean	4113	3210	3146		
	Yield advantage		903	967		
	% increase over Check		28.13	30.73		

The entry was tested in AICRIP trials in six states and the results revealed that the entry registered 4820 kg/ha and found to be significantly superior over the national check, Sabitha (3120 kg/ha) and zonal check Purnendu (3150 kg/ha). Per cent increase over National check was 54.46 and zonal Check was 53.00 (**Table 5**).

Table 5: Performance of MTU 1184 (IET 24486) in AICRIP trials across locations in 2016 in AVT 1

State	Location	IET 24486	NC	ZC	CD (0.05)	CV (%)
Orissa	BBN	5391	2305	2140	1240	21.29
WB	CHN	4167	3712	3384	744	9.57
UP	GGT	2933	2189	2978	289	6.15
Assam	GER	5614	4654	4067	699	8.6
AP	MTU	5994	2742	3182	1135	14.29
	Mean	**4820**	**3120**	**3150**		
	Yield advantage		**1699**	**1670**		
	% increase over check		**54.46**	**53.00**		

The entry was tested in AICRIP trials in four states and the results revealed that the entry registered 4376 kg/ha and found to be significantly superior over the national check, Sabitha (2863 kg/ha) and zonal check Purnendu (2771 kg/ha). Per cent increase over National check was 52.85 and zonal Check was 57.93 (**Table 6**).

Table 6: Performance of MTU 1184 (IET 24486) in AICRIP trials across locations in 2017 in AVT2

State	Location	IET No 24486	Sabitha (NC)	Purnendu (ZC)	C.D. 5%	C.V.%
Orissa	CTK	3599	1583	1546	297	5.44
Orissa	BBN	5147	2778	2574	1240	19.15
West Bengal	CHN	4741	4296	4185	520	6.38
Assam	GGT	3511	3144	2956	483	7.80
AP	MTU	4881	2513	2593	588	10.99
	Mean	**4376**	**2863**	**2771**		
	Yield advantage kg		**1513**	**1605**		
	% increase over check		**52.85**	**57.93**		

The variety was tested in AICRIP trials from 2014 to 2017 over all mean performance of the variety in eight locations of six states of Orissa (Bhuvaneswar, Cuttuck), Bihar (Pusa), Uttar Pradesh (Ghaghraghat), Assam (Gerua, North Lakhimpur) Karnataka (Sirsi) and Andhra Pradesh (Maruteru) was presented in **Table 7**. The variety recorded a mean grain yield 4281 kg/ha and found to be significantly superior over the national check, Sabitha (3011kg/ha) and yield advantage was 1270 kg/ha and per cent increase over national check was 42.17 and zonal check Poornendu (1297 kg/ha and 43.46 respectively).

Multi location testing of the variety from 2015 to 2017 revealed that the variety has out yielded (5370 kg/ha) and found superior over Check PLA 1100 (4290 kg/ha) and per cent increase over check was 25.18 when tested in different locations **(Table 8)**.

Table 8: Performance of MTU 1184 under Multi location Yield Trials (MLTs)

Name of the Trial	Code/ IET No	Year of testing	Entry	PLA 1100 (Check)	Percentage increase over check	Remarks
			Grain yield (kg/ha)	Grain yield (kg/ha)		
MLT (I year)	L516	*Kharif* 2015	5376	4531	18.64	Normal condition
MLT (II year)	S32	*Kharif* 2017	5364	4048	32.51	Normal condition
MEAN			5370	4290	25.18	

The variety was tested in minikit in 890 locations for a period of three years from 2016 (245 locations), 2017 (350 locations) and 2018 (295 locations) and the average mean yield of the variety over three years was 6039 kg/ha against local popular check PLA 1100 (5700 kg/ha) and per cent increase over check was 6.0 when tested in Andhra Pradesh (**Table 9**).

Table 9: Compiled performance of three years in minikits

S. No	Year	No. of locations	Average minikit yield (kg/ha)	Check average yield (kg/ha)	Aver-age% increase
1	2016	245	6241	5883	6.10
2	2017	350	6154	5814	5.86
3	2018	295	5721	5404	5.86
Average		**890**	**6039**	**5700**	**6.00**

Table 7: Overall Mean Performance of MTU 1184 (IET 24486) for Grain Yield (Kg/ha) in AICRIP Trials from 2014-2017

S. No.	Year of study	Mean performance in Eight locations MTU 1184 (IET 24486)	Sabitha (National Check)	Purnendu (Zonal check)	Yield Advantage over NC	Yield Advantage over ZC	Per cent increase over National check	% increase over Zonal check
1	2014	3818	2852	2871	967	947	33.89	32.99
2	2015	4113	3210	3146	903	967	28.13	30.73
3	2016	4820	3120	3150	1699	1670	54.46	53.00
4	2017	4376	2863	2771	1513	1605	52.85	57.93
Overall Mean		**4281**	**3011**	**2984**	**1270**	**1297**	**42.17**	**43.46**

Conclusion

The performance of the variety in station yields trials, AICRIP trials, multi-location trials and minikit testing over 890 locations showed that the significant superiority of the variety performance not only in Andhra Pradesh but also in six states of coastal regions of India. It has good adaptability parameters of tillering ability, kneeing ability, elongation ability in deep water conditions, low grain shattering and good phenotypic acceptability. It has dark green foliage possessing long panicles with medium slender brown glume with semi-tall plant type of 140-150 cm depending upon water depth. It has good grain quality having translucency with grain length 5.28 mm, L/B ratio 2.5, milling 78% and head rice recovery 67%. In future, the new flood tolerant rice variety MTU 1184 could secure stable rice production in country's flood prone areas.

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Assessment of Genotypic Variability for Nitrogen Use Efficiency (NUE) and Improving NUE through Urease Inhibitors in Irrigated Rice

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Abstract

Field experiments (*Kharif* 2021 and *Rabi* 2021-2022) were conducted on a deep black clayey vertisol at the ICAR-Indian Institute of Rice Research farm in Hyderabad to identify efficient rice genotypes for their use of soil N (no external application) and response to applied N (100 kg N/ha) and to improve NUE using urease inhibitors (UIs). Twenty-one popular high-yielding genotypes were tested under two nitrogen levels: N_0 (no nitrogen) and N_{100} (100 kg N/ha). Significant differences were observed among the genotypes in terms of grain yield and various nitrogen use efficiency indices, including agronomic efficiency (AE), physiological efficiency (PE), recovery efficiency (RE), internal efficiency (IE), partial factor productivity (PFP), N requirement (NR), and nitrogen harvest index (NHI). Based on the grain yield data and NUE indices, the top-performing genotypes were Varadhan, Rasi, PSV 181, MTU 1010 and PUP 221 during the wet season, while KRH 4, PSV 181, PSV 344, PSV 190, and PUP 221 excelled during the dry season. Notably, PSV 181 and PUP 221 consistently ranked among the top 5 genotypes in both seasons. Additionally, the application of two urease inhibitors (NBPT and allicin) resulted in a significant increase in grain yield while reducing nitrogen levels by 15-20%.

Key words: Genotypes, Nitrogen levels, Nitrogen use efficiency, Ranking, urease inhibitors.

Introduction

Among the cereal food crops, rice is the most important staple food crop in Asia. Also, it is the livelihood for one fifth of the world's population who depend on rice cultivation as an income source. Among the nutrients, nitrogen is an evergreen essential plant nutrient and its use efficiency is very low (30-40%) in flooded environment. Urea applied to soils undergoes rapid hydrolysis, producing ammonia (NH_3), which can be lost to the atmosphere.

Nitrogen use efficiency (NUE) not only depends on efficient fertilizer management but also on the cultivar that is used. While efficient fertilizer management practices can enhance NUE, their adoption by farmers is limited unless the cultivar exhibits responsiveness. Varieties vary in their capacity to absorb and utilize nutrients, and previous studies (Ladha *et al.,* 1998; Singh *et al.,*1998; Hiroshi, 2003; Surekha *et al.,* 2018) have reported genetic variations in NUE among rice genotypes.

Urease inhibitors are commonly employed to mitigate nitrogen losses in fields and enhance NUE by delaying urea hydrolysis. NBPT, N-(butyl) thiophosphoric triamide is the most efficient and commonly used chemical urease inhibitor worldwide (Cantarella *et al.,* 2018) and their availability is limited. Therefore, natural plant-origin inhibitors such as allicin ($C_6H_{10}OS_2$), an organosulfur compound obtained from garlic (*Allium sativum* L.) extracts were found to exhibit inhibitory properties against urease (Juszkiewicz *et al.*, 2004 and Modolo *et al.,* 2015).

Hence, the present study was undertaken to evaluate the NUE of some existing popular rice varieties and to improve it using urease inhibitors in irrigated rice.

Materials and Methods

Experimental site and soil characteristics

Field experiments were conducted over two seasons: the wet season (*Kharif* 2021) and the dry season (*rabi* 2021-2022) at the Indian Institute of Rice Research farm in Hyderabad on a deep black clayey vertisol (*Typicpellustert*). The study aimed to assess genotypic differences in NUE, identify efficient rice genotypes in terms of soil N utilization and responsiveness to applied N and explore the potential for improving NUE using urease inhibitors (UIs). The experimental soil exhibited slightly alkaline conditions (pH 8.2), was non-saline (EC 0.65 dS/m) and calcareous (with 5.21% free CaCO3). The soil had a cation exchange capacity (CEC) of 42.3 C mol (p+)/kg soil and a medium soil organic carbon content (0.62%). Available nitrogen (N) in the soil was low (220 kg/ha), while available phosphorus (50 kg P/ha), potassium (470 kg K/ha), and zinc (10.5 ppm) were relatively high.

Experiments and their treatment details

In the present study, there were three field experiments and one laboratory experiment. In the first experiment, detailed field studies were conducted for two seasons (*kharif* and *rabi*) at two nitrogen levels [without any external N application (N0) and with a recommended level (100 kg N/ha, N100) of N application] as the main treatments. Twenty-one (21) popular and high-yielding genotypes (varieties and hybrids) were tested as sub-treatments in a split-plot design. In the second experiment, two urease inhibitors (UIs, allicin and NBPT) along with neem-coated urea (NCU) were evaluated at graded levels of N (N0, N50, N75 and N100 kg/ha) in RBD. In experiment three, these two urease inhibitors were tested at 20% reduced N in comparison to 100% NCU in RBD. In all experiments, the recommended dose of fertilizers were given at the rate of 100-40-40-10 kg N, P_2O_5, K_2O and Zn/ha during both seasons through urea, single super phosphate, muriate of potash and zinc sulphate, respectively. Nitrogen was given in three equal splits at basal, maximum tillering and panicle initiation stages while P, K and Zn were given as basal doses only. Plant protection measures, irrigation and weeding operations were done as per the normal practice uniformly for all the experiments. In the laboratory experiment, urease activity in soil was estimated five times during crop growth period by Tabatabai and Bremner, (1972) method.

Observations and data recorded

Grain and straw yields were recorded at harvest and grain and straw samples were analysed for N content using standard procedure by micro Kjeldahl method. Nitrogen uptake by grain, straw and total (grain + straw) was calculated and different parameters of NUE indices *viz*; agronomic (AE), physiological (PE), recovery (RE) and internal efficiency (IE), N requirement (NR), N harvest index (NHI), partial factor productivity (PFP) etc. were computed using grain yield and nitrogen uptake data. Based on the grain yield data at N0 and N100, the genotypes were grouped into efficient (E), responsive (R) and efficient and responsive (ER) genotypes as per Fageria and Baliger, (1993). Based on their NUE indices, the genotypes were ranked based on their mean rank value for all indices as per the procedure followed by Singh *et al.,* (1998). All the data were subjected to standard statistical analysis, by applying analysis of variance for split plot and randomized block designs.

Results and Discussions

Experiment-1

Grain yield at two levels of N application

In the first season (*kharif* 2021), grain yield was significantly higher at N100 compared to N0 which was higher by 30% (**Table 1**) and all genotypes were superior at N100 over N0. With regard to genotypes, some performed very well at N0 showing their high efficiency in utilizing the soil available N in the absence of external N application. The genotypes PUP-221, PUP-223 and PSV-868 are coming in this category of efficient (E) group. Genotypes MTU 1010 and KRH 4 responded well to added N and these are considered as responsive (R) genotypes. Whereas, the genotypes Varadhan and PSV-344 performed well at both levels (N0 and N100) of N showing their efficient as well as responsive nature (ER).

In the second season (*rabi* 2021-22) also, grain yield was significantly higher at N100 compared to N0 by 48% and the per cent yield reduction in N0 over N100 was higher in *rabi* compared to *kharif* indicating high N requirement in dry season **(Table 1)**. With regard to genotypes, similar to the *kharif* season, all genotypes recorded higher yields at N100 than at N0. In this season, the genotypes PSV -344 and PSV-469 at N0; Varadhan at N 100; KRH 4 and PUP 221, PSV 190 at N0 as well as N100 recorded higher yields and are considered as efficient (E), responsive (R) and efficient plus responsive (ER) genotypes, respectively. Best performance of high yielding rice cultivars even at reduced N fertilizer rate was reported by Hiroshi (2003).

Higher grain yield and high response to N in dry season than in wet season in the tropics was also reported by De Datta and Malabuyoc (1976). Superior

Table 1: Grain yield (t/ha) of 21 genotypes at two nitrogen levels

***Kharif* 2021**				***Rabi* 2021-22**			
Variety/Hybrid	**N0**	**N100**	**Mean**	**Varieties**	**N0**	**N100**	**Mean**
Rasi	3.36	4.79	4.08	Rasi	2.90	4.29	3.60
Varadhan	4.10	5.50	4.68	Varadhan	3.81	5.85	4.83
Shanthi	3.69	4.72	4.21	Shanthi	2.86	4.22	3.54
MTU-1010	3.94	5.25	4.72	MTU-1010	3.63	5.61	4.62
Tellahamsa	2.80	3.84	3.32	Tellahamsa	2.90	4.32	3.61
KRH-4	3.95	5.14	4.55	KRH-4	4.07	6.27	5.17
CSR-23	3.33	4.44	3.89	CSR-23	2.84	4.63	3.74
PUP-221	4.14	5.00	4.62	PUP-221	4.05	6.12	5.09
PUP-223	4.07	4.96	4.52	PUP-223	3.82	5.15	4.29
PSV-56	3.81	5.04	4.53	PSV.56	3.37	4.45	3.91
PSV -167	2.83	4.37	3.60	PSV 167	3.81	5.90	4.86
PSV-181	3.81	5.06	4.44	PSV.181	3.44	5.56	4.50
PSV-190	3.46	4.47	3.97	PSV-190	4.20	6.27	5.24
PSV-344	4.20	5.15	4.68	PSV-344	4.10	5.92	5.01
PSV-469	3.46	4.54	4.00	PSV.469	4.00	5.98	4.99
PSV-414	2.97	4.03	3.50	PSV-414	3.52	5.31	4.42
PSV-703	3.43	4.28	3.86	PSV-703	3.53	5.28	4.41
PSV-868	4.04	4.95	4.50	PSV.868	3.67	5.1	4.39
PSV-1103-3	3.56	4.72	4.14	PSV.1103-3	3.99	5.46	4.73
PSV-1110	3.63	4.66	4.15	PSV.1110	3.87	5.42	4.65
PSV-1128	3.25	4.49	3.87	PSV.1128	3.71	5.53	4.62
Mean	3.64	4.73 (30%)		**Mean**	3.62	5.36 (48%)	
CD(0.05)	**Main -0.32; Sub - 0.50; MxS - NS**			**CD(0.05)**	**M-0.51; S- 0.55; MxS - NS**		

performance of genotypes at N100 over N0 could be attributed to the increased chlorophyll formation and photosynthesis thereby leading to increased plant growth, dry matter, yield and yield parameters (Kanade and Kalra, 1986; Tejeswara Rao *et al.,* 2014).

The variation in grain yield among different rice varieties due to their differential efficiency in converting dry matter into grain under different N levels in rice was also reported by Priyadarshini and Prasad (2003) and Srilaxmi *et al.,* (2005).

Nitrogen use efficiency (NUE) indices of genotypes

Some important NUE indices of the genotypes tested in two seasons are given in **Tables 2 and 3**. In general, the agronomic efficiency (AE), physiological efficiency (PE), internal efficiency (IE), recovery efficiency (RE) and partial factor productivity (PFP) are higher in the genotypes that recorded higher grain yield either with or without N addition and these values are in the range of optimum recommended values as suggested by Dobermann and Fairhurst (2000). N requirement was low at N0 due to limited N availability compared to N100 and NHI, that is, partitioning of N to grain was also high with N addition. If we see the seasonal variation, in general, all NUE indices were higher in dry season which could be attributed to better sunshine in dry season that might have helped for efficient utilization of the absorbed nitrogen and comparatively higher grain yield in dry season. NHI also serves as an indicator of the grain's protein content, thereby reflecting its nutritional quality (Sinclair, 1998). Genetic variation in NUE of irrigated rice was also reported by Gueye and Becker (2011).

Table 2: Important nitrogen use efficiency (NUE) indices of genotypes (*Kharif* 2021)

Varieties	**AE**	**PE**	**RE**	**PFP**	**NR**		**IE**		**NHI**		**Rank**		
					N0	N100	N0	N100	N0	N100	N0	N100	Overall
Rasi	14	31	48	48	17.1	21.6	60	46	0.61	0.58	**2**	**1**	**2**
Varadhan	10	17	62	52	16.7	25.2	60	40	0.59	0.58	**1**	**4**	**1**
Shanthi	10	27	41	47	19.7	24.0	51	42	0.54	0.56	16	6	9
MTU-1010	16	22	70	55	18.0	25.6	56	39	0.50	0.58	9	**3**	**4**
Tellahamsa	10	26	41	38	18.6	24.0	55	42	0.53	0.55	18	13	17
KRH-4	11	20	54	50	18.8	25.4	54	39	0.57	0.55	6	**5**	7
CSR-23	11	20	49	44	18.0	24.4	55	41	0.49	0.60	15	8	13
PUP-221	8	17	48	51	17.7	24.3	57	41	0.53	0.55	**3**	11	**5**
PUP-223	8	17	44	50	18.4	24.1	54	42	0.53	0.55	7	14	8
PSV-56	9	16	57	50	19.5	27.2	51	37	0.47	0.55	20	15	16
PSV -167	15	30	50	44	20.1	24.4	50	41	0.52	0.53	21	7	19
PSV-181	12	22	56	51	17.3	24.1	58	42	0.51	0.55	**5**	**2**	**3**
PSV-190	10	21	47	45	19.0	25.1	53	40	0.54	0.55	17	19	20
PSV-344	8	16	52	51	18.9	25.8	53	39	0.52	0.52	13	17	14
PSV-469	11	19	57	45	17.2	25.6	58	39	0.53	0.51	**4**	18	12
PSV-414	11	22	46	40	18.2	24.9	55	40	0.54	0.52	11	20	18
PSV-703	9	17	48	43	18.9	26.3	53	38	0.53	0.53	19	21	21
PSV-868	9	21	43	49	19.8	24.8	51	40	0.55	0.50	14	16	15
PSV-1103-3	12	24	46	47	18.3	23.6	55	42	0.56	0.53	8	**9**	6
PSV-1110	10	22	44	47	18.7	23.9	54	42	0.54	0.51	12	12	11
PSV-1128	12	20	55	45	17.9	25.0	56	40	0.53	0.55	10	10	10
Mean	**10.8**	**21.3**	**50.4**	**47.2**	**18.4**	**24.7**	**55**	**41**	**0.53**	**0.55**			

AE- Agronomic efficiency (kg grain yield increase/kg N added); PE- Physiological efficiency (kg grain/ kg N uptake; RE- Recovery efficiency (% of N recovered); PFP- Partial factor productivity (kg grain/ kg N added); NR- N requirement (kg N/ton); IE - Internal efficiency (kg grain/ kg N taken up); NHI-Nitrogen harvest index

Ranking of genotypes based on nitrogen use efficiency (NUE) indices

Based on the NUE indices at both N levels, the genotypes were ranked **(Tables 2 and 3)**. Since no single genotype recorded maximum values for all indices and none of the genotypes possessed same rank for all NUE indices, the ranking was done based on the mean value of their ranks at N0 and N 100 and overall ranking was done as was also done as per Singh *et al.,* (1998) and Rao *et al.,* (2006). Thus, Varadhan, Rasi, PSV 181, MTU 1010 and PUP 221 in *kharif;* KRH 4, PSV 181, PSV 344, PSV 190 and PUP 221 in *rabi* stood in the top 5 out of 21 genotypes while PSV 181 and PUP 221 were in the top 5 in both seasons. The consistent performance of efficient genotypes over a range of soil and fertilizer N supply was also reported by Singh *et al.,* (1998). Grouping of genotypes based on grain yield and their ranking based on NUE indices indicated the emergence of same genotypes from both categories as the most N use efficient genotypes. Similar ranking system and genotype performance for NUE in rice was also given by Broadbent *et al.,* (1987).

Table 3: Important nitrogen use efficiency (NUE) indices of genotypes (*Rabi* 2020-21)

Varieties	AE	PE	RE	PFP	NR		IE		NHI		Rank		
					N0	N100	N0	N100	N0	N100	N0	N100	Overall
Rasi	11	24	46	43	14.0	21.8	71	46	0.49	0.64	**7**	19	13
Varadhan	16	24	66	58	14.6	22.5	68	44	0.59	0.66	**3**	14	7
Shanthi	11	27	40	42	15.5	21.5	64	46	0.53	0.65	12	18	15
MTU-1010	14	27	52	56	15.7	21.7	64	46	0.48	0.67	20	11	17
Tellahamsa	11	29	38	43	17.1	21.8	58	46	0.55	0.66	17	15	18
KRH-4	19	31	61	63	13.5	19.4	74	51	0.57	0.69	**1**	**1**	**1**
CSR-23	15	29	51	46	15.3	21.8	66	46	0.52	0.65	11	12	11
PUP-221	18	28	64	61	15.5	21.8	65	46	0.58	0.68	**6**	**5**	**5**
PUP-223	14	26	54	51	15.5	22.2	64	45	0.47	0.65	19	17	19
PSV-56	8	35	22	44	16.2	18.6	62	54	0.55	0.67	15	**5**	12
PSV -167	16	36	45	59	17.3	20.4	58	49	0.56	0.65	18	**6**	14
PSV-181	14	33	44	56	14.5	19.3	69	52	0.58	0.68	**2**	**3**	**2**
PSV-190	18	29	60	63	14.9	20.6	67	48	0.51	0.66	10	**2**	**4**
PSV-344	18	27	68	59	13.9	21.6	72	46	0.53	0.63	**4**	8	**3**
PSV-469	17	28	61	60	14.8	21.2	67	47	0.55	0.62	**5**	9	**6**
PSV-414	10	18	55	53	15.4	23.3	65	43	0.46	0.57	16	21	20
PSV-703	15	27	53	53	16.0	22.0	63	46	0.56	0.60	14	16	16
PSV-868	11	26	43	51	17.1	22.0	58	45	0.53	0.64	21	20	21
PSV-1103-3	12	26	45	55	14.6	20.0	69	50	0.50	0.70	8	10	8
PSV-1110	13	24	53	54	14.5	21.2	69	47	0.47	0.65	9	13	9
PSV-1128	15	33	46	55	15.4	19.6	65	51	0.49	0.61	13	7	10
Mean	**14**	**28**	**51**	54	**15.3**	**21.2**	**66**	**47**	**0.53**	**0.65**			

AE- Agronomic efficiency (kg grain yield increase/kg N added); PE- Physiological efficiency (kg grain/ kg N uptake; RE- Recovery efficiency (% of N recovered); PFP- Partial factor productivity (kg grain/ kg N added); NR- N requirement (kg N/ton); IE - Internal efficiency (kg grain/ kg N taken up); NHI-Nitrogen harvest index

Experiment-2

Grain yield at graded levels of N with urease inhibitors (UIs)

During *kharif* 2021, grain yield was maximum at N100 (5.68 t/ha) but was on par to N75 (5.41 t/ha). These two treatments were significantly superior to other N levels (N0 and N50 with 3.97 and

4.53 t/ha, respectively) (**Figure 1**). With regard to urease inhibitors (UIs), two UIs, allicin and NBPT recorded significantly higher yield than NCU by 17 and 25%, respectively. During *rabi* 2021-22, the trend was same showing no significant difference between N75 and N100 with 6.37 and 6.48 t/ha, respectively. Here also, UIs recorded higher yield by 12% over NCU (**Figure 2**). Overall, a 25% saving in N was observed in both seasons. Improved NUE in addition to 25% Nitrogen saving with INM was also reported by Lakshmi *et al.,* (2012). Similar findings were reported by Yang *et al.,* (2020) that the application of urea combined with Azolla and a urease inhibitor (NAUI) reduced NH_3 volatilization by 54.6% compared to plots treated with urea and Azolla alone (NA). Additionally, the NAUI-treated plots showed an increase in grain yield by 9.0-9.7%, primarily attributed to enhanced nitrogen uptake (35.8%). Carlos *et al.,* (2022) also highlighted the relevance of using the urease inhibitor NBPT to mitigate ammonia volatilization, improve agronomic efficiency, and enhance grain yield, especially when there are delays in irrigation.

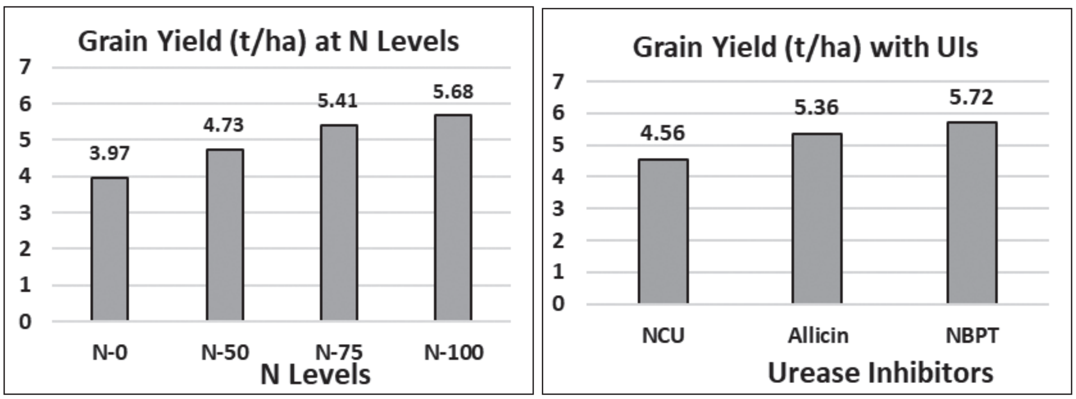

Figure 1: Grain Yield at graded levels of N and with Urease inhibitors (*kharif* 2021)

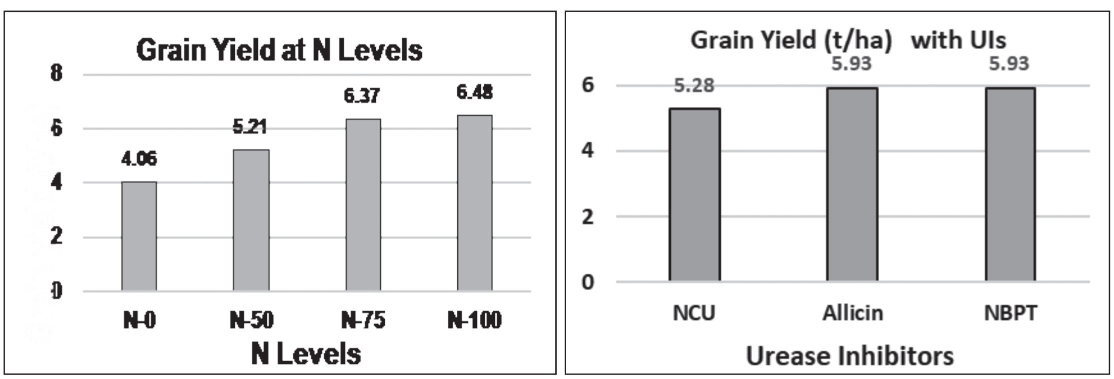

Figure 2: Grain Yield at graded levels of N and with Urease inhibitors (*rabi* 2021-22)

Experiment-3

Grain yield at reduced levels of N with urease inhibitors (UIs)

For the confirmation of benefit from UIs, in this separate experiment conducted simultaneously with 20% reduced N with UIs and 100% N with NCU, UIs recorded higher yield by 9 and 13% in *kharif* and 20 and 28% in *rabi* with allicin and NBPT, respectively over NCU (**Figure 3**). Thus, a 20% saving can be achieved when UIs are used in both seasons. Drulis *et al.,* (2022) found that Urease inhibitors along with biologics have showed effective increase in maize yield and also showed decreased usage of nitrogen fertilizers. Cui *et al.,* (2024) reported combined use of Controlled release urea (CRU) and Urease Inhibitor (UI) treatment achieve higher yields than with CRU at same N level and at 20% reduction of N use, one-time application of CRU + UI recorded same high yield as the conventional split application of urea.

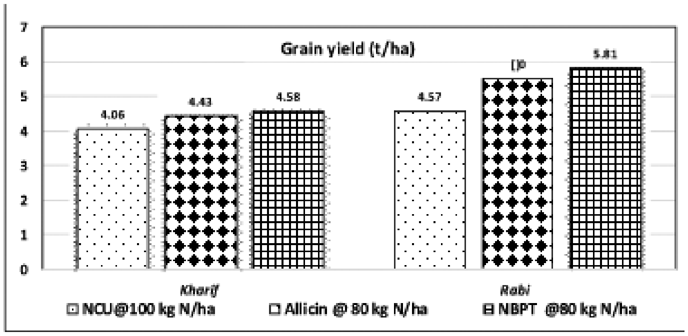

Figure 3: Grain Yield with urease inhibitors at reduced levels of N

Urease activity in soil with urease inhibitors

Urease activity was estimated five times during crop growth period *viz*; after basal, before and after first split application and before and after second split application to know the pattern of N release from urea with and without urease inhibitors and presented in **Figure 4**. Urease activity was high with NCU and low when UIs were used for coating on NCU. Urease inhibition was high with NBPT compared to allicin but these two exhibited higher inhibition than NCU. Similar results from a laboratory study by Ranitha Mathialagan *et al.,* (2017) demonstrated the potential of allicin as a viable urease inhibitor and higher inhibition by NBPT compared to allicin. This indicated the slow and gradual release of N over a period of time as per the crop needs when UIs are used and this might have reflected in higher yield. Further, the loss of N through many ways might have been reduced by keeping the N in amide form for longer period and the released NH4-N was also retained in the soil for a longer period due to clayey texture of the soil and was made available to the crop. Greater adsorption of NH4-N on the clay complex in fine textured soils with higher clay content was also reported by Suraya *et al.,* (2007).

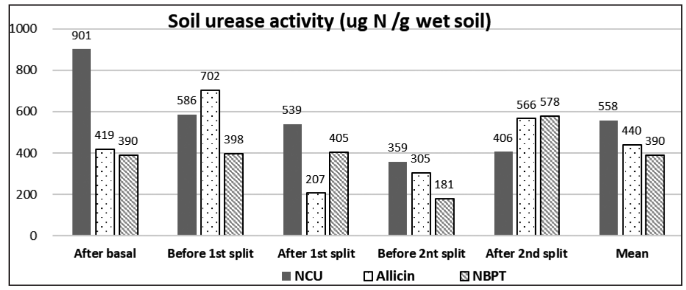

Figure 4: Urease activity (ug N /g wet soil) during *kharif* 2022

Conclusion

The conclusions that can be drawn from the present study are: significant genotypic variation with regard to grain yield and various nitrogen use efficiency (NUE) indices under reduced levels as well as at recommended N conditions; urea coating with urease inhibitors can save about 20-25% N and N release was slow and gradual throughout the crop growth period when urease inhibitors are used thus reducing the soil, water and environmental pollution.

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Energy Use Efficiency of Late Sown Short Duration Rice Varieties Under Different Nitrogen Management Practices

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Abstract

One of the major causes of low nitrogen use efficiency in rice is the application of fertilizer nitrogen (N) more than crop requirement at times when it is not required by plant during late sown conditions. This experiment was conducted at Rajendranagar farm of ICAR-Indian Institute of Rice Research, Hyderabad during *kharif* 2021. The experiment was laid out in split plot design with three replications. Main plots consisted of three short duration rice varieties DRR Dhan-44, MTU 1010, MTU 1156 and four nitrogen management practices (sub-plots) *viz.,* recommended dose of nitrogen (RDN) @ 120 kg N ha^{-1}, Silicon coated urea (SCU) @ 90 kg ha^{-1}, Leaf Colour Chart based N application (LCC) @ 105 kg N ha^{-1}, Soil test crop response based N application (STCR) @ 114.5 kg N ha^{-1}. Among the varieties highest energy input (13.22 GJ ha^{-1}) was recorded in DRR Dhan-44 but energy output (172.6 GJ ha^{-1}) and energy use efficiency (10.26 GJ ha^{-1}) were recorded in MTU 1156. Among the N management practices highest energy input (13.94 GJ ha^{-1}) was recorded in RDN @ 120 kg N ha^{-1} and energy use efficiency (10.38 GJ ha^{-1}) was recorded with Leaf colour chart based N application@105 kg Nha^{-1}.

Key words: LCC, nitrogen use efficiency, STCR, short duration variety, silicon coated urea.

Introduction

Rice (*Oryza sativa* L.) is a staple food for more than half of the world's population. India is the world's second largest producer of rice, accounting for 20 per cent of world rice production. Global warming and aberrant weather conditions causes unpredictable rainfall during monsoon and it leads to late sowing of rice specially in *kharif*. Late sown long duration rice varieties are often victims of cyclones. So, there is a great need to introduce short duration rice varieties in such areas which can escape these extreme climatic aberrations. And also proper sowing time of *rabi* crops therefore, improving the cropping intensity. Under late sown conditions, sowing of medium and short duration varieties is the best option as they will be exposed to high or low temperature stress for shorter time in their reproductive phase compared to long duration varieties, therefore, reducing the chances of spikelet sterility and poor grain filling (Murthy *et al*., 2010). Energy use in agricultural production has become more intensive now a days due to the use of fossil fuel, inorganic fertilizers, pesticides, machinery and electricity to provide substantial increases in food production (Tuti *et al.,* 2014, 2013). Hence, energy use efficiency has been important for sustainable development in agriculture systems. Efficient use of input energy resources such as fertilizers and seeds not only save fossil fuel resources but also provides financial savings of farmers (Singh and Singh, 2004).

Recently, by knowing the initial soil nitrogen status with STCR and with the help of Leaf Color Chart (LCC) real-time N management strategies have been developed for rice (Ladha *et al*., 2005). Recent research has mentioned that efficient use of energy in agriculture is one of the requisites for sustainable agricultural production, since it offers financial savings, fossil resource preservation and above all reduction in its global warming potential (Agha Alikhani *et al.,* 2013). Besides land, farm power is the second most important input to agriculture production. So, there is great need to improve the energy use efficiency of input energy resources such as fertilizers and varieties under the late sown and climatic aberration conditions.

Materials and Methods

The trial was conducted at Indian Institute of Rice Research (IIRR) farm, Rajendranagar geographically situated at an altitude of 542.3 m above the mean sea level and located at 17° 19' N latitude and 78° 23" E longitude, Hyderabad. During the crop growth period, a total rainfall of 782.6 mm was received. The daily mean bright sunshine during the crop growth period ranged from 1.7 to 8.1 hours, with an average of 4.6 hours and the daily mean evaporation (mm) during the crop growth period was 3.36 mm. The weekly mean maximum temperature ranged from 27.6 to 31.6 °C with an average of 29.6 °C, weekly mean minimum temperature ranged from 16.4 to 25.5 °C with an average of 21.2 °C. The soil of the experimental site was clay loam in texture, non-saline in nature, low in available soil nitrogen is (250 kg ha^{-1}), phosphorus (34.0 kg ha^{-1}) and potassium (265.5 kg ha^{-1}) with pH of 7.4.

The trial was laid out in split plot design with three replications. And it consists of 3 main plots three short duration rice varieties DRR Dhan-44, MTU 1010, MTU 1156 with 120 days duration was selected for the study. Good quality seed of three varieties @ 25 kg/ha was soaked and incubated in moist gunny bag for 24 hours. The sprouted seed was broadcasted uniformly on a well-prepared nursery bed for transplanting in respective beds. The seedlings were maintained in the nursery for up to 30 days and Thirty days old seedlings were line planted by adopting a spacing of 20 cm x 15 cm. and sub-plots with four N management practices *viz.,* recommended dose of N (RDN) @ 120 kg N ha^{-1}, Silicon coated urea (SCU) @ 90 kg ha^{-1}, Leaf Colour Chart based N application (LCC) @ 105 kg N ha^{-1} Soil test crop response based N application (STCR) @ 114.5 kg N ha^{-1} with target yield of 6 t ha^{-1}.

All rice varieties are short duration (120 days) and sown at August 1st week 2021 and harvested at December 18th 2021. Recommended dose of N-P_2O_5-K_2O was 120-60-40 kg per hectare. Recommended dose of nitrogen (120 kg ha^{-1}) was applied through urea in three equal splits at basal, active tillering and panicle initiation stages. Silicon coated slow-release urea was developed in laboratory of ICAR-IIRR and applied @ 75% of RDN (90 kg ha^{-1}) in equal three splits. Whenever, the LCC values were found to be below the fixed critical level of three, the recommended quantity of N was applied @ 25 kg ha^{-1} and the basal dose of N was applied at 30 kg ha^{-1}. In LCC based N management total 105 kg N ha^{-1} was applied in 4 splits. The fertilizer prescription equation to attain specific yield targets based on soil available nutrient levels for the experimental field was FN = 42 T - 0.55 SN. The targeted yield was 6 t ha^{-1}. Accordingly, the N dose was 114.5 kg ha^{-1}.

Weeds in the experimental field were managed by hand weeding at critical period of crop weed competition *i.e.,* 15 and 45 DAT to keep the field weed free. Bispyribac sodium was applied at 2-3 leaf stage of weeds at 15 DAT of rice crop to control the weeds. At the time of sowing a thin film (2-3 cm) of water was maintained for better establishment of seedlings. A depth of 5 to 2 cm water level was maintained during the entire crop period except at the time of top dressing of fertilizers. From panicle initiation stage to 21 days after flowering, 5 cm depth of water was maintained. Last irrigation was provided at seven to ten days before physiological maturity stage of the crop. Spraying of chloripyriphos 1.6 ml $L^{-1}$and carbofuran granules 7.5 kg ha^{-1}, Cartap hydrochloride 50% SP @ 2g L^{-1} for the control of leaf folder and yellow stem borer respectively. The crop was harvested when grain and straw color changed from green to straw yellow colour. Harvesting was carried out manually with the help of sickles leaving about 5 to 10 cm stubbles in the field. Energy input, output and energy use efficiency of individual varieties and nitrogen management practices was calculated using an energy co-efficient value for each treatment. The energy input was calculated as the summation of energy requirements for labour, farm machinery, seed, fertilizers and irrigation used in the system and expressed in (GJ ha^{-1}). output energy from the main product (grain) and byproduct (straw) was calculated by multiplying the amount of production by its corresponding energy equivalent expressed as (GJ ha^{-1}) and the energy use efficiency was calculated by using the following formula.

$$\text{Energy Use Efficiency} = \frac{\text{Gross energy output (GJ ha}^{-1})}{\text{Total energy input (GJ ha}^{-1})}$$

The level of significance used in ‘F’ and ‘t’ test was at 5% probability. Wherever ‘F’ test was found significant, the ‘t’ test was used to estimate critical differences among various treatments **(Table 1).**

Table 1: Yield total input energy, energy output and energy use efficiency of rice varieties and nitrogen management practices

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)	Energy Input (GJ ha^{-1})	Energy Output (GJ ha^{-1})	Energy use Efficiency (GJ ha^{-1})
Varieties						
M_1: DRR Dhan-44	5314	6636	44.50	13.22	161.0	9.52
M_2: MTU 1010	4856	6054	44.43	13.17	147.0	8.72
M_3: MTU 1156	5707	7102	44.60	13.14	172.6	10.26
SEm (±)	96.7	116	0.75	-	1.85	0.06
CD (P=0.05)	379	456	NS	-	7.2	0.26
CV (%)	6.3	6.1	5.8	-	4.1	3.25
N management practices (kg ha^{-1})						
S_1: RDN @ 120 kg N ha^{-1}	5478	6778	44.71	13.94	165.2	9.37
S_2: Silicon coated urea @ 90 kg N ha^{-1}	4731	5967	44.21	12.12	144.1	9.12
S_3: Leaf colour chart @ 105 kg N ha^{-1}	5758	7112	44.79	13.03	173.5	10.38
S_4: Soil test crop response @ 114.5 kg N ha^{-1}	5203	6530	44.34	13.61	158.1	9.14
SEm (±)	127	147.8	0.82	-	2.69	0.16
CD (P=0.05)	378	439	NS	-	7.9	0.48
CV (%)	7.2	6.7	5.59	-	5.1	5.25

Results and Discussions

Yield and Harvest Index

Among short-duration rice varieties, MTU 1156 recorded the highest grain yield (5707 kg ha^{-1}), followed by DRR Dhan-44 (5314 kg ha^{-1}), both significantly outperforming MTU 1010 (4856 kg ha^{-1}). These results align with Mohapatra *et al.,* (2021). Higher seed yield is associated with a greater number of tillers per square meter (Nayaka *et al.,* 2021). Similar results were also reported by Senthil Kumar *et al.,*

(2021) short duration variety CO 53 and Anna 4 is best suitable under semi-dry system with 100 per cent recommended dose of fertilizer.

In terms of nitrogen management, the highest grain yield was observed with LCC @ 105 kg N ha⁻¹ (5758 kg ha⁻¹), on par with RDN @ 120 kg N ha⁻¹ (5478 kg ha⁻¹). STCR @ 114.5 kg N ha⁻¹ yielded 5203 kg ha⁻¹, like RDN @ 120 kg N ha⁻¹. The lowest yield was with silicon-coated urea @ 90 kg N ha⁻¹ (4731 kg ha⁻¹). Effective nitrogen management during critical physiological phases enhances photosynthate assimilation (Suresh *et al.,* 2017; Moharana *et al.,* 2017). The nitrogen level 120 kg N ha⁻¹ recorded the highest grain yield as compared to the 80 kg N ha⁻¹ (Kacha *et al.,* 2023).

MTU 1156 also achieved the highest straw yield (7102 kg ha⁻¹), significantly higher than other varieties, with MTU 1010 having the lowest (6054 kg ha⁻¹). This is attributed to MTU 1156's higher tiller production and nitrogen use efficiency (Chandra and Kumar, 2020). LCC @ 105 kg N ha⁻¹ led to the highest straw yield (7112 kg ha⁻¹), similar to RDN @ 120 kg N ha⁻¹ (6778 kg ha⁻¹). STCR @ 114.5 kg N ha⁻¹ recorded 6530 kg ha⁻¹, superior to silicon-coated urea @ 90 kg N ha⁻¹ (5967 kg ha⁻¹) due to better growth parameters (Kumar *et al.,* 2018).

MTU 1156 had the highest harvest index (44.60%). Among N management practices, LCC based N management showed the highest harvest index (44.79%) due to effective N application and increased efficiency, leading to higher grain yield and harvest index (Huang *et al.,* 2021; Moharana *et al.,* 2017).

Total input energy

Among the varieties (**Figure 1**) DRR Dhan-44 recorded the highest total input energy (13.22 GJ ha⁻¹) followed by MTU 1010 (13.17 GJ ha⁻¹) and the lowest input energy was found with MTU 1156 (13.14 GJ ha⁻¹). Among the N management practices (**Figure 2**) RDN @ 120 kg N ha⁻¹ resulted in the highest total input energy (13.94 GJ ha⁻¹) followed by STCR @ 114.5 kg N ha⁻¹ (13.61 GJ ha⁻¹). LCC @ 105 kg N ha⁻¹ recorded the total input energy of 13.03 GJ ha⁻¹. The lowest total input energy (12.12 GJ ha⁻¹) was recorded in silicon coated slow-release urea @ 90 kg N ha⁻¹.

Total output energy and energy use efficiency

Regarding the total output energy and energy use efficiency among the varieties MTU 1156 recorded the highest total output energy (172.60 GJ ha⁻¹) so it has higher energy use efficiency of 10.26 GJ ha⁻¹. MTU 1010 recorded the lowest total output energy (147.0 GJ ha⁻¹) and energy use efficiency (8.72 GJ ha⁻¹). Among the N management practices, LCC @ 105 kg N ha⁻¹ recorded the highest total output energy (173.5 GJ ha⁻¹) and energy use efficiency (10.38 GJ ha⁻¹). RDN @ 120 kg N ha⁻¹ recorded total output energy and energy use efficiency of 165.2 GJ ha⁻¹ and 9.37 GJ ha⁻¹, respectively. STCR @ 114.5 kg N ha⁻¹ recorded with total output energy and energy use efficiency of 158.1 GJ ha⁻¹ and 9.14 GJ ha⁻¹, respectively. The lowest total output energy (144.1 GJ ha⁻¹) and energy use efficiency (9.12 GJ ha⁻¹) were recorded with silicon coated slow-release urea @ 90 kg N ha⁻¹.

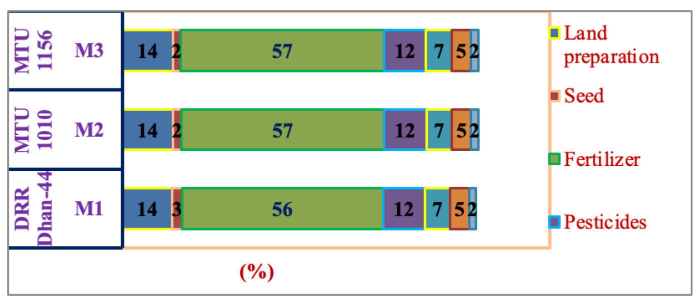

Figure 1: Distribution of total input energy (%) of short duration varieties

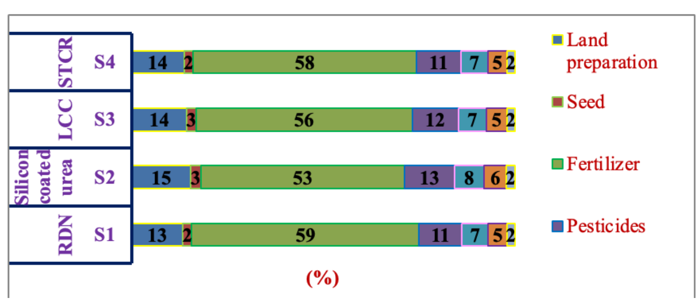

Figure 2: Distribution of total input energy (%) of rice cultivation as influenced by nitrogen management practices

Higher total input energy in DRR Dhan-44 this might be due the more seed rate as compared to other varieties. Higher total input energy in RDN @ 120 kg N ha^{-1} might be due to the more application of N as compared to the other management practices (Paramesh *et al.,* 2017). Soni and Soe (2016) also reported that higher total energy input in rice due to application more N fertilizers, manure management (FYM application) and frequent irrigation in rice. Regarding total output energy and energy use efficiency among the varieties, MTU 1156 had produced the highest grain and straw yield as compared to rest of the varieties. Higher grain and straw yields in MTU 1156 led to higher gross output energy and net energy. Nayaka *et al.,* (2021) reported that among the varieties, significant variations in grain and straw yields brought out dissimilarity in gross output energy and energy use efficiency.

Among the N management practices, the highest total output energy and energy use efficiency was recorded in LCC @ 105 kg N ha^{-1}. This might be due to the higher grain and straw yield in this treatment compared to other N management practices. Variation in energy input among nutrient management practices may be attributed to varying inputs and crop management practices like tillage, fertilizer application, water, weed, pest and disease management, etc. Likewise, higher energy consumption under this practice was due to higher energy equivalents of fertilizers applied to the crop (Varatharajan *et al.,* 2019). Application of nitrogen based on LCC and STCR recorded significantly higher gross output energy and net energy as compared to other nitrogen management practices. The higher gross output energy with LCC was attributed to maximum grain and straw yields, higher net energy due to less input energy and more total energy output (Sudhakara *et al.,* 2017).

Conclusion

From the results of the present study it can be concluded that among the varieties MTU 1156 recorded the highest in yield, harvest index and energy output, energy use efficiency of 172.and 10.26 respectively under late sown conditions and among the nitrogen management practices LCC@105 kg N recorded the highest in yield, energy output (173.5), energy use efficiency (10.38) of rice. Even though low application of nitrogen as compared to RDN@120 kg N due to real time nitrogen management it escapes the climatic aberrations like cyclone and performs better. So, under late sown conditions MTU 1156 with LCC@105 kg N recommended to the farmers of Telangana to get normal yield without reduction in yield.

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Field Screening of Rice Genotypes for Resistance to Major Rice Pests

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Abstract

Preliminary screening studies against rice stem borer and leaf folder were conducted at Regional Agricultural Research Station, Pattambi during *kharif* 2016 and *rabi* 2016-17 involving 14 rice cultures and susceptible check TN 1. The promising rice genotypes were evaluated under All India Coordinated Research Project on Rice (AICRPR) Hyderabad during *kharif* 2017, 2018 and 2019 under Stem borer screening trial, Leaf folder screening trial and multiple pest resistance screening trial. The rice culture KAUPTB 0627-2-11 (Cul 06-1) offered resistance to stem borer (both dead hearts and white ears). Cultures JS1,3,5 and 7 showed tolerance to both Stem borer and Leaf folder while Cul M9 exhibited field tolerance to multiple pests like Stem borer, mixed population of planthoppers and leaf folder.

Key words: Stem borer, Leaf folder, Field screening, multi-location testing, AICRPR

Introduction

Rice is an important staple crop of Asia occupying about 145 m ha or in about 11 per cent of the world's cultivated land (Raheja, 1995). India being the second-largest rice growing country produces about 104.32 million tonnes in about 44.6 million hectares at an average productivity of 2.34 tonnes per hectare (Rajasekaran and Jeyakumar, 2014). Rice plant is subjected to attack by more than 100 species of insects, of which 20 species are of economic importance causing 20-30% yield losses every year (Chatterjee *et al*., 2017). Yellow stem borer, *Scirpophaga incertulas* (Walker) and Leaf folder (*Cnaphalocrocis medinalis* Guenée) of rice are considered as prime devastators responsible for major economic loss (Chatterjee and Mondal, 2014; Chatterjee *et al*., 2017). The host plant resistance depends upon the relationship between the plant-feeding insects and their host plants (Painter, 1951) which enables plants to avoid, tolerate or recover from the effects of insect pest attack and this mechanism has been proved to be a successful tool to protect crops from insects attack (Felkl *et al*., 2005). This investigation reports the performance of cultures from Regional Agricultural Research Station, Pattambi against Leaf folder and Stem borer.

Materials and Methods

Field screening at RARS Pattambi

Field evaluation of 14 rice cultures was carried out at Regional Agricultural Research Station, Pattambi during *kharif* 2016 and *rabi* 2016-17. The entries were planted in a row of 20 hills at a spacing 20x15 cm with TN1 as the susceptible check. The promising entries against yellow stem borer and leaf folder were selected and nominated for testing at multiple locations during *kharif* 2017, 2018 and 2019 under All India Co-ordinated Research Program on rice (AICRPR), Hyderabad. The rice genotypes were tested separately under stem borer screening trial (SBST), leaf folder screening trial (LFST). The most performing entries were further evaluated in Multiple resistance screening trial (MRST) at ICAR-IIRR, Hyderabad. The standard screening methodology (IIRR Technical programme 2019) was followed with resistant checks: PTB 33 for brown planthopper, W 1263 for leaf folder and gall midge, TKM 6 for stem borer and TN1 as susceptible check. The observations on total tillers, number of dead hearts (vegetative phase); panicle bearing tillers and number of white ears (reproductive phase), total leaves and damaged leaves for leaf folder were recorded and the percent damage was calculated. Damage by mixed population of planthoppers was assessed on visual basis and damage score was given in the scale of 0-9. At all the locations data was considered when the field incidence was very high and at ICAR-IIRR the stem borer damage though natural incidence was supplemented with release of larvae.

Multilocation evaluations under AICRPR: The best entries identified at Pattambi were tested at multiple locations in the pest specific trials *viz*., in stem borer screening trial (SBST) for stem borer and in Leaf folder screening trial (LFST) for leaf folder for two seasons. The entries were also tested in MRST trial to observe the reaction against other pests.

Results and Discussions

Field evaluation at Pattambi

Pooled analysis of the pest damage data of *kharif* 2016 and *rabi* 2016-17 revealed that the dead heart damage did not vary significantly among the cultures tested. However, at reproductive phase, significantly lower white ear damage was noticed in KAUPTB 0627-2-11(1.08%) and KAUPTB 0627-2-14 (1.50%), CulM9 (1.66%), JS1(1.81%), JS3(1.70%), JS5 (1.87%) and JS 7 (1.92%). At 45 days after transplanting nil leaf damage of leaf folder was noticed in Cul M9 while significantly lower damage was recorded in four entries *viz.,* Cul M8 (0.36), JS1 (0.58), Cul M4 (1.03), JS 3 (1.20). At 60 DAT Cul M9 recorded lower leaf damage (5.82) followed by Cul M8 (6.55), JS1 (9.70), JS 3 (10.22), JS4 (10.42), JS (10.89) and Kalluri sel (14.62) as against highest leaf damage in TN1 (82.75) followed by KAUPTB 0627-2-11 (70.24) (**Table 3**).

Reaction to stem borers: During *kharif* 2017 and 2018, KAUPTB 0627-2-11and KAUPTB 0627-2-14 were evaluated along with other cultures in the multilocation testing under stem borer screening trial. The mean per cent dead heart, per cent white ear and per cent leaf folder damaged leaves did not significantly differ among the cultures tested in both the seasons. However, it was interesting to note that KAUPTB 0627-2-11 (Cul 06-1) recorded lower dead heart damage (**Table 3**).

The results of screening under station trials showed that among the 14 cultures tested during *kharif* 2016, the cultures KAUPTB 0627-2-11 and KAUPTB 0627-2-14 lowest dead heart and white ear with 0.90, 1.03 per cent and 1.12, 1.50 followed by Cul M9 with 2.35, 1.57 per cent at 30 and 75 DAT against TN 1 with 12.50 and 15.50 per cent dead hearts and white ears at 30 and 75 days after transplanting. The results during *rabi* 2016-17 showed similar results with KAUPTB 0627-2-11 and KAUPTB 0627-2-14 showed lowest dead hearts and white ear with 5.41, 1.12 per cent and 4.52,1.50 followed by Cul M9 with 9.05, 1.74 per cent and JS 3 with 9.72 and 1.80 per cent at 30 and 75 days after transplanting against TN 1 (Check) with 16.50 and 30.15 per cent dead hearts and white ears at 30 and 75 days after transplanting as in **Table 1 and 2**. Results from All India coordinated programme during *kharif* 2017 under SBST showed that the dead heart damage in the trial varied from 0.0-48.1% with an average damage of 17.4% DH across the 6 locations in 8 valid tests. Evaluation of entries for dead heart damage at six locations in two staggered sowings identified KAUPTB 0627-2-11 was found promising with nil damage in one of the 8 tests. The white ear damage across 8 locations in 11 valid tests varied from 0 to 82% with a mean of 9.7% white ears. KAU PTB 0627-2-11 was found promising in 11 valid tests

Table 1: Screening rice genotypes against major rice pests at RARS, Pattambi (*kharif* 2016)

Cultures	Parentage	Stem borer		Leaf folder	
		%DH (30DAT)	%WE (75 DAT)	% DL (45 DAT)	% DL (60 DAT)
KAUPTB 0627-2-11 (Cul 06-1)	Swetha x Kuruka	**0.90**	**1.03**	2.00	85.56
KAUPTB 0627-2-14 (Cul 06-2)	Swetha x Kuruka	**1.12**	**1.50**	3.50	45.50
Cul M4	Mutant of PTB 18	3.50	16.50	4.40	56.01
Cul M6-2	170 Gy Mutant of PTB 18	3.51	14.30	**0.00**	**5.25**
Cul M8	170 Gy Mutant of PTB 21	3.53	7.92	0.00	9.01
Cul M9	Mutant 220 Gy of PTB 18	**2.35**	**1.57**	**0.00**	**8.28**
Cul JS 1	Pure line sln from Jaya	7.70	1.98	0.00	10.60
Cul JS-2	Pure line sln from Jaya	5.88	8.70	1.84	71.43
Cul JS 3	Pure line sln from Jaya	8.33	1.60	0.54	11.13
Cul JS 4	Pure line sln from Jaya	0.00	14.75	0.84	11.20
Cul JS 5	Pure line sln from Jaya	9.43	1.80	1.01	11.62
Cul JS 6	Pure line sln from Jaya	8.51	10.96	1.10	18.88
Cul JS 7	Pure line sln from Jaya	9.32	1.85	0.61	13.01
Kalluruli Sel.	Sln from land race Kalluruli	3.70	18.82	1.12	21.14
TN1		12.50	15.50	5.76	100

with nil white ear damage (**Tables 4 and 5**) (AICRIP progress report 2018 and 2019). During the second year of testing under SBST trial during *kharif* 2018, the dead heart damage varied from 3.0 to 42.1% with an average damage of 19.9% DH across 5 locations in 9 valid tests. Evaluation of entries for dead heart damage at 30 and 50 DAT in two staggered sowings helped in identification of four retested entries - KAUPTB 0627-2-11, as promising in 2 of the 9 tests with ≤10% DH (DS3.0). The white ear damage across 5 locations in 6 valid tests varied from 0.0 to 78.8% with a mean of 21.1%WE. KAUPTB 0627-2-11 showed lowest white ear incidence of 2.2, 6.4 and 8.1% at three locations. In terms of grain yield, KAUPTB 0627-2-11, and TKM 6 were promising in 3 of the 4 tests (**Tables 6 and 7**) with ≥15g/hill in 3 of the 4 valid tests (AICRIP Progress report, 2019 and 2020).

Table 2: Screening rice genotypes against major rice pests at RARS, Pattambi (*rabi* 2016-17)

Cultures	Parentage	Stem borer		Leaf folder	
		%DH (30 DAT)	%WE (75 DAT)	% DL (45 DAT)	% DL (60 DAT)
KAUPTB 0627-2-11Cul 06-1	Swetha x Kuruka	**5.41**	**1.12**	8.11	54.87
KAUPTB 0627-2-14 (Cul 06-2)	Swetha x Kuruka	**4.52**	**1.50**	3.15	42.50
Cul M4	Mutant of PTB 18	22.80	36.11	**2.06**	**9.42**
Cul M6-2	170 Gy Mutant of PTB 18	31.25	18.91	4.08	75.60
Cul M8	170 Gy Mutant of PTB 21	23.07	11.11	**0.71**	**4.08**
Cul M9	Mutant 220 Gy of PTB 18	**9.05**	**1.74**	**0.00**	**3.35**
Cul JS 1	Pure line sln from Jaya	**9.08**	**1.63**	1.15	8.80
Cul JS 2	Pure line sln from Jaya	12.50	7.05	5.86	12.41
Cul JS 3	Pure line sln from Jaya	**9.72**	**1.80**	1.85	9.31
Cul JS 4	Pure line sln from Jaya	18.36	12.50	3.21	9.63
Cul JS 5	Pure line sln from Jaya	9.80	1.94	**3.40**	**10.16**
Cul JS 6	Pure line sln from Jaya	25.00	19.23	10.54	20.80
Cul JS 7	Pure line sln from Jaya	7.27	1.98	9.84	18.88
Kalluruli Sel.	Sln from land race Kalluruli	9.25	11.95	**1.11**	**8.10**
TN1		16.50	30.15	15.25	65.50

Chatterjee *et al*., (2011) identified rice entries *viz.,* Anjali, Pusa RH 10, ADT 44, JKRH 10, Pant Dhan 19, Gorsa, CSR 27, IC 115737, LF 270 resistant to stem borer at vegetative stage (dead hearts) and CHOORAPUNDY, INRC 3021, PTB 12, CR-MR-1523, LF 256 and AGANNI at flowering stage (white ear). Singh *et al*., (2006) screened fifty-three cultivars of rice against *S. incertulas* under natural infestation and found that only eighteen rice varieties were totally free from stem borer damage in terms of DH and WE. Balasubramanian *et al*., (2000) screened 178 advanced yield trial genotypes of rice for their reaction to insect pests under natural conditions and found that genotypes, IET 15742 and IET 15072 were moderately resistant against yellow stem borer. Visalakshmi *et al*., (2014) reported that cultures *viz.,* CR 2711-76, CR 3005-230-5 were resistant and CR 3005-77-2 was moderately resistant to stem borer. Paramasiva *et al*., (2021) screened 28 rice cultures, and found that nil dead heart incidence was observed in NLR 3548, 3582, 3585, 3589, 3601, 3635, 3637, 3643 and NLR 3647 at 30 DAT and were rated as highly resistant.

Reaction to leaf folder: The results of screening under station trials showed that among the 14 cultures tested during *kharif* 2016 the culture Cul M9 showed lower leaf damage of 0.00, 8.28 per cent Cul M6-2 with 0.00, 5.25 per cent and Cul M8 with 0.00 and 9.01 at 45 and 60 DAT against TN 1 with 5.76 and 100 per cent leaf damage at 45 and 60 days after transplanting respectively. During *rabi* 2016-17 similar observation made with Cul M9 exhibiting lowest damaged leaves with 0.00, 3.35 per cent followed by Cul M8 and Cul M4 with 0.71, 4.08 per cent and 2.06 and 9.42 damaged leaves at 45 and 60 days after transplanting against TN 1 (Check) with 15.25 and 65.50 per cent damaged leaves at 45 and 60 days after transplanting as in **Tables 1 and 2**. Pooled analysis of both the crop seasons showed that Cul M9 was promising with low leaf damage of 0.00 and 5.82 damaged leaves followed by Cul M8 with 0.36 and 6.55 per cent damaged leaves at 45 and 60 days after transplanting (**Table 3**).

Table 3: Pooled Analysis of the reaction of Pattambi cultures to stem borer and leaf folder in two crop seasons at Pattambi (*kharif* 2017 and *rabi* 2017-2018)

Cultures	Parentage	Stem borer (% DH)	Stem borer (% WE)	Leaf folder% DL (45 DAT)	Leaf folder% DL (60 DAT)
KAUPTB 0627-2-11 (Cul 06-1)	Swetha x Kuruka	3.16 (0.17)	**1.08 (0.11)**	5.06 (0.22)	70.24 (1.01)
KAUPTB 0627-2-14 (Cul 06-2)	Swetha x Kuruka	2.82 (0.16)	**1.50 (0.12)**	3.33 (0.19)	44.00 (0.73)
Cul M4	Mutant of PTB 18	13.15 (0.35)	26.31 (0.53)	1.03 (0.07)	32.72 (0.58)
Cul M6-2	170 Gy Mutant of PTB 18	17.38 (0. 40)	16.61 (0.42)	4.24 (0.21)	40.43 (0.64)
Cul M8	170 Gy Mutant of PTB 21	13.30 (0.35)	9.52 (0.31)	**0.36 (0.04)**	**6.55 (0.25)**
Cul M9	Mutant 220 Gy of PTB 18	5.70 (0.23)	**1.66 (0.13)**	**0.00 (0.00)**	**5.82 (0.24)**
Cul JS 1	Pure line sln from Jaya	8.39 (0.30)	**1.81 (0.14)**	0.58 (0.06)	9.70 (0.32)
Cul JS-2	Pure line sln from Jaya	9.19 (0.30)	7.88 (0.29)	3.85 (0.19)	41.92 (0.69)
Cul JS 3	Pure line sln from Jaya	9.03 (0.31)	**1.70 (0.13)**	1.20 (0.11)	10.22 (0.33)
Cul JS 4	Pure line sln from Jaya	9.18 (0.22)	13.63 (0.38)	2.03 (0.14)	10.42 (0.33)
Cul JS 5	Pure line sln from Jaya	9.62 (0.32)	**1.87 (0.14)**	2.21 (0.14)	10.89 (0.34)
Cul JS 6	Pure line sln from Jaya	16.76 (0.41)	15.10 (0.40)	5.82 (0.22)	19.84 (0.46)
Cul JS 7	Pure line sln from Jaya	8.30 (0.30)	**1.92 (0.14)**	5.23 (0.20)	15.95 (0.41)
Kalluruli Sel.	Sln from land race Kalluruli	6.48 (0.25)	15.39 (0.40)	1.12 (0.11)	14.62 (0.39)
TN1	Susceptible check	14.50 (0.39)	22.83 (0.49)	10.51 (0.32)	82.75 (1.26)
CD (0.05)		NS	0.12	0.12	0.54

*Values in parentheses are arc sine transformed values.

Table 4: Reaction of promising genotypes against stem borer in SBST trail (*kharif* 2017) across locations (AICRIP progress report 2018)

Designation	Reaction to stem borer (% DH)							
	CHN	IIRR1	IIRR2	MSD	NVS1	PNT1	PNT1	PTB
	33-60 DT	68DT	70DT	78-82 DT	50DT	60DT	68DT	50DT
JGL 32467	10.4	20.7	23.1	4.6	0.0	31.0	19.3	25.7
JGL 32485	11.1	15.9	27.8	2.0	0.0	28.7	18.8	19.9
BK 39-179*	6.0	19.8	28.7	2.9	0.0	27.7	21.4	21.4
JGL 33080	5.9	10.7	30.6	4.2	7.5	30.5	11.7	16.3
JGL 33124	9.6	16.1	34.5	3.0	10.6	34.8	15.5	15.6
JGL 34508	9.5	10.8	28.9	6.6	9.2	31.3	19.5	25.3
RP 5587-B-B-B-209	11.0	NT	NT	3.5	NG	NG	NT	NT
RP 5587-B-B-B-253-2	7.9	10.7	13.3	0.0	0.0	38.4	22.2	28.0
BK 35-155	11.0	13.6	23.8	3.4	0.0	32.4	18.6	13.9
JGL 34505	8.0	7.0	17.4	4.8	9.9	30.9	30.6	23.2
KAUPTB 0627-2-11 (Cul 06-1)	8.6	26.0	22.1	4.5	0.0	32.9	21.7	26.3
KAUPTB 0627-2-14 (Cul 06-2)	7.1	21.8	26.0	1.6	7.1	37.6	14.6	25.4
RP 5587-B-B-B-258-1	8.1	23.1	20.0	3.1	14.5	31.0	21.8	36.8
RP 5587-B-B-B-262	6.7	20.7	27.3	0.0	11.1	35.6	21.1	35.8
RP 5588-B-B-B-B-232	8.8	28.8	22.4	3.5	0.0	33.1	21.2	14.3
JGL 28547	9.5	2.2	13.4	4.3	0.0	31.6	10.3	13.3
TKM6	12.6	16.8	15.8	4.4	9.4	25.2	12.5	19.4
Pusa Basmathi 1	15.7	36.8	27.9	2.9	9.0	41.2	16.8	27.3

*CHN:Chinsurah; IIRR: Indian Institute of Rice Research; MSD:Masoda; NVS: Navsari; PNT: Pantnagar; PTB: Pattambi

Table 5: Reaction of promising genotypes against stem borer in SBST trail (*kharif* 2018) across locations (AICRIP progress report 2019)

Designation	Reaction to stem borer (%WE)							
	CHN	ADT	CBT	PTB	RNR	PNT1	PNT2	NVS
	80-110DT	90DT	Pre.h	85DT	101DT	Pre Harvest		
JGL 32467	4.1	8.4	10.5	3.3	0.0	22.6	3.8	0.0
JGL 32485	4.8	8.8	15.8	5.0	3.2	29.2	9.0	0.0
BK 39-179*	0.0	5.9	14.4	4.6	6.7	17.2	4.5	0.0
JGL 33080	0.0	7.0	10.0	3.3	2.5	9.8	0.0	5.6
JGL 33124	9.3	7.7	15.2	18.5	2.3	23.5	4.8	7.2
JGL 34508	4.5	7.8	6.2	0.0	1.4	32.5	2.7	4.3
RP 5587-B-B-B-209	NG	NG	NG	NG	16.2	NT	NT	NG
RP 5587-B-B-B-253-2	4.8	9.5	12.2	17.7	7.4	1.4	1.0	0.0
BK 35-155	6.4	4.4	13.5	15.6	2.1	29.8	9.6	0.0
JGL 34505	11.6	6.3	6.0	0.9	3.1	30.2	6.0	3.9
KAUPTB 0627-2-11 (Cul 06-1)	1.7	5.2	9.5	1.3	1.7	22.4	1.0	0.0
KAUPTB 0627-2-14 (Cul 06-2)	7.4	12.5	6.3	2.9	3.7	11.8	0.0	4.3
RP 5587-B-B-B-258-1	7.1	6.2	17.5	0.0	7.8	4.5	4.5	5.8
RP 5587-B-B-B-262	13.0	4.8	9.8	0.0	4.0	21.3	7.9	8.6
RP 5588-B-B-B-B-232	10.5	4.8	8.1	0.0	12.7	15.0	10.3	0.0
JGL 28547	7.1	7.0	10.3	0.0	7.7	15.1	1.0	0.0
TKM 6	31.7	11.7	6.0	1.0	8.5	19.8	18.1	5.9
Pua Basmathi 1	19.1	8.3	5.7	3.8	9.6	43.0	11.8	6.0

*CHN: Chinsurah; ADT: Aduthurai; CBT: Coimbatore; RNR: Rajendranagar; PNT: Pantnagar; NVS: Navsari; MSD: Masoda; RPR: Raipur

Table 6: Reaction of promising genotypes entries against stem borer in SBST trail (*kharif* 2018) across locations (AICRIP progress report 2019)

Designation	Reaction to Stem borer (%WE)					
	IIRR1	IIRR2	MNC	PSA	PSA	ADT
KAUPTB 0627-2-11	31.0	8.2	2.2	15.5	8.1	6.4
JGL 34452	26.7	26.7	8.4	2.5	11.2	14.6
JGL 33440	42.3	35.4	4.7	11.8	9.2	4.5
NND 2	48.7	32.1	8.8	11.7	0.0	3.8
JGL 32994	23.4	36.8	4.4	2.5	27.0	10.4
JGL 33080	33.1	29.6	5.6	3.6	11.5	10.2
BK 49-76	32.1	20.2	10.7	11.4	7.7	10.0
RP bio 4919-385	40.2	36.6	14.5	10.5	4.9	14.3
KMR3	61.9	54.5	4.5	15.1	5.2	5.0
IET 27049	48.3	64.7	14.8	13.4	21.2	3.7
CRCPT 7	58.4	54.9	1.8	15.9	4.9	5.1
TKM 6	25.0	8.4	4.4	13.2	14.1	7.7
TN1	34.5	49.8	8.4	12.7	30.4	2.6

*IIRR: Indian Institute of Rice Research; MNC: Moncompu ; PSA: Pusa; ADT: Aduthurai; PNT: Pantnagar

Table 7: Reaction of promising genotypes against stem borer in SBST trail (*kharif* 2019) across locations (AICRIP progress report 2020)

Designation	Reaction of entries to stem borer (Dead hearts%)								
	ADT (50DT)	MNC	IIRR1 (47DT)	IIRR2 (68DT)	PSA (39DT)	PNT1 (53DT)	PNT2 (53DT)	PNT1 (71DT)	PNT2 (73DT)
KAUPTB 0627-2-11	8.2	11.1	31.6	8.6	18.2	12.9	13.1	29.4	28.4
JGL 34452	14.1	8.7	20.8	16.8	3.0	22.9	13.0	30.2	21.9
JGL 33440	5.0	8.6	28.5	11.6	15.4	24.2	10.9	29.5	24.2
NND 2	6.5	9.7	39.6	25.0	16.8	16.6	24.9	32.5	26.7
JGL 32994	10.7	11.2	24.6	26.5	4.2	17.5	19.7	25.4	30.2
JGL 33080	19.4	13.7	33.6	20.0	5.2	23.2	12.8	28.0	26.7
BK 49-76	22.1	9.8	28.4	15.9	12.9	8.5	13.9	25.3	22.8
RP bio 4919-385	18.6	13.0	26.9	15.5	13.8	9.8	21.9	28.5	21.1
KMR3	4.5	10.4	26.5	20.4	18.6	10.4	17.8	27.5	23.3
IET 27049	3.6	21.9	28.3	19.3	18.1	17.4	19.6	36.8	30.0
CRCPT 7	5.0	11.2	34.6	24.2	19.8	24.3	18.0	40.8	24.9
TKM 6	20.6	11.9	23.3	21.9	17.6	20.8	10.4	26.3	27.7
TN1	23.7	12.4	26.0	18.4	15.1	15.6	19.6	33.8	29.5

*ADT: Aduthurai; MNC: Moncompu; IIRR: Indian Institute of Rice Research; PSA: Pusa; PNT: Pantnagar

Nine cultures were evaluated against leaf folder during *kharif* 2018 and *kharif* 2019 with TN1 as susceptible check and W 1263 as resistant check in LFST trial under AICRPR. During *kharif* 19, four entries as promising in 3-4 tests of nine valid field tests**.** Average damage in the trial varied from 7.7 to 78.2% while the maximum damage ranged between 14.7 and 92.8% across locations. The average damage by leaf folder in susceptible check varied from 13.8 to 82.1%. Two mutant cultures, Cul M8 and Cul M9 were found promising in four out of nine valid field tests. Another mutant culture, Cul M6-2 and a selection from landrace Kalluruli were found promising in three of the nine valid field tests (**Table 8**) and were found at par with resistant check, W 1263. (AICRIP progress report 2019).

Table 8: Reaction of promising genotypes entries against leaf folder in LFST trail (*kharif* 2018) across locations (AICRIP progress report 2019)

Designation	Parentage	CHT	KRK	LDN	MLN	NVS	NWG	PTB	ADT	RNR	NPT
		60DT	60DT	80DT	114DT	80DT	60DT	50DT	80DT	83DT	(9)
Cul M8	Mutant 170 GY of PTB 21	23.7	4.4	14.1	35.4	3.2	32.3	49.3	22.8	3.9	4
Cul M9	Mutant 220 GY of PTB 18	22.9	11.3	19.8	29.4	9.4	34.1	81.9	31.6	10.4	4
Cul M6-2	Mutant 170 GY of PTB 18	19.7	24.4	27.3	28.5	13.4	71.5	85.2	28.4	6.0	3
Kalluruli	Selection from landrace Kalluruli	25.0	14.6	16.5	31.7	7.9	29 .0	74.0	31.8	11	3
JS 3	Pureline selection from Jaya	27.1	27.7	30.3	32.1	8.0	26.0	86.0	32.2	1.4	2
JS 4	Pureline selection from Jaya	22.4	22.5	31.5	42.9	9.5	26.6	85.8	31.1	7.4	2
JS 5	Pureline selection from Jaya	22.8	34.0	31.1	32.8	6.6	32.6	81.8	30.8	2.2	2
Cul 3	Swetha x Kuruka	25.4	33.5	27.5	36.9	13.6	24.4	84.5	27.8	7.7	2
Cul M4	Mutant of PTB 18	22.1	17.1	34.3	32.9	9.9	38.2	61.4	22.0	2.8	2
Matali	Local red rice from Kullu valley in HP	24.2	16.7	20.9	26.6	13.8	43.2	66.5	19.6	12.4	2
NWGR 16041	NWGR 2006/ Mahisugandha/47-1-1-1-1-1-1	23.4	42.3	28.8	29.6	8.5	31.4	87.1	31.4	12.0	2
JS 1	Pureline selection from Jaya	24.0	23.6	33.3	37.8	15.6	34.0	88.0	28.1	8.0	1
JS 6	Pureline selection from Jaya	22.8	28.8	26.3	30.8	13.3	25.3	86.1	29.3	7.7	1
Cul 7	Pureline selection from Jaya	22.2	32.5	31.7	34.9	11	41.7	89.4	22.6	3.9	1
Chohartu	Local red rice from Rohru in Shimla region	27.1	27.8	28.8	41.5	10.6	32.8	85.5	22.3	4.8	1
NWGR 9078	GR 7/NWGR 99038/1-1-1-1	24.9	36.9	23.1	30.4	19.6	50.4	82	20.8	6.6	1
JS 7	Pureline selection from Jaya	23.5	30.3	31.9	34	18.2	29.7	92.8	31.4	11.4	0
W 1263	Resistant check	22.8	27.6	18.7	34.2	0.2	43.5	36.3	9.2	11.9	3
TN 1	Susceptible check	24 4	30.1	0.9	37.6	32.6	47.0	82.1	32.5	13.8	0
Minimum damage		19.7	4.4	14.1	26.6	0.2	24.4	36.3	9.2	1.4	
Maximum damage		27.1	42.3	34.3	42.9	36.7	71.5	92.8	32.2	14.7	
Average damage in trial		23.8	25.7	26.7	33.3	12.4	35.9	78.2	25.9	7.7	
Promising level		20	15	20	30	10	25	30	20	10	
No. Promising		1	3	4	4	9	1	0	3	12	
Total entries tested		20	20	20	20	20	20	20	20	20	

*CHT: Chatha; KRK: Karaikal; LDN: Ludhiana; MLN: Malan; NVS: Navsari; NWG: Nawagam; PTB: Pattambi; ADT: Aduthurai; RNR: Rajendranagar

During *kharif 2018*, the trial was conducted at 16 locations with 36 entries replicated twice in a randomised block design under All India Coordinated Trials. The average damage in the trial ranged between 8.4 and 47.2% while the maximum damage varied from 13.0 to 63.1%. Data analysis revealed 14 entries as Promising in 4-6 tests of 13 valid field tests. In the second year of testing *kharif* 2019, Cul M9 the mutant culture of PTB 18 was found promising in 6 out of 13 valid tests. Two pureline selections from Jaya (JS 1 & JS 3) were found promising in 5 out of 13 valid tests. JS 5, JS 6, Cul M8, Cul M6-2, were found promising in 4 out of 13 valid tests conducted at different locations (**Table 9**) (AICRIP progress report 2020).

Table 9: Reaction of promising genotypes entries against leaf folder in LFST trail (*kharif* 2019) across locations (AICRIP progress report 2020)

Designation	Parentage	ADT	BPT	CHT	CHN	JDP	KRK	LDN	MLN	NVS	NWG	PTB	RNR	KUL	NPT (13)
		80 DT	88 DT	57 DT	80 DT	82 DT	80 DT	80 DT	78 DT	80 DT	80 DT	50 DT	79 DT	60 DT	
Cul M8	Mutant 170 GY of PTB 21	17.5	11.2	13.8	10.9	4.0	38.8	25.5	20.8	7.8	31.2	36.9	4.4	24.2	4
Cul M9	Mutant 220 GY of PTB 18	6.5	10.5	13.5	8.2	7.0	44.5	19.2	22.1	3.2	29.2	21.9	4.8	22.3	6
Cul M6-2	Mutant 170 GY of PTB 18	27.3	10.5	12.5	8.9	12.9	43.3	27.5	26.4	2.8	24.6	31.2	8.0	22.1	4
JS 3	Pureline selection from Jaya	14.6	11.6	15.0	9.0	8.9	56.0	25.8	19.9	8.2	21.7	22.9	6.4	29.1	5
JS 5	Pureline selection from Jaya	11.8	12.8	17.5	12.2	7.6	46.4	23.0	20.2	8.8	18.2	26.1	6.4	31.9	4
JS 6	Pureline selection from Jaya	9.6	14.6	15.4	7.1	7.3	56.0	22.1	23.9	11.1	19.1	20.8	7.6	34.7	4
Matali	Local red rice from Kullu valley in HP	4.3	NG	NG	11.8	NG	NG	23.7	22.8	7.4	18.8	30.5	8.3	34.7	4
Ghocha	Landrace from tribal belt of Kangra	3.8	16.1	24.0	7.4	4.2	52.8	33.4	19.4	NG	31.0	30.1	11.9	31.7	4
BPT 2932	BPT 5204/ MTU 1075	31.7	16.0	12.1	9.0	9.8	46.3	25.5	25.3	5.4	22.9	26.4	4.8	21.6	4
BPT 2677	MTU 2077/ Ajay/ MTU 2077	30.1	14.8	12.5	9.1	7.5	43.0	33.5	24.0	7.6	24.4	19.8	6.4	28.0	4
BPT 2954	NLR 34449/ Annada/NLR 34449	29.7	13.5	13.2	5.4	6.2	42.2	32.2	25.6	7.9	18.9	26.9	6.1	32.8	4
BPT 3049	MTU 1010/IR 50	29.3	11.2	17.1	5.4	9.0	50.6	24.7	23.1	1.0	23.6	27.4	8.5	23.2	4
NPS 54	Swarna/*Oryza nivara* BIL	28.4	27.0	16.0	4.7	3.6	46.8	32.1	24.8	17.0	25.4	17.8	7.0	33.4	4
W 1263	Resistant check	4.9	7.7	9.6	5.6	2.5	4.4	19.4	19.5	0.7	18.3	19.9	7.7	27.3	12
TN 1	Susceptible check	33.4	19.4	14.5	10.3	14.5	40.9	25.5	38.2	29.1	48.3	30.4	18.5	39.9	0
Minimum damage		3.8	7.7	9.6	4.7	2.4	4.4	19.2	18.9	0.7	18.2	17.8	2.9	21.6	
Maximum damage		62.9	29.3	24.0	14.4	13.0	63.1	36.3	28.8	36.6	47.3	45.0	14.6	34.7	
Average damage in trial		21.7	15.6	15.0	9.1	8.6	47.2	26.0	23.0	9.0	24.8	26.7	8.4	28.9	
Promising level		15	10	10	10	5	15	20	20	10	20	20	10	25	
No. Promising		11	1	1	24	4	1	2	5	24	5	6	26	10	

*CHT: ADT: Aduthurai; BPT: Bapatla; CHT: Chatha; CHN: Chinsurah; JDP: Jagdalpur; KRK: Karaikal; LDN: Ludhiana; MLN: Malan; NVS: Navsari; NWG: Nawagam; PTB: Pattambi; RNR: Rajendranagar; KUL: Kaul

Chatterjee *et al.,* (2011) screened 51 rice genotypes and reported that five cultures CSR 23, TNAU 831311, ARC 6626, IC 115737, AGANNI, IC 155876 and ARC 5982 were resistant to rice leaf folder. Balasubramanian *et al*., (2000) screened 178 advanced yield trial genotypes of rice for their reaction to insect pests under natural conditions and found that genotype, IET 16120 was moderately resistant against rice leaf folder. Sudhakar *et al*., (1991) evaluated 24 rice varieties in India for resistance against *C. medinalis* and reporded that IET 7564, ES 29-3-3-1; Pusa 2-21 and Type-3 were the least susceptible entries. Paramasiva *et al*., (2021) found 15 cultures *viz.,* NLR 3542, NLR 3548, NLR 3582, NLR 3595, NLR 3598, NLR 3601, NLR 3634, NLR 3635, NLR 3636, NLR 3637, NLR 3641, NLR 3643, NLR 3644, NLR 3645 and NLR 3647 recorded resistant reaction by recording less than 10 per cent leaf damage (8.06 to 10.18%).

Performance of entries to multiple injuries

Reaction to Mixed population of planthoppers: The rice genotypes of various states were evaluated for multiple resistance to two or more pests under Multiple resistance trial during *kharif* 2018 and *kharif* 2019 under All India coordinated programme wherein Cul M9 (Mutant 220 Gy of PTB 18) and PTB33 exhibited field tolerance with a DS ≤3.0 in two valid tests at against mixed population of planthoppers, where BPH was predominant at Maruteru and WBPH at Gangavathi (**Tables 10 and 11**) (AICRIP progress report 2019 and 2020). Dhawande *et al*., (2018) assessed 1003 germplasm for resistance to brown plant hopper and found that 37 entries exhibited a damage score (DS) ranging from 0-5 and were designated as highly resistant and moderately resistant to BPH, and the remaining 966 entries were susceptible with a damage score of 5.1-9.0. Out of 37 accessions, two accessions *viz.,* IC 75975 (DS-0.77), IC 216750 (DS-0.80) were highly resistant, 21 accessions were resistant (DS-1.0-3.0) and 14 accessions were moderately resistant (DS-3.1-5.0).

Table 10: Reaction of promising genotypes entries under MRST trail (*kharif* 2018) across locations (AICRIP progress report 2019)

Designation	Stem borer (% White ears)					PH		Stem borer (% Dead hearts)				
	PSA (69DT)	MSD (85DT)	CHN (69DT)	RPR (110DT)	RNR (113DT)	GNV	MTU	IIRR (68DT)	PNT (55DT)	MSD (70DT)	NVS (50DT)	PSA (39DT)
Sinna sivappu	10.3	38.1	6.7	23.1	11.09	3.0	9.0	15.44	14.2	38.5	19.0	13.3
JS 5	11.6	0.0	10.5	7.4	7.77	5.0	1.0	23.80	26.9	0.0	22.2	15.5
SKL -07-11-177-50-65-60-267	14.5	0.0	13.4	30.9	19.45	3.0	9.0	19.90	15.3	0.0	11.1	17.1
Cul M9	7.6	1.7	1.6	0.0	0.0	3.0	GF	12.30	13.8	0.0	5.3	16.7
Checks												
PTB 33	12.3	36.5	3.5	0.0	0.00	1.0	1.0	27.30	14.7	21.7	0.0	13.6
W1263	13.4	12.5	6.9	15.3	9.24	3.0	9.0	17.54	18.9	61.2	10.5	15.3
TN1	11.0	23.8	3.4	13.5	4.97	5.0	9.0	15.72	28.5	38.0	35.3	12.9

*PSA: Pusa; MSD: Masoda; CHN: Chinsurah RPR: Raipur; RNR: Rajendranagar; GNV:Gangavathi; MTU: Maruteru; IIRR: Indian Institute of Rice Research; PNT: Pantnagar; NVS: Navsari; PSA: Pusa

Table 11: Reaction of promising Pattambi genotypes entries under MRST trail (*kharif* 2019) across locations (AICRIP progress report 2020)

Designation	Stem borer (% Dead hearts)				Stem borer (% White ears)				Leaf folder (% damaged leaves)				PH
	IIRR 52DT	TTB 45DT	PSA 45DT	PNT 54DT	IIRR 83DT	PSA 68DT	NWG 95DT	TTB 100DT	PSA 45DT	TTB 50DT	PTB 50DT	ADT 50DT	GNV No./ 10 hill
Cul M9	22.1	31.4	9.0	36.8	NF	5.9	4.4	8.7	5.4	12.4	3.8	1.4	193
SKL -07-11-177-50-65-60-267	23.0	21.7	13.6	43.2	21.7	13.7	18.2	7.9	11.2	7.9	NG	NT	255
BK 35-155	26.0	14.3	15.9	30.7	26.6	12.5	14.3	19.4	9.9	4.1	10.8	10.0	224
JS 5	17.0	7.3	14.6	37.3	31.8	15.7	8.3	6.8	14.0	9.0	6.8	7.3	216
RP 5587-B-B-B-262	24.4	51.5	14.3	30.7	26.0	13.6	22.7	10.3	10.8	17.0	11.0	5.0	200
JGL 33440	21.9	24.1	19.0	36.1	41.7	13.0	24.3	15.5	17.1	13.8	8.5	1.0	202
Checks													
PTB 33	30.2	30.4	8.4	33.5	NF	7.6	4.3	10.4	6.6	16.7	8.2	6.6	190
W1263	22.0	16.7	15.3	23.4	18.4	13.4	12.1	14.5	14.2	7.1	6.3	8.1	184
TN 1	11.8	9.1	20.4	44.4	32.2	23.4	50.9	10.6	14.1	11.4	10.3	23.5	226

*IIRR: Indian Institute of Rice Research; TTB: Titabar; PSA: Pusa; PNT:Pantnagar; NWG: Nawagam; PTB: Pattambi; ADT: Aduthurai GNV: Gangavathi

Stem borer

During *kharif* 2018 and 2019, evaluation of entries against stem borer at vegetative phase for dead heart damage in seven valid tests identified JS1 (a pure line selection from Jaya) with nil damage. Cul 7, Cul M9, JS 3, PTB33 and Suraksha were identified as promising in 2 of the14 valid tests at reproductive phase for white ear damage. In *kharif* 2019, under Multiple screening trial, culture Cul M9 was promising in 3 tests *viz.,* JS 3, JS 5 and PTB33 were identified as promising in two of the four valid tests at reproductive phase for white ear damage. Of these, CulM9, JS 3 and PTB 33 were promising in second year of testing as in **Table 10 and 11** (AICRIP progress report 2019 and 2020).

Leaf folder: During *kharif* 2019, under Multiple screening trial cultures, Cul M9, RP 5587-B-B-B-262 and Suraksha were promising for leaf folder damage in two of the seven valid tests with ≤5% DL under All India coordinated testing programme as in **Table 10** (AICRIP progress report 2020) **Table 11** (AICRIP progress report 2020). Chatterjee *et al*., (2016) screened rice entries for multiple tolerance to various rice pests and found that entries CN 2008-3-2, CN 2017-3-2 and W 1263 showed multiple tolerance against stem borer, leaf folder and whorl maggot of rice. Entries CR 2274-2-3-3-1, RP 5587-B-B-B-305-13, CN 2015-5-4, IET 23148 and CN 1233-33-9 showed multiple against stem borer and leaf folder while entries RP 2068-18-3-5, RP 5588-B-B-B-B-76 and RNT 14-1-1-2-2 showed multiple tolerance against stem borer and whorl maggot. Chatterjee *et al.*, (2021) found that the early duration varieties Narendra 97, IR 50 and mid-early duration varieties IR 64 and IET 17904 were resistant against both yellow stem borer (dead heart) and leaf folder. The medium duration variety, Ranjit was highly resistant against both yellow stem borer (dead heart) and leaf folder, and the variety, Pratiksha showed a fair degree of resistance against both yellow stem borer and leaf folder. Padmavathi *et al.,* (2017) screened forty eight genotypes by two methods of screening methods against rice leaf folder and found that six genotypes were resistant with a damage score of 3.0 including resistant check W 1263 and ten genotypes were moderately resistant with score of 5.0 in first method of screening and in another special method of screening entries IET 22449 and W 1263 showed minimum leaf area damage of 68.41 to 428.81 mm^2.

Conclusion

The evaluation of rice cultures from Pattambi against major rice pests and in multi-locations in AICRPR showed that KAUPTB 0627-2-11 (Cul 06-1) was resistant to stem borer and cultures JS 1,3,4,5 and 7 resistant to both stem borer and leaf folder while Cul M9 showing multiple resistance to stem borer, mixed population of plant hoppers and leaffolders.

Authors contribution: KK, screened the cultures at Pattambi against stem borer and leaf folder. FKV and BKR were involved in development of the material. CHPV designed the LFST trial for multilocation testing in AICRPR and analysed the data. APPK designed the SBST and MRST trials in AICRPR and analysed the data. KK, APPK and CHPV wrote the manuscript. All authors read and approved the manuscript.

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Evaluation of Rice Local Landraces for Resistance Against Yellow Stem Borer, *Scirpophaga incertulas* (Walker)

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Abstract

Field evaluation of 50 (fifty) local landraces of rice against paddy yellow stem borer (YSB), *Scirpophaga incertulas* (Walker) was carried out at the College of Agriculture, V.C. Farm, Mandya during *kharif* and *Summer* 2022-23. The per cent of damage by YSB on different genotypes was evaluated at 30, 60 and 90 days after transplanting (DAT) in both the seasons. Based on the mean per cent incidence rice genotypes were grouped into different resistance categories. In *kharif* 2022, out of 50 local landraces screened ten (10) genotypes recorded resistance reaction with a damage score of 1, twenty seven (27) genotypes were found to be moderately resistant with a score of 3, nine (9) genotypes reacted as moderately susceptible with score of 5 and four genotypes showed susceptible reaction with score of 7. During summer 2023 as well, the same results were observed but the per cent incidence was varied. In both the seasons none of the genotypes were found to be highly resistant or highly susceptible to YSB. The promising resistant and moderately resistant genotypes found in the current study can be further used in resistant breeding programs.

Keywords: *Scirpophaga incertulas,* Screening, local landraces, resistance breeding, SES.

Introduction

Rice (*Oryza sativa* Linn.) is the staple food of more than half of the world's population (Kulagod *et al*., 2011). India is the second-largest producer and consumer of rice in the world after China with an area of 463.79 lakh ha with an annual production of 130.29 million tonnes and productivity of 2809 kg ha^{-1} (Anonymous, 2023). Paddy cultivation, a vital component of global food production, faces formidable challenges from various pests that jeopardize crop yield and quality. Among these, the yellow stem borer poses a significant threat to paddy fields, causing substantial economic losses and compromising food security.

Rice yellow stem borer (YSB; *Scirpophaga incertulas* Walker) is the most destructive pest causing about a 25-30% reduction in yield. This results in an annual yield loss of 27-34% (Pasalu *et al*., 2002) of the production. During the vegetative stage of the crop, the newly emerged caterpillar bores into the stem and feeds on the internal content. As a result, the central shoot dries up and produces dead heart. In the reproductive stage of the crop, grownup larvae bore into the peduncle leading to white ears and offering higher loss to the crop (Karthikeyan and Purushothaman, 2000). Given the substantial impact of YSB infestation on paddy crops, there is a growing need for effective and sustainable pest management strategies. Screening, a comprehensive and systematic approach, emerges as a pivotal tool in identifying and developing resistant varieties capable of withstanding the onslaught of YSB. This process involves the meticulous evaluation of diverse rice germplasm to pinpoint genetic traits that confer resistance to the YSB.

Several studies have also underscored the importance of screening initiatives in developing YSB-resistant paddy varieties. The work of Pathak and Khan (1994) emphasized the necessity of continuous screening efforts to stay ahead of evolving pest populations. Growing resistant variety is an excellent alternative compared to other management strategies. It is also highly compatible with all other methods of pest management. Hence, identifying the source of resistance against yellow stem borer is an important step, so the current study aims to screen the genotypes for resistance to YSB under field conditions.

Materials and Methods

Field evaluation of local landraces and popular cultivars of rice for resistance against YSB in rice was conducted at A-block, College of Agriculture, V. C Farm, Mandya, UAS, GKVK, Karnataka during *kharif* and *summer* seasons of 2022-23.

Screening material: A total of 50 local landraces of rice (**Tables 2 and 3**) were collected from the Zonal Agricultural Research Station, V.C. Farm Mandya and sown separately for the evaluation. 25 days seedlings of local landraces were transplanted in 3 rows with the spacing 20 cm & 15 cm between rows and plants, respectively. Each entry was raised as per the package of practice, except the plant protection measures (Anonymous, 2016).

In each genotype, the infestation of YSB was recorded during the vegetative stage (before panicle emergence) by counting the number of dead hearts to the total number of tillers, in 10 randomly selected hills in each test entry at 30 and 60 days after transplanting (DAT). Likewise, at pre-harvest, the infestation of YSB was recorded by counting the total number of ear-bearing tillers and white ears on 10 randomly selected hills and per cent white ears was worked out at 90 DAT.

$$\text{Dead heart (\%)} = \frac{\text{Number of dead hearts}}{\text{Total number of tillers}} \times 100$$

$$\text{White ear (\%)} = \frac{\text{Number of white ears}}{\text{Total number of productive tillers}} \times 100$$

The mean and standard deviation were worked out and based on the level of infestation, rice genotypes were grouped into different resistance categories for the data interpretation. Further, the scoring of rice YSB infestation was made and interpreted based on the Standard Evaluation System for Rice (SES) developed by the International Rice Research Institute (IRRI, 2013) (**Table 1**).

Results and Discussions

Kharif 2022

Results revealed that, among 50 local landraces studied, the per cent dead hearts caused by YSB ranged from 7.04± 4.82 to 41.83± 4.68 per cent, in Chinagari batta and Bili nellu respectively, similarly the per cent white ears ranged from 2.77 ±2.9 to

Table 1: Standard Evaluation System for Screening Rice Yellow Stem Borer

For dead heart			For white ear		
Scale	Per cent damage	Category	Scale	Per cent damage	Category
0	No damage	Highly Resistant	0	No damage	Highly Resistant (HR)
1	1- 10%	Resistant	1	1-5%	Resistant (R)
3	11- 20%	Moderately Resistant	3	6- 10%	Moderately Resistant (MR)
5	21-30%	Moderately Susceptible	5	11-15%	Moderately Susceptible (MS)
7	31-60%	Susceptible	7	16-25%	Susceptible (S)
9	61% and above	Highly Susceptible	9	26% and above	Highly Susceptible (HS)

22.1 ±4.28 in Bul Bul -1 and Bili nellu respectively (**Table 2**). Overall, in *kharif* 2022, 10 genotypes were found to be resistant (scale 1), 27 genotypes with score 3 were found to be moderately resistant, 9 genotypes were found to be moderately susceptible (scale 5) and 4 genotypes were susceptible with score 7. However, none of the genotypes were found to be highly resistant or susceptible with scores of 0 and 9 respectively.

At 30 DAT, per cent incidence due to dead heart ranged from 7.04± 4.82 to 9.49± 4.2 per cent in Chinagari batta and Aishwarya and those landraces were categorized as resistant genotypes with score 1. Whereas, in moderately resistant categories (score 3), the per cent dead heart ranged between 11.72± 2.95 and 18.81± 7.05 in the Bangara sanna - 3 and Hasnudi. Likewise, in moderately susceptible categories (score 5) the infestation varied from 21.49± 6.07 to 25.35± 6.94 per cent dead heart in the genotypes *viz*., Mysore mallige – 1 and Kavadari. However, per cent dead heart at 30 DAT was observed between 31.48± 4.06 and 41.83± 4.68 in Kanakunja and Bili nellu, which were categorized as susceptible (score 7). Of all the local landraces screened, none of the genotypes were found highly resistant (HR) and highly susceptible with scores of 0 and 9 (**Table 2**).

Similarly, at 60 DAT, none of the genotypes were found to be highly resistant and the genotypes with per cent incidence ranged from 6.1± 5.64 to 9.64± 4 in Chinagari batta and Bilikanna hegge were categorized as resistant genotypes with score 1. Whereas, in moderately resistant categories (score 3), the per cent dead heart showed between 10.82± 2.79 and 17.96± 5.12 in Itan gidda and Hasnudi. Likewise, in moderately susceptible categories (score 5) the infestation varied from 21.49± 6.63 to 26.42± 9.86 per cent dead heart in the genotypes Bangara kaddi and Kavadari. However, per cent dead heart at 60 DAT was observed between 31.21± 4.44 and 42.35 ± 3.33 in Kulaj and Bili nellu and was categorized as susceptible (score 7), meanwhile, none of the genotypes were found to be highly susceptible (score 9) (**Table 2**).

At 90 DAT, per cent white ear was observed between 2.77 ± 2.9 and 4.53 ± 4.12 in Bul Bul -1 and Chinagari batta, which were considered resistant varieties. Likewise, per cent white ear was observed between 6.43 ± 3.42 and 9.4 ± 2.92 in Moradda and Black Basumathi and was categorized as moderately resistant. The infestation varied from 12.01 ± 3.08 to 14.24 ± 5.08 per cent white ears in the genotypes Kannur and Chinna ponni - 4 and they were regarded as moderately susceptible genotypes. The infestation varied from 16.64 ± 2.57 to 22.1 ± 4.28 per cent white ear in Kulaj and Bili nellu, were regarded as susceptible. However, none of the genotypes were found to be highly resistant and highly susceptible (**Table 2**).

Summer 2023

Results revealed that, among 50 local landraces studied, the per cent dead hearts caused by YSB ranged from 7.18± 3.17 to 37.17 ± 9.43 per cent, similarly the per cent white ears ranged from 2.7 ± 3.25 to 23.39 ± 6.72 (**Table 3**) in the summer screening. During *summer* 2023, 10 genotypes were found to be resistant with scale 1, followed by 27 genotypes with score 3 were moderately resistant, 9 genotypes were found to be moderately susceptible (scale 5) and 4 genotypes were susceptible with score 7. But, none of the genotypes were observed as highly resistant or susceptible with scores of 0 and 9 respectively.

At 30 DAT, the percent of dead heart incidence varied, with Bul Bul-1 and Doddi Batta exhibiting a range of 7.18 ± 3.17 to 8.78 ± 1.65 per cent, categorizing them as resistant genotypes with a score of 1. In the moderately resistant category (score 3), Anandi - 1 and Hasnudi showed dead heart percentages ranging from 11.16 ± 4.06 to 19.05 ± 7.76 per cent.

Table 2: Reaction of local landraces of rice against yellow stem borer, *S. incertulas* during *kharif* 2022

Sl. No.	Genotypes	%DH		%WE	Score	Category
		30 DAT	60 DAT	90 DAT		
1	Aishwarya	9.49 ± 4.2	7.49 ± 3.95	4.51 ± 1.36	1	R
2	Anandi - 1	12.41 ± 4.3	12.29 ± 4.08	6.58 ± 2.49	3	MR
3	Arvath Pilai	8.03 ± 2.79	7.91 ± 3	3.89 ± 4.16	1	R
4	Anilam Anil	11.88 ± 2.28	13.04 ± 1.82	8.1 ± 2.2	3	MR
5	Bangara sanna - 3	11.72 ± 2.95	12.83 ± 4.61	6.55 ± 3.07	3	MR
6	Bheema sale - 2	12.51 ± 3.07	11.96 ± 3.38	6.76 ± 4.73	3	MR
7	Bilikanna hegge	8.4 ± 2.59	9.64 ± 4	3.56 ± 2.96	1	R
8	Bele jaddi alneram batta	13.13 ± 2.76	13.72 ± 3.87	7.41 ± 4.9	3	MR
9	Bul Bul -1	8.15 ± 3.61	6.67 ± 4.15	2.77 ± 2.9	1	R
10	Bangara kaddi	22.64 ± 6.3	21.49 ± 6.63	12.05 ± 4.24	5	MS
11	Bili nellu	41.83 ± 4.68	42.35 ± 3.33	22.1 ± 4.28	7	S
12	Black basumathi	12.25 ± 3.82	12.36 ± 2.39	9.4 ± 2.92	3	MR
13	Barma Black	14.43 ± 6.58	14.5 ± 6.64	7.28 ± 3.95	3	MR
14	Bili dadi goltiga	8.14 ± 3.14	7.82 ± 3.01	3.14 ± 3.45	1	R
15	Chinna ponni - 4	23.37 ± 6.08	22.81 ± 6.96	14.24 ± 5.08	5	MS
16	Chinagari batta	7.04 ± 4.82	6.1 ± 5.64	4.53 ± 4.12	1	R
17	Dodda Byranellu	12.28 ± 2.46	12.31 ± 2.38	8.44 ± 2.99	3	MR
18	Doddi Batta	8.78 ± 1.7	8.46 ± 1.74	3.29 ± 1.22	1	R
19	Dunda	22.88 ± 4.57	22.65 ± 5.21	12.47 ± 2.58	5	MS
20	Dubainallu	23.13 ± 4.17	21.58 ± 3.9	14 ± 7.18	5	MS
21	Esadli	14.12 ± 7.01	12.29 ± 5.62	8.07 ± 3.32	3	MR
22	G K variety tall	13.18 ± 3.87	13.48 ± 4.14	6.84 ± 4.27	3	MR
23	Giddaraja kamal	18.25 ± 5.52	17.82 ± 5.81	7.11 ± 2.91	3	MR
24	Gujarath basamati	31.85 ± 5.64	31.67 ± 13.2	18.34 ± 5.06	7	S
25	Gulwadi sannaki	14.91 ± 4.52	14.65 ± 5.43	8.36 ± 4.36	3	MR
26	Hasnudi	18.81 ± 7.05	17.96 ± 5.12	8.98 ± 4.76	3	MR
27	Itan gidda	12.31 ± 5.06	10.82 ± 2.79	9.15 ± 2.68	3	MR
28	Jadda batta	18.16 ± 5.08	16.7 ± 7.14	7.96 ± 4.86	3	MR
29	Kempu dadi gidda	21.75 ± 3.92	22.55 ± 5.75	13.25 ± 3.32	5	MS
30	Kulaj	32.55 ± 5.19	31.21 ± 4.44	16.64 ± 2.57	7	S
31	Kalikatesi	14.31 ± 5.71	13.63 ± 2.09	6.82 ± 4	3	MR
32	Kari kandake	17.61 ± 4.12	15.71 ± 5.15	7.41 ± 1.67	3	MR
33	Kanakunja	31.48 ± 4.06	33.12 ± 5.86	16.99 ± 3.81	7	S
34	Kalanamak - 1	7.12 ± 2.87	6.6 ± 2.79	4.05 ± 2.11	1	R
35	Kavadari	25.35 ± 6.94	26.42 ± 9.86	12.19 ± 2.29	5	MS
36	Kaduvelpe	15.02 ± 4.9	14.66 ± 4.8	7.27 ± 2.18	3	MR
37	KN- local	15.78 ± 3.15	15.62 ± 4.09	7.3 ± 2.29	3	MR
38	Kempurajmudi	12.73 ± 3.91	11.92 ± 3.31	7.13 ± 2.34	3	MR
39	KS Local	14.36 ± 5.34	12.12 ± 6.51	6.82 ± 2.81	3	MR
40	Kannur	22.04 ± 2.92	23.3 ± 7.99	12.01 ± 3.08	5	MS
41	Kyasare - 2	14.56 ± 3.47	12.16 ± 1.79	7.31 ± 3.93	3	MR
42	Kari swarna	12.86 ± 3.1	12.65 ± 4.38	7.32 ± 3.51	3	MR
43	Malgudi sanna - 2	8.6 ± 2.5	8.31 ± 2.89	3.51 ± 2.8	1	R
44	Mysore mallige - 1	21.49 ± 6.07	21.8 ± 7.14	13.22 ± 5.94	5	MS
45	Mavaokar	16.82 ± 3.16	17.31 ± 5.61	8.83 ± 3.22	3	MR
46	Manjupani	12.47 ± 4.53	12.49 ± 4.69	7.94 ± 3.19	3	MR
47	Mallige - 2	12.33 ± 2.53	11.71 ± 2.4	6.76 ± 3.12	3	MR
48	Mobikar	23.42 ± 3.38	22.11 ± 5.18	12.92 ± 2.46	5	MS
49	Moradda	15.48 ± 5.29	17.22 ± 5.92	6.43 ± 3.42	3	MR
50	Malgudi sanna - 1	7.81 ± 4.98	8.4 ± 5.31	4.21 ± 4.17	1	R

DAT- Days after transplanting, R- Resistant, MR- Moderately Resistant, MS- Moderately Susceptible; S- Susceptible; DH- dead heart; WE- white ears.

Similarly, in the moderately susceptible category (score 5), Mobikar and Kavadari had infestations ranging from 22.08 ± 6.15 to 26.33 ± 12.39 per cent. However, genotypes Kulaj and Bili nellu, falling into the susceptible category (score 7), exhibited dead heart percentages between 32.38 ± 5.86 and 38.48 ± 7.33 per cent at 30 DAT. Notably, none of the local landraces screened demonstrated high resistance (HR) or high susceptibility with scores of 0 and 9, respectively (**Table 3**).

Table 3: Reaction of local landraces of rice against yellow stem borer, *S. incertulas* during *summer* 2023

Sl. No.	Genotypes	% DH		% WE	Score	Category
		30 DAT	60 DAT	90 DAT		
1	Aishwarya	8.19 ± 5.72	7.45 ± 3.02	3.8 ± 2.52	1	R
2	Anandi - 1	11.16 ± 4.06	13.3 ± 5.34	7.36 ± 3.1	3	MR
3	Arvath Pilai	7.33 ± 3.03	8.07 ± 3.09	4.3 ± 5.65	1	R
4	Anilam Anil	12.86 ± 3.2	12.04 ± 2.94	7.5 ± 2.8	3	MR
5	Bangara sanna - 3	13.46 ± 4.58	12.39 ± 5.32	7.38 ± 3.95	3	MR
6	Bheema sale - 2	12.62 ± 3.77	12.72 ± 4.12	7.75 ± 6.11	3	MR
7	Bilikanna hegge	8.66 ± 3.42	8.98 ± 2.75	2.88 ± 2.33	1	R
8	Bele jaddi alneram batta	14.67 ± 6.04	13.21 ± 3.02	7.81 ± 5.19	3	MR
9	Bul Bul -1	7.18 ± 3.17	7.66 ± 3.55	3.22 ± 3.62	1	R
10	Bangara kaddi	23.58 ± 5.77	21.9 ± 4.57	12.56 ± 5.78	5	MS
11	Bili nellu	38.48 ± 7.33	37.17 ± 9.43	23.39 ± 6.72	7	S
12	Black basumathi	12.99 ± 4.27	12.26 ± 3.84	8.82 ± 1.66	3	MR
13	Barma Black	14.04 ± 6.6	14.03 ± 5.64	6.93 ± 3.31	3	MR
14	Bili dadi goltiga	7.61 ± 3.81	7.86 ± 3.1	2.7 ± 3.25	1	R
15	Chinna ponni - 4	23.51 ± 9.78	23.12 ± 9.99	13.89 ± 6.25	5	MS
16	Chinagari batta	7.38 ± 6.49	6.37 ± 5.09	3.38 ± 3.53	1	R
17	Dodda Byranellu	12.49 ± 3.19	12.41 ± 2.89	8.72 ± 4.01	3	MR
18	Doddi Batta	8.78 ± 1.65	8.93 ± 2.42	4.04 ± 1.75	1	R
19	Dunda	24.14 ± 5.86	24.93 ± 15.13	13.79 ± 3.69	5	MS
20	Dubainallu	22.32 ± 4.2	21.54 ± 3.67	13.34 ± 7.41	5	MS
21	Esadli	13.91 ± 6.47	13.76 ± 5.97	8.58 ± 5.23	3	MR
22	G K variety tall	13.2 ± 3.94	13.25 ± 4.1	7.21 ± 4.67	3	MR
23	Giddaraja kamal	17.41 ± 7.5	18.72 ± 7.13	8.05 ± 3.68	3	MR
24	Gujarath basamati	33.57 ± 5.03	31.81 ± 9.57	16.67 ± 5.52	7	S
25	Gulwadi sannaki	14.57 ± 4.9	14.48 ± 4.59	8.58 ± 4.75	3	MR
26	Hasnudi	19.05 ± 7.76	18.54 ± 6.13	9.39 ± 6.52	3	MR
27	Itan gidda	12.04 ± 4.16	11.48 ± 4.08	9.3 ± 3.31	3	MR
28	Jadda batta	18.47 ± 6.25	18.97 ± 7.53	8.14 ± 4.89	3	MR
29	Kempu dadi gidda	22.81 ± 8.53	22.71 ± 8.54	14.31 ± 4.77	5	MS
30	Kulaj	32.38 ± 5.86	31.62 ± 6.9	15.43 ± 3.34	7	S
31	Kalikatesi	14.31 ± 5.71	13.88 ± 3.48	6.5 ± 3.24	3	MR
32	Kari kandake	17.62 ± 3.94	18.15 ± 6.57	7.33 ± 1.13	3	MR
33	Kanakunja	33.1 ± 7.57	32.05 ± 7.35	17.77 ± 6.62	7	S
34	Kalanamak - 1	7.3 ± 2.3	6.08 ± 2.04	3.65 ± 2.61	1	R
35	Kavadari	26.33 ± 12.39	25.42 ± 7.49	13.12 ± 2.89	5	MS
36	Kaduvelpe	14.9 ± 4.51	14.7 ± 3.39	7.85 ± 3.78	3	MR
37	KN - local	18.23 ± 5.38	16.33 ± 4.83	8.4 ± 2.88	3	MR
38	Kempurajmudi	12.69 ± 3.78	13.12 ± 5.66	7.42 ± 3.58	3	MR
39	KS Local	13.1 ± 5.93	11.88 ± 5.79	7.11 ± 3.82	3	MR

Sl. No.	Genotypes	% DH		% WE	Score	Category
		30 DAT	60 DAT	90 DAT		
40	Kannur	22.85 ± 7.52	23.83 ± 11.79	13.53 ± 6.62	5	MS
41	Kyasare - 2	12.6 ± 2.83	12.55 ± 2.64	7.28 ± 4.21	3	MR
42	Kari swarna	13.31 ± 4.88	13.32 ± 4.76	7.39 ± 3.44	3	MR
43	Malgudi sanna - 2	8.52 ± 2.21	8.59 ± 2.65	3.64 ± 2.94	1	R
44	Mysore mallige - 1	23.87 ± 10.24	21.78 ± 6.9	15.28 ± 14.14	5	MS
45	Mavaokar	17.39 ± 5.97	17.2 ± 5.46	9.35 ± 4.82	3	MR
46	Manjupani	13.32 ± 3.4	12.46 ± 4.49	8.21 ± 4.33	3	MR
47	Mallige - 2	13.29 ± 2.28	13.37 ± 4.73	7.08 ± 3.32	3	MR
48	Mobikar	22.08 ± 6.15	22.18 ± 6.69	13.11 ± 3.55	5	MS
49	Moradda	15.56 ± 5.74	16.44 ± 7.95	6.79 ± 4.1	3	MR
50	Malgudi sanna - 1	8.18 ± 5.79	7.05 ± 4.31	4.62 ± 5.11	1	R

DAT- Days after transplanting, R- Resistant, MR- Moderately Resistant, MS- Moderately Susceptible; S- Susceptible; DH- dead heart; WE- white ears.

Likewise, at 60 DAT, no genotypes exhibited high resistance. Among the genotypes, Kalanamak - 1 and Bilikanna hegge demonstrated dead heart incidences ranging from 6.08 ± 2.04 to 8.98 ± 2.75 per cent, classifying them as resistant with a score of 1. In the moderately resistant category (score 3), KS Local and Jadda batta showed dead heart percentages ranging from 11.88 ± 5.79 to 18.97 ± 7.53 per cent. Similarly, within the moderately susceptible category (score 5), Dubainallu and Kavadari had infestations ranging from 21.54 ± 3.67 to 25.42 ± 7.49 per cent. However, at 60 DAT, Kulaj and Bili nellu exhibited dead heart percentages between 31.62 ± 6.9 and 37.17 ± 9.43 per cent, categorizing them as susceptible with a score of 7. However, none of the genotypes were highly susceptible with a score of 9 (**Table 3**).

At 90 DAT, the percent of white ear incidence ranged between 2.7 ± 3.25 and 4.62 ± 5.11 per cent in Bili dadi goltiga and Malgudi sanna - 1, designating them as resistant varieties. Similarly, Kalikatesi and Hasnudi exhibited white ear percentages ranging from 6.5 ± 3.24 to 9.39 ± 6.52 per cent, categorizing them as moderately resistant. Genotypes Bangara kaddi and Mysore mallige - 1 demonstrated infestations ranging from 12.56 ± 5.78 to 15.28 ± 14.14 per cent, considered moderately susceptible. The white ear infestation in Kulaj and Bili nellu varied from 15.43 ± 3.34 to 23.39 ± 6.72 per cent, marking them as susceptible. However, none of the genotypes were identified as highly resistant or highly susceptible (**Table 3**).

The results of the present study corroborate with Balaji *et al*., (2023) who reported that out of 50 local landraces, five genotypes recorded resistance reaction with a damage score of 1, 23 genotypes were found to be moderately resistant with a score of 3, 17 genotypes reacted as moderately susceptible with score of 5 and five genotypes showed susceptible reaction with score of 7. Among all the screened popular cultivars four genotypes were found to be resistant, four genotypes showed moderately resistant reactions, one genotype was moderately susceptible and one genotype reacted as susceptible. None of the local landraces and popular cultivars were found to be highly resistant or highly susceptible to YSB.

Similarly, Justin and Preetha (2014) reported that among the 77 genotypes screened during *kharif* 2011, TP 08079, TP 10015, TP 10019, TP 10029 and TP 10031 were found to be highly resistant with damage score '0'. During *kharif* 2012, the genotypes *viz.,* TP 10006, TP 10007, TP 10008, TP 10009, TP 10010, TP 10011 and TP 10012 were found to be highly resistant with score '0'. During *rabi* 2011, TP 10007 was found to be highly resistant without any dead heart or white ear damage. During *rabi* 2012, fifty-seven genotypes were screened for resistance to rice stem borer and 15 genotypes recorded zero incidence of stem borer. Similarly, the highest incidence of stem borer (white ears) was observed in TN-1 and RpPatho-02 (13.13% WE). The rice cultures CR 2711-76 and CR 3005-230-5 were found resistant to stem borer at the reproductive stage. The genotypes CR 3005-77-2 and CR 3006-8-2 showed moderate resistance (Visalakshmi *et al.*, 2014).

Meanwhile among the 231 paddy genotypes screened against yellow stem borer, per cent white ears at 80 DAT varied between 0.84 (resistant) and 25.96 (susceptible). 74 genotypes proved to be resistant by recording less than 5 per cent white ears. Eighty-seven genotypes reacted as moderately resistant (6-10% white ear), forty-five genotypes showed moderately susceptible by recording less than 15 per cent white ears and twenty-five genotypes showed susceptible reaction by recording a white ear per cent in between 16 to 25%. The susceptible check TN1 recorded 25.96 per cent white ear. None of the genotypes were free from white ear, to categorized as highly resistant (0% white ear), similarly, none of the genotypes reacted as highly susceptible (26-100% white ear) (Girish *et al.*, 2013).

Likewise, the results of the rice germplasm screening for resistance to stem borer recorded the white ear at 75 and 95 DAT. Out of forty-six rice cultures screened, TP 10003, TP 10004, TP 10039 and TP 08095 were found minimal incidence and were rated as resistant categories. TP 10002, TP 10005, TP 10016, TP 10038, TP 10051, TP 10052, TP 09048 and TP 09052 were rated as moderately resistant (Preetha, 2017). Meanwhile, five accessions (AD 16124, AD 15101, AD 16189, AD 12182 and AD 12272) recorded no dead heart and white ear head damage and were found to be highly resistant. Three accessions (AD 16157, AD 12132, AD 16157) were found to be highly susceptible (Sharmitha *et al.,* 2019).

Yadav *et al*., (2023) reported that among the 20 rice accessions screened against *S. incertulus* during *summer* 2022, the rice variety Radha-13 showed a lower infestation (about 0.54% dead heart) than other accessions against YSB. Moreover, the rice accessions Subarna Sub-1 and NR2188-13-5-2-5-1 were moderately resistant to YSB, with 9.95 per cent. Conclusively, most of the rice accessions evaluated had better plant resistance against YSB. Further, Rajadurai and Kumar (2017) reported that out of 193 genotypes screened, fifty-six genotypes were found resistant, ninety-five were found moderately resistant, twenty-eight were moderately susceptible, eight were susceptible and six were highly susceptible. The resistance in all the genotypes is due to the strong antibiosis and phenolics, as they cause mortality in rice stems (Zhu *et al*., 2002).

Pest screening is necessary to evaluate the damage caused by different rice genotypes/varieties and investigate host plant resistance against insects as a pest-mitigating strategy. In our current study, we have undertaken an effort to identify rice varieties that exhibit resistance to the YSB across various aspects. These resilient varieties show promise for integration into breeding programs. Employing host plant resistance mechanisms emerges as a promising, eco-friendly and cost-effective approach to pest control, leading to reduction in the pesticide consumption. Cultivating these resistant varieties becomes crucial for effective insect pest management. Our research highlights that a majority of the tested genotypes demonstrate either resistance or moderate resistance. Consequently, it is essential to delve into the mechanisms underpinning this resistance, paving the way for their application in future breeding programs targeted at combating the YSB in paddy cultivation.

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Efficacy of Novel Fungicides for the Management of False Smut of Rice Caused by *Ustilaginoidea virens*

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Abstract

In the present investigation eight fungicides were tested against the false smut disease of rice during *kharif*-2016-19. Among the different fungicides evaluated, two sprays of Trifloxystrobin 25% + Tebuconazole 50% (75 WG) at 0.03 per cent (4 gm/10 l) and Propiconazole 25 EC at 0.025 per cent (10 ml/10 l.) applied at booting and post flowering stage were found effective for the management of false smut. The other effective fungicides were Mancozeb 75 WP, Tebuconazole 25.9 EC, Tricyclazole 75 WP, Kresoxim methyl 50 SC, Azoxystrobin 23 SC and Carbendazim 50 WP.

Key Words: Rice, False smut, Fungicides, mycotoxins, *Ustilaginoidea virens.*

Introduction

Rice (*Oryza sativa* L.) is one of the important cereal crops and staple food for more than two-thirds of the Indian population and playing a crucial role in the people's food and livelihood security. False smut [*Ustilaginoidea virens* (Cooke) Takahashi] also known as green smut or pseudo-smut is emerging as one of the important diseases of rice in India and the world. The pathogen infects individual spikelets and causes direct economic losses. The disease has been reported from almost all the rice growing states of India in moderate to severe forms symbolizing a major threat to rice cultivation. Earlier it was considered as a minor disease, occurred in sporadically in certain regions, but recent scenario of epidemics of the false smut disease are also reported in different parts of the world including India (Rush *et al.,* 2000; Anon., 2016). The disease incidence of 10-20 per cent and 05-85 per cent, respectively was reported from Punjab and Tamil Nadu states on different rice genotypes (Ladhalakshmi *et al*., 2012). In recent years, its outbreak is expected due to high input cultivation practices, maximum use of hybrid varieties and change in climate (Lu *et al*., 2009). The fungus produces mycotoxins that are harmful to humans and animals. The disease is severe when environmental conditions like high humidity (>80%) and temperature range from 25 to 30°C (Mathew *et al*., 2021). Adoption of correct control measures against this disease would help reduce the economic loss.

Materials and Methods

A field experiment was conducted at Hill Millet Research Station, NAU, Waghai, Gujarat during *kharif*, 2016-19 to find out most effective fungicides for the management of false smut disease. Experiment was carried out in Randomised Block Design (RBD) with nine treatments with three replications. Cultivar used during experiment was GR-11 and the gross plot size was 3.0 m x 2.4 m. square and the recommended agronomical packages of practices were followed for conducting the experiment. Two sprays of fungicides were given for each treatment at booting stage [75 days after transplanting (DAT)] and milking/post flowering stage (95 DAT). The false smut observations were recorded by fixing three sampling units of one m^2 at random in each treatments and data was recorded as infected spikelets/panicle and infected panicles/m^2. The grain and straw yield data was recorded at the time of harvest of crop.

Results and Discussions

The results of the experiments indicated that the different treatments had significantly reduced the per cent infected panicles over control during all the years as well as in pooled results. The results on per cent infected panicles are given in **Table 1**. In the year 2016-17, the treatment T_1 (Trifloxystrobin 25% + Tebuconazole 50% 75 WG) was found to be significantly superior and recorded minimum infected panicles (3.07%) and minimum per cent infected spikelets (10.43%) when compared to control (19.57% and 40.53%). The next best treatment is T_6 (Propiconazole 25 EC) which was on par with T_7 (Mancozeb 75 WP) and T_8 (Tebuconazole 25.9 EC). In the second year trials (2017-18), the same treatment T_1 was showed significantly superior performance and recorded minimum infected panicles (3.10%) and minimum per cent infected spikelets (10.23%) which was on par with T_6 (4.47%) and (13.03%). The next best fungicide in order of merit was T_7. Similarly, in the 3rd year of the trials, T_1 was observed significantly superior and recorded minimum percentage of infected panicles (3.70%) and minimum per cent infected spikelets (11.77%) which was on par with T_6 (5.03%) and (14.53%). The next best in order of merit was T_7. In the case of pooled results, the treatment T_1 *i.e.,*

Table 1: Effect of different treatments on per cent infected panicles and per cent infected spikelet/panicle of rice false smut

Sr. No.	Treatments	Per cent infected panicles/ m^2				Per cent infected spikelet/panicle			
		2016	2017	2019	Pooled	2016	2017	2019	Pooled
T_1	Trifloxystrobin 25% + Tebuconazole 50% (75 WG)	3.07 (10.01)	3.10 (10.10)	3.70 (11.07)	3.29 (10.39)	10.43 (18.84)	10.23 (18.64)	11.77 (20.04)	10.81 (19.17)
T_2	Kresoxim methyl 50 SC	7.87 (16.29)	7.33 (15.71)	11.90 (20.11)	9.03 (17.37)	19.37 (26.09)	19.50 (26.16)	22.37 (28.22)	20.41 (26.82)
T_3	Azoxystrobin 23 SC	7.93 (16.35)	8.07 (16.47)	7.87 (16.28)	7.96 (16.37)	20.90 (27.18)	20.17 (26.59)	20.03 (26.57)	20.37 (26.78)
T_4	Tricyclazole 75 WP	7.17 (15.52)	6.23 (14.43)	6.90 (15.20)	6.77 (15.05)	18.63 (25.56)	17.87 (24.96)	19.60 (26.25)	18.70 (25.59)
T_5	Carbendazim 50 WP	10.57 (18.93)	10.33 (18.71)	8.60 (17.03)	9.83 (18.22)	21.13 (27.36)	22.00 (27.96)	21.93 (27.88)	21.69 (27.73)
T_6	Propiconazole 25 EC	4.80 (12.66)	4.47 (12.16)	5.03 (12.96)	4.77 (12.59)	12.97 (21.09)	13.03 (21.10)	14.53 (22.37)	13.51 (21.52)
T_7	Mancozeb 75 WP	5.40 (13.42)	4.90 (12.76)	5.33 (13.33)	5.21 (13.17)	14.37 (22.23)	14.83 (22.62)	15.87 (23.45)	15.02 (22.77)
T_8	Tebuconazole 25.9 EC	6.10 (14.29)	5.83 (13.89)	6.40 (14.59)	6.11 (14.25)	17.03 (24.34)	17.03 (24.33)	17.98 (25.04)	17.35 (24.57)
T_9	Control (No spray)	19.57 (26.22)	17.33 (24.53)	15.97 (23.49)	17.62 (24.75)	40.53 (39.53)	34.60 (36.01)	28.17 (32.03)	34.43 (35.85)
	S.Em ±	0.65	0.86	0.74	0.82	0.93	1.25	1.04	1.17
	C.D. at 5%	1.95	2.58	2.22	2.34	2.79	3.75	3.11	3.34
	C.V.%	7.06	9.68	8.01	8.97	6.24	8.53	6.97	7.89
	Y x T				N.S				N.S

Note: Figures in the outside parenthesis are the original values while in parenthesis are arcsine transformed value. NS: Non-significant

Trifloxystrobin 25% + Tebuconazole 50% (75 WG) significantly reduced the infected panicles (3.29%) and per cent infected spikelets (10.81%) which was statistically on par with (T_6) Propiconazole 25 EC (4.77%) and (13.51%). The year effect was found non-significant.

Grain and Straw yield

The results on grain and straw yield of rice are given in **Table 2**. The results indicated that each fungicide treatment influenced the grain and straw yield during all the three years as well in pooled result. All the treatments were found to be significantly superior over control. Among the treatments, higher grain yield (6065 kg/ha) and straw yield (7361 kg/ha) was recorded in the treatment T_1 (Trifloxystrobin 25% + Tebuconazole 50% 75 WG) which was on par with the treatment T_6 (Propiconazole 25 EC) and T_7 (Mancozeb 75 WP) in the year 2016-17. Similarly, during the 2nd year, significantly higher grain yield (5977 kg/ha) and straw yield (7269 kg/ha) were recorded in treatment T_1 which was on par with the treatments T_6 and T_7. In the 3rd year trials, the treatment T_1 recorded significantly higher grain (5949 kg/ha) and straw yield (7037 kg/ha) that were at par with treatment T_6 grain yield (5657 kg/ha) and treatment T_6 and T_7 straw yield *i.e.,* 6690 and 6366 kg/ha, respectively. In the case of pooled results, the lowest grain yield (3511 kg/ha) and straw yield (4901 kg/ha) were recorded in control plot and the treatment T_1 *i.e.,* Trifloxystrobin 25 + Tebuconazole 50 (75 WG) @ 0.4 g/l was recorded significantly higher grain yield (5997 kg/ha) and straw yield (7222 kg/ha) which was statistically at par with T_6 *i.e.,* Propiconazole 25 EC @ 1.0 ml/l for grain yield (5798 kg/ha) and straw yield with treatment Propiconazole 25 EC (T_6) @ 1.0 ml/l and Mancozeb 75 WP (T_7) @ 3.3 g/l *i.e.,* 6983 and 6420 kg/ha, respectively. More or less similar results were reported by earlier workers for efficacy of different fungicides under field condition that is carbendazim and propiconazole (Dodan and Singh, 1997), Carbendazim (Hegde *et al*., 2000), Propiconazole, Tebuconazole and Carbendazim (Bagga and Kaur, 2006), Propiconazole, Tebuconazole, Carbendazim and Carbendazim + Mancozeb (Paramjit *et al*., 2006), Tebuconazole + Trifloxystrobin, Propiconazole, (Chen *et al*., 2013; Ladhalakshmi *et al*., 2014; Shivamurthy, 2017). Muniraju *et al.,* (2017) reported that Azoxystrobin+ Difenconozole and Metiram + Pyraclostrobin, (Surendren *et al.,* (2023) reported that Difenconazole and Isoprothiolane were found best in efficacy against sheath blight and grain discoloration. Systemic fungicide Trifloxystrobin + Tebuconazole

Table 2: The effect of fungicidal treatments on yield parameters

Sr. No.	Treatments	Grain Yield (kg/ha)				Straw Yield (kg/ha)			
		2016	2017	2019	Pooled	2016	2017	2019	Pooled
T_1	Trifloxystrobin 25% + Tebucona-zole 50% (75 WG)	6065	5977	5949	5997	7361	7269	7037	7222
T_2	Kresoxim methyl 50 SC	4639	4583	4421	4548	5833	5741	5370	5648
T_3	Azoxystrobin 23 SC	4481	4259	4583	4441	5579	5648	5602	5610
T_4	Tricyclazole 75 WP	4644	4606	4639	4630	6019	5926	5671	5872
T_5	Carbendazim 50 WP	4074	3981	4495	4184	5486	5463	5532	5494
T_6	Propiconazole 25 EC	5903	5833	5657	5798	7153	7106	6690	6983
T_7	Mancozeb 75 WP	4963	5000	4745	4903	6505	6389	6366	6420
T_8	Tebuconazole 25.9 EC	4653	4676	4704	4677	6111	5949	5972	6011
T_9	Check (No spray)	3565	3449	3519	3511	5120	4815	4769	4901
	S.Em $\pm$	372	389	283	380	398	386	373	418
	C.D. at 5%	1116	1168	850	1086	1196	1159	1120	1194
	C.V. %	13.50	14.33	10.35	13.89	11.30	11.10	11.01	12.04
	Y x T				N.S				N.S

and Propiconazole were shown to be effective against neck blast and recorded maximum yield (Yadav *et al.,* 2022).

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BPT 2848 - A Black Rice Variety with High Protein Content and Anti - oxidant Activity

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Abstract

BPT 2848 is a black pericarp coloured rice variety which was registered with NBPGR as genetic stock for high protein content (10.5%) in polished rice. It is a cross between Improved Samba Mahsuri*1 and IRGC 48493. It has 125-130 days duration coupled with tolerance to bacterial blight, blast and BPH. BPT 2848 has medium slender grain which recorded intermediate amylose content and alkali spreading value hence the cooked rice will be soft and flaky. Due to its black pericarp, it exhibits high anti-oxidant activity, high total phenol content and flavonoid content which has potential health benefits. It can be utilized in making food products to utilize its rich phytochemicals content and nutraceutical properties to combat the malnutrition.

Keywords: Black rice, protein content, Anti-oxidant activity, micronutrient, flavonoid content.

Rice (*Oryza sativa* L.) is the predominant staple food crop for more than half of the world's population and plays a pivotal role in human nutrition, energy supply and food security. Even though rice protein content is slightly lower than other cereals, with respect to protein quality, the rice protein amino acid profile is better balanced compared to other cereals such as wheat and maize (Hegsted, 1969). Therefore, the impact of improving the protein content in rice would be enormous in combating the protein energy malnutrition which is prevalent in more than one third of world's child population. Research on biofortification of rice was initiated a decade back at Agricultural Research Station, Bapatla and many genotypes possessing high protein and micronutrient content were identified. Among these, one advanced breeding line *viz.*, BPT 2848 was identified as possessing high protein content and was nominated to IVT-Biofortification trial conducted under AICRP on rice. BPT 2848 (IET 28692) is a derivative of the cross between RP Bio 226*1 and IRGC 48493 which was developed through pedigree method of breeding at Agricultural Research Station, Bapatla. The performance of BPT 2848 for protein content in IVT-Biofortification trial during *kharif*, 2019 including 4 checks (IR 64 and BPT 5204 as yield checks and DRR Dhan 45 and Chittimuthyalu as micronutrient checks) revealed that BPT 2848 recorded highest overall mean protein content of 10.5% in polished rice among all the entries tested**.** The two micronutrient checks *viz.*, DRR Dhan 45 and Chitimuthyalu recorded 6.43% and 8.30% mean protein content on overall basis respectively. IET 28692 recorded more than 10.0% protein content in polished rice at 5 locations *viz*., Jeypore (13.17%), Cuttack (13.33%), Sirsi (10.52%), Aduthurai (12.28%) and Coimbatore (10.36%), out of 9 testing locations **(Table 1)**.

BPT 2848 (IET 28692) possess medium slender grain with straw glume and black pericarp and has a test weight of 13.5 g to 14.0 g. BPT 2848 matures in 125-130 days duration during *kharif* season and recorded a mean grain yield of 4415 kg/ha on over all basis when tested at 20 locations in IVT-Biofortification trial. In this trial, the yield check BPT 5204 recorded 4484 kg/ha and micronutrient check variety

Table 1: Protein content (%) of polished rice samples of BPT 2848 in Initial Variety Trial-Biofortification (IVT-Biofortification) at different locations analysed at ICAR-NRRI, Cuttack, *Kharif*, 2019

IET No	JYP	CTK	SKL	NVS	SRS	ADT	CBT	MNC	MTU	Overall Mean
IET 28692 (BPT 2848)	13.17	13.33	7.17	8.83	10.52	12.28	10.36	9.46	9.34	**10.50**
BPT 5204	8.12	7.79	7.45	6.17	6.00	8.36	8.93	7.92	5.47	**7.36**
DRR Dhan 45	7.11	7.94	4.43	5.53	5.44	6.53	6.59	6.22	8.08	**6.43**
Chittimuthyalu	7.85	7.88	8.65	7.17	7.62	9.32	9.10	9.52	7.60	**8.30**
IR 64	7.82	7.78	5.19	6.65	6.00	6.72	6.86	-	6.32	**6.67**

Source: AICRP trials data from IVT-Biofortification trial from Varietal Improvement Progress Report Volume 1

Chittimuthyalu recorded 3671 kg/ha. BPT 2848 recorded 13.2% protein content in unpolished rice (**Table 2**). BPT 2848 possesses intermediate amylose content (22.46%) and alkali spreading value (4.3) which determines the soft and flaky texture of cooked rice. It also recorded high total phenol content (123.31 mg/100 g), high flavonoid content (784.54 mg/100 g) and anti-oxidant activity (86.63 mg/100 g) which plays a major role in free radical balance. The phenolic compounds are also known as antioxidants and are likely to have functional effects against oxidative damage and associated with reduced risk of chronic diseases such as diabetes and cardiovascular diseases (Adom and Liu 2002; Liu, 2007). Unlike other *desi* glutinous black rice varieties, it possesses intermediate amylose content and alkali spreading value, hence cooks soft and flaky which is preferred by South Indian consumers. Li *et al.,* (2016) also stated that the amylose content of the rice variety has culinary implications because it has an influence on the organoleptic qualities of rice once cooked.

Recently, pigmented rice varieties have been receiving increased attention from health conscious consumers for their high bioactive compounds which possess potential nutraceutical benefits to human health. During the last few decades, the people have been more concerned about the natural health supplements from food resources. Rice has good quality protein compared to other cereals (Juliano, 1993) and is rich in branched chain amino acids such as leucine, isoleucine and valine. According to Ke *et al.,* (2018), protein is an important modulator in glucose homeostasis by increasing gluconeogenesis and preventing insulin

Table 2: Physico-chemical, nutritional and biochemical quality characteristics of BPT 2848

Sl. No	Quality parameter	BPT 2848	Sl. No	Quality parameter	BPT 2848
1	Kernel length (mm)	5.63	11	Protein content (%) in polished rice	10.5
2	Kernel breadth (mm)	1.96	12	Crude fiber (%)	1.21
3	Length/ breadth ratio	2.88	13	Carbohydrate (%)	73. 17
4	Grain type	Medium slender	14	Energy (Kcal.)	358
5	Volume expansion Ratio	3.73	15	Fe content (ppm)	12.30
6	Water uptake (ml)	417	16	Zn content (ppm)	18.00
7	Alkali spreading value	4.33	17	Total Antioxidant activity in unpolished rice (mg AAE/100 g)	86.63
8	Gel consistency (mm)	78.0	18	Total anthocyanin content in unpolished rice (mg C3g/100 g)	24.99
9	Amylose content (%)	22.48	19	Total phenol content in unpolished rice (mg GAE/100 g)	123.31
10	Protein content (%) in unpolished rice	13.2	20	Flavonoid content in unpolished rice (mg GAE/100 g)	784.54

resistance, hence genotypes possessing high protein content digest slowly and aids in slow release of blood glucose. Due to its high protein content, high bioactive compounds coupled with desirable cooking quality, BPT 2848 black rice may be included in daily diet to get potential nutraceutical benefits to health.

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DRR Dhan 70 - (IET 29415) - An Aerobic Rice Variety

Senguttuvel P*, Sundaram RM, Gireesh C, HariPrasad AS, Anantha MS, Subba Rao LV, Swamy AVSR, Sai Prasad SV, Padmavathi G, Kalyani MB, Sanjeeva Rao D, Prasad MS, Mahender Kumar R, Sreedevi B, Gobinath R, Prakasam V, Muthuraman P, Laha GS, Neeraja CN, Rao PR, Akshay S Sakhare, Jhansi Laxmi, Nirmala B, Somasekhar N, Kannan C, Jeyakumar P, Sadath Ali M, Koteshwar Rao P, Muralidhar Reddy C, Chandra Kumar M, Nagarjuna E, Chaitanya U, Jaldhani V, Beulah P and Nagaraju P

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Abstract

DRR Dhan 70 [IET 29415 (RP 6326-278-14-1)], an aerobic rice variety was developed from MTU 1010 × WGL 505. It was evaluated in AICRIP multi-location aerobic rice trials during wet seasons of 2020 to 2022. The DRR Dhan 70 consistently surpassed the performance of the comparison varieties in Odisha and Bihar states (Zone III), achieving a mean grain yield of 4287 kg/ha. This yield superiority is evident over the national check by 16%, the zonal check by 11% and the local check by 18%. In addition, it exhibited moderate resistance to leaf blast, brown spot, sheath rot, rice tungro, plant hoppers, stem borer, gall midge and leaf folder. DRR Dhan 70 has a duration of 120 days (seed to seed) and possesses desirable grain and cooking quality parameters. It was released for cultivation in aerobic ecosystems of Odisha and Bihar (Zone III) states through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 1560(E) dated March 26, 2024 [CG-DL-E-28032024-253429].

Keywords: Aerobic rice, Grain yield, Cooking quality, Direct seeded.

Introduction

Rice (*Oryza sativa* L.) cultivation spans approximately 22 million hectares under irrigated ecology in India, which represents around 50% of the total rice production area in the country. Given the challenges posed by climate change, resource constraints in terms of water availability, and labor, there is a growing imperative for transitioning to aerobic rice cultivation methods to ensure substantial and consistent crop yields. Recognizing this need, the Indian Institute of Rice Research (ICAR-IIRR) embarked on a focused effort towards aerobic rice cultivation, commencing in 2011 with the cross of MTU 1010 × WGL 505. The resulting segregating populations underwent rigorous evaluation under direct seeded aerobic conditions to advance the development of suitable aerobic rice cultivars.

The promising line RP 6326-278-14-1 was identified and nominated in AICRIP Aerobic trial 2020. Subsequently, the entry performed well in all the three years and released as a direct seeded aerobic rice variety DRR Dhan 70 through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 1560 (E) dated March 26, 2024 [CG-DL-E-28032024-253429]. Suitable for cultivation in Odisha and Bihar states of the eastern zone (Zone III), DRR Dhan 70 demonstrated an overall mean grain yield of 4287 kg/ha. This yield surpassed the national check by 16%, the zonal check by 11% and the local check by 18%. In Odisha state, the mean grain yield reached 4454 kg/ha, marking a significant increase compared to the national check (15%), zonal check (21%) and the local check (63%). In Bihar state, the mean grain yield stood at 4216 kg/ha, displaying notable improvements over the national check (17%), zonal check (7%) and the local check (5%) **(Table 1).**

Table 1: Yield performance of DRR Dhan 70 in Odisha and Bihar states (Zone III)

States	DRR Dhan 70	Superiority over checks (%)		
Mean Grain Yield (Kg.ha^{-1})	**(IET29415)**	**National Check**	**Zonal Check**	**Local Check**
Odisha	4454	15	21	63
Bihar	4216	17	7	5
Overall	4287	16	11	18

The rice variety demonstrated moderate resistance to a range of prevalent diseases and pests, including leaf blast, brown spot, sheath rot, rice tungro, plant hoppers, stem borer, gall midge and leaf folder. In contrast to the standard checks and qualifying varieties, it demonstrates admirable hulling efficiency at 78.85%, milling quality at 70.40% and head rice recovery rate at 64.80%. Additionally, it exhibits intermediate levels of amylose content at 21.26%, an alkali spreading value of 3.0, and a gel consistency of 38 mm. With a long bold (LB) grain type characterized by a kernel length of 6.14 mm and breadth of 2.20 mm, it also exhibits other desirable grain and cooking quality attributes **(Figure 1).**

DRR Dhan 70 variety is exceptionally well-suited for cultivation in dry direct seeded aerobic conditions with intermittent irrigation. Optimal timing for dry direct seeding falls between the second week of June to the second week of July, coinciding with the onset of rainfall or preceded by pre-sowing irrigation. Immediate post-sowing lifesaving irrigation is crucial to ensure uniform germination and crop establishment. Weed management poses a significant challenge in aerobic rice cultivation. To address this issue effectively, Pendimethalin herbicide should be applied at a rate of 1 kg per hectare at field capacity moisture within 3 days of sowing. Additionally, it is advisable to apply a

Figure 1: Field view of DRR Dhan 70 (Left); Paddy, Brown rice and Polished rice of DRR Dhan 70 (Right)

post-emergence, broad-spectrum systemic herbicide like Bispyribac Sodium 10% SC (Nominigold) at a rate of 50 ml per hectare at field capacity moisture within 5-15 days of sowing. One intermittent weeding is recommended during the crop growth period, with a provision for two if weed pressure is high. Irrigation should be applied as per the crop's physiological requirements until maturity. DRR Dhan 70 offers a significant advantage with a duration of 113-120 days (seed to seed) compared to transplanted rice varieties. It has the potential to yield between 5.0-5.5 t/ha when cultivated within the designated area of adoption, recommended climate conditions, and adherence to prescribed agronomic practices. This variety is suitable for direct seeding in both early *kharif* (wet) and *rabi* (dry) seasons.

SHORT COMMUNICATION https://doi.org/10.58297/XOCN7966

DRR Dhan 71 - (IET 29421) - An Aerobic Rice Variety

Senguttuvel P*, Sundaram RM, Hari Prasad AS, Gireesh C, Anantha MS, Revathi P, Abdul Fiyaz R, Subba Rao LV, Swamy AVSR, Sai Prasad SV, Aravind Kumar J, Divya Balakrishnan, Mangrauthia SK, Jyothi Badri, Suvarna Rani Ch, Kumar RM, Sreedevi B, Neeraja CN, Prasad MS, Mangaldeep Tuti, Muthuraman P, Arun Kumar S, Nirmala B, Somasekhar N, Sridhar Y, Brajendra P, Chitra Shanker, Santhosha Rathod, Sadath Ali M, Koteshwar Rao P, Nagarjuna E, Chaitanya U, Amudhan Srinivas, Beulah P, Jaldhani V and Nagaraju P

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Abstract

DRR Dhan 71 [IET 29421 (RP 6324-123-14-4-1)], an aerobic rice variety was developed from CR 691-1 × CR Dhan 202. It was evaluated in AICRIP multi-location aerobic rice trials during wet seasons of 2020 to 2022. Consistently outperforming the check varieties in Odisha, Gujarat, and Tamil Nadu, DRR Dhan 71 achieved a mean grain yield of 4870 kg/ha. This yield superiority is evident with a significant increase over the national check (20%), zonal check (38%) and local check (28%). In addition, it exhibited moderate resistance to leaf blast, neck blast, sheath rot, brown spot, rice tungro, sheath blight, plant hoppers, stem borer, gall midge and leaf folder. DRR Dhan 71 has a duration of 120 days (seed to seed) and possesses desirable grain and cooking quality parameters. It was released for cultivation in aerobic ecosystems of Odisha, Gujarat and Tamil Nadu states through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 1560(E) dated March 26, 2024 [CG-DL-E-28032024-253429].

Keywords: Aerobic rice, Grain yield, Cooking quality, Direct seeded.

Introduction

Rice (*Oryza sativa* L.) cultivation in India encompasses approximately 22 million hectares under irrigated ecology, accounting for >50% of the nation's total rice production area. In light of the challenges arising from climate change and limitations in water availability and labour resources, there is a collective need to adopt aerobic rice cultivation techniques to secure substantial and reliable crop yields. Recognizing this need, the Indian Institute of Rice Research (ICAR-IIRR) embarked on a focused effort towards aerobic rice cultivation, commencing in 2011 with the cross of CR 691-1 × CR Dhan 202. The resultant segregating populations underwent thorough evaluation under direct seeded aerobic conditions to propel the advancement of suitable aerobic rice cultivars. The promising line RP 6324-123-14-4-1 was identified and nominated in AICRIP Aerobic trial 2020. Subsequently, the entry performed well in all the three years and released as a direct seeded aerobic rice variety DRR Dhan 71 through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 1560(E) dated March 26, 2024 [CG-DL-E-28032024-253429]. It was suitable for cultivation in Odisha, Gujarat and Tamil Nadu states. The overall mean grain yield of DRR Dhan 71 in Odisha, Gujarat, and Tamil Nadu states stood at 4870 kg/ha, marking a marked increase over the national check (20%), zonal check (38%) and the local check (28%). In Odisha state, the mean grain yield reached 4496 kg/ha, showing a 16% (national check), 22% (zonal check) and 64% (local check) yield superiority. In Gujarat state, the mean grain yield was 4917 kg/ha, indicating a notable increase over the national check (15%), zonal check (38%) and local check (12%). In Tamil Nadu state, the mean grain yield reached 5314 kg/ha, exhibiting a 39%, 68% and 35% increase over the national check, zonal check, and local check, respectively **(Table 1).**

Table 1: Yield performance of DRR Dhan 71 in Odisha, Gujarat and Tamil Nadu states

States	DRR Dhan 71 (IET29421)	Superiority over checks (%)		
Mean Grain Yield ($Kg.ha^{-1}$)		National Check	Zonal Check	Local Check
Odisha	4496	16	22	64
Gujarat	4917	15	38	12
Tamil Nadu	5314	39	68	35
Overall	4870	20	38	28

The rice variety demonstrated moderate resistance to a range of prevalent diseases and pests, including leaf blast, neck blast, sheath rot, brown spot, rice tungro, sheath blight, plant hoppers, stem borer, gall midge and leaf folder. In contrast to the standard checks and qualifying varieties, it demonstrates admirable hulling efficiency at 79.85%, milling quality at 71.20% and head rice recovery rate at 64.60%. Additionally, it exhibits intermediate levels of amylose content at 24.75%, an alkali spreading value of 7.0 and a gel consistency of 24 mm. With a medium slender (MS) grain type characterized by a kernel length of 5.72 mm and breadth of 2.06 mm, it also exhibits other desirable grain and cooking quality attributes **(Figure 1).**

DRR Dhan 71 variety excels in cultivation under dry direct seeded aerobic conditions with intermittent irrigation. The optimal timing for dry direct seeding ranges from the second week of June to the second week of July, coinciding with the onset of rainfall or preceded by pre-sowing irrigation. Immediate post-sowing lifesaving irrigation is essential to ensure uniform germination and crop establishment. Weed management presents a significant challenge in aerobic rice cultivation. To effectively address this issue, Pendimethalin herbicide should be applied at a rate of 1 kg per hectare at field capacity moisture within 3 days of sowing. Additionally, it is advisable to apply a post-emergence, broad-spectrum systemic herbicide like Bispyribac Sodium 10% SC (Nominigold) at a rate of 50 ml per hectare at field capacity moisture within 5-15 days of sowing. One intermittent weeding is recommended during the crop growth period, with the option for two if weed pressure is high.

Figure 1: Field view of DRR Dhan 71 (Left); Paddy, Brown rice and Polished rice of DRR Dhan 71 (Right)

Irrigation should be applied in accordance with the crop's physiological requirements until maturity. DRR Dhan 71 offers a significant advantage with a duration of 113-120 days (seed to seed) compared to transplanted rice varieties. It has the potential to yield between 5.0-5.5 t/ha when cultivated within the designated area of adoption, recommended climate conditions, and adherence to prescribed agronomic practices. This variety is suitable for direct seeding in both early *kharif (*wet) and *rabi* (dry) seasons.

SHORT COMMUNICATION https://doi.org/10.58297/RGBA1509

DRRH - 5 (IET 27847) - World's First Coastal Salinity Tolerant Rice Hybrid

Senguttuvel P[1]*, Sundaram RM[1], Hari Prasad AS[1], Revathi P[1], Kemparaju KB [1], Sruthi K[1], Suneetha Kota[1], Jauhar Ali[2], Subba Rao LV[1], Swamy AVSR[1], Sai Prasad SV[1], Surekha K[1], Prasad MS[1], Kumar RM[1], Muthuraman P[1], Prasad Babu MBB[1], Gobinath R[1], Bhadana VP [3], Thirumeni S[4], Sadath Ali M[1], Koteshwar Rao P[1], Chaitanya U[1], Beulah P[1], Jaldhani V[1] and Nagaraju P[1]

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Abstract

DRRH-5 [IET 27847 (IIRRH-115)], stands as the world's first coastal salinity-tolerant rice hybrid, developed from APMS-6A × NH 12-124. It was evaluated in AICRIP multi-location Coastal Saline Tolerant Variety Trial (CSTVT) during wet seasons spanning from 2018 to 2022. DRRH-5 consistently out-performed the checks in West Bengal, Gujarat, Goa and Andhra Pradesh with a mean grain yield of 3.7 t/ha in saline conditions and 6.0 t/ha in irrigated conditions. In addition, it exhibited moderate resistance to leaf blast, neck blast, sheath rot and plant hoppers. DRRH-5 has a duration of 124 days (seed to seed) and possesses medium slender (MS) grain type with desirable grain and cooking quality parameters. It was released for cultivation in coastal saline ecosystems of West Bengal, Gujarat, Goa and Andhra Pradesh states through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 1560(E) dated March 26, 2024 [CG-DL-E-28032024-253429].

Keywords: Coastal salinity tolerant rice hybrid, Grain yield, Medium slender grains, Cooking quality.

Introduction

Hybrid rice cultivation currently spans over 350,000 hectares and is projected to surpass the four million-hectare mark. However, amidst a backdrop of shifting climate patterns, over 80% of the rice hybrids released thus far are susceptible to abiotic stresses such as salinity, high-temperature, and drought. Given this scenario, the demand for tolerant rice hybrids becomes increasingly imperative, offering a vital solution for achieving substantial and consistent crop yields amidst changing environmental conditions. Indian Institute of Rice Research (ICAR-IIRR) has initiated the development of salinity tolerant rice hybrids suitable for coastal saline ecologies and a promising cross combination, APMS-6A × NH 12-124 (IIRRH-115) was identified. The hybrid, IIRRH-115 was nominated in AICRIP CSTVT trail-2018. Subsequently, the entry performed well in all the four years and released as world's first coastal salinity tolerant rice hybrid, DRRH-5 through Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops vide S.O. 1560 (E) dated March 26, 2024 [CG-DL-E-28032024-253429]. It is suitable for cultivation in the states of West Bengal, Gujarat, Goa and Andhra Pradesh. The overall mean grain yield of DRRH-5 was 3.7 t/ha, which was 71%, 35% and 59% higher than CSR10 (Early duration saline check), FL 478 (Saline Tolerant Check), and Pusa 44 (Sensitive Check), respectively. In Andhra Pradesh state, the weighted mean grain yield was 4132 kg/ha and it out yielded the CSR 10 (85%), FL478 (17%) and Pusa 44 (44%). In GOA state, the weighted mean grain yield was 4532 kg/ha and out yielded the CSR 10 (70%), Bhuthnath (89%), FL478 (180%) and Pusa 44 (140%) **(Table 1).**

Table 1: Yield performance of DRRH-5 in West Bengal, Gujarat, Goa and Andhra Pradesh

States	DRRH-5 (IET 27847) (IIRRH-155)	Superiority over checks (%)		
Mean Grain Yield (Kg. ha^{-1})		ED Saline Check CSR10	Saline Tolerant Check-FL478	Sensitive Check Pusa 44
West Bengal	5111	60	41	78
Gujarat	2829	63	29	47
Goa	4532	70	180	140
Andhra Pradesh	4132	85	17	44
Overall	3710	71	35	59

It exhibited moderate resistance to leaf blast, neck blast, sheath rot and plant hoppers. It has good hulling (79.20%), milling (69.87%) and head rice recovery (62.0%) in comparison with the checks and qualifying varieties. It possesses amylose content (26.16%), alkali spreading value (5.0), gel consistency (49.67 mm), medium slender (MS) grain type (KL-5.85 mm; KB-2.11 mm) and other desirable grain and cooking quality parameters **(Figure 1A & B).** DRRH-5 is highly suitable for cultivation in coastal

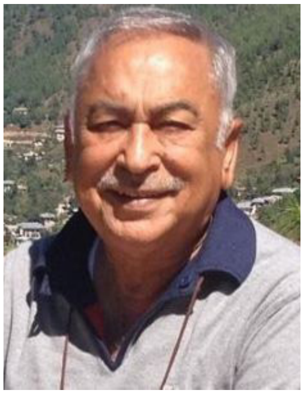
Figure 1A: Field view of DRRH-5

Figure 1B: Paddy, Brown rice and Polished rice of DRRH-5

saline ecologies. Seed sowing is preferably during the second week of June to second week of July. Seed rate is 20-30 Kg/ha. Seedlings of 15-30 days old are pulled out from nurseries and transplanted with a spacing of 20 × 15 cm (2-3 seedling per hill). For weed management, apply Pendimethalin herbicide @ 1 kg per hectare at field capacity moisture within 3-5 days of transplanting. Use of rotary weeder from 15 DAT for every 10 days. Perform one to two rounds of hand weeding between 15 and 40 days after transplanting. Maintain water level of 2 cm till 7 days of transplanting and 5 cm throughout the crop period. Timely irrigation should be provided at moisture sensitive period (Active tillering, panicle initiation, booting and grain-filling stages). DRRH-5 exhibits a maturity duration of 124 days (from seed to seed) and has the potential to achieve yields ranging from 3.7 to 4.0 t/ha under saline conditions and 6.0 to 6.5 t/ha under irrigated conditions, provided it is cultivated within the designated area of adoption and recommended climate conditions, and with the adoption of appropriate agricultural practices.

Rice Germplasm Registered during January to June 2024 at ICAR-National Bureau of Plant Genetic Resources, New Delhi

Sl. No.	Crop Name	Botanical Name	National Identity	Donar Identity	INGR No.	Novel Unique Features
1.	Rice	*Oryza sativa*	IC651966	IBL57 X IRGC66651=IJD38 (RP6368)	**24001**	Wide Compatible Restorer
2	Rice	*Oryza sativa*	IC651967	RPHR1096 X IRGC66755= IJD34 (RP6367)	**24002**	Wide Compatible Restorer
3	Rice	*Oryza sativa* x *O. nivara*	IC651968/	Swarna x *O. nivara* IRGC81832 BC2F8 (NPK77-3)	**24003**	Wild introgression line with high resistance to BLB 4 consistent BB QTLs: qBB15-4-1, qBB15-5-1, qBB15-5-3 and qBB15-6-1 *O. nivara* alleles for *Xa4* gene



Tributes to

Dr. Ish Kumar

Globally Renowned Hybrid Rice Breeder

Dr. Ish Kumar born on April 1, 1945, He earned his B.Sc in Agriculture and Animal Husbandry and M.Sc in Plant Breeding degrees in 1966 and 1968, respectively, from PAU. He later worked as a rice breeder at PAU from 1968 to 1988, earning his Ph.D in Plant Breeding in 1979 as an in-service candidate. He also worked at the International Rice Research Institute (IRRI), Philippines as a Visiting Scientist in 1984-1986. Thereafter, he joined in the Directorate of Rice Research (DRR) on deputation and worked as Principal Scientist and National Programme Leader, Hybrid rice from 1989-1992. Besides he led a joint collaborative ICAR / IRRI / Asian Development Bank funded project on the Development and use of Hybrid Rice Technology in India. He was also a rising scientist at the University of Birminghan in 1992 and hybrid rice breeder at IRRI, 2002-2004. He worked in many private companies in Senior Positions *viz.,* Pro Agro / Bayer, Syngenta, Nath Bio-Gene for almost three decades.

He was instrumental in the development and release of basmati rice variety Punjab Basmati 1 and played a leading role in the evolution and commercialisation of various leading rice hybrids for South and Southeast Asia. He was also a Visiting Scientist at the University of Birmingham, UK in 1992 Dr Kumar was awarded the most prestigious International Award, the "10th Yuan Long Ping Prize in Agricultural Science and Technology" at Changsha, China in 2018 and the "Lifetime Achievement Award" in 2020 by the Nath Bio-Genes and Bayer Bioscience.

Dr Ish Kumar, a well-known name in the Indian seed industry and possessing more than 50 years of experience in varietal and hybrid rice breeding, has died on 11th January, 2024 at the age of 78. Considering his immense contributions, it is appropriate that Dr. Ish Kumar is called the "Globally Renowned Hybrid Rice Breeder".

(Dr. RM Sundaram)
President, SARR, Hyd

Journal of Rice Research - Author Guidelines

Scope: Journal of Rice Research is a channel for publication of full length papers covering results of original research, invited critical reviews or interpretative articles related to all areas of rice science, rice based crop systems and rice crop management. The journal also publishes short communications, book reviews and letters to the editor.

Articles reporting experimentation or research in any field involving rice or rice based cropping systems will be accepted as original articles while critical reviews are generally invited. Short articles concerned with experimental techniques or observation of unique nature will be accepted as short communication. Letters to the editor concerning previous articles are welcome and are published subject to review and approval by the editorial board. The original authors will be invited to reply to the points raised in these letters for their response which are also published together.

General Requirement:

Submission to the journal must be reports of original research of at least two crop seasons and must not be previously published or simultaneously submitted to any other scientific or technical journal. At least one of the authors (in case of joint authorship) should be member of the Society for Advancement of Rice Research (SARR) and not in arrears of subscription. Authors of invited articles are exempted from this.

Submission of Manuscript:

Manuscripts should be sent by email to the chief editor (jrrchiefeditor@gmail.com) as an attachment. All the enclosed figures (as ppt/jpg files), graphs (as MS Excel worksheet with original data) and photographs (as jpg or ppt files with high resolution) may be submitted as separate files. Avoid using more than one font. The manuscript should be typed in double spaced times new roman font with margins of at least 2.5 cm. On the first page give the title, a byline with the names of authors, their affiliation and corresponding author's e-mail ID. Abstract should be followed by a list of key words. The usual order of sections to be included after title and abstract pages are: Introduction which includes literature review; materials and methods; results and discussion; conclusion (optional), acknowledgements and references followed by figures and tables.

Title should give a clear idea what the articles is about. It should be brief and informative (12-15 words).

Materials and Methods should include experimental design, treatment details, replications and techniques/ methods employed.

Results and Discussion should be supported by sound scientifically analysed data along with explanatory text with relevant tables and figures.

References should be quoted in author-year notation system only. All the references should be arranged alphabetically by author. All single author entries precede multiple author entries for the same first authors. Use chronological order within entries with identical authorship and add a low case letter a, b, c, etc., to year for same year entries of the same author. References should be presented in the format given below:

Research papers

1. Durvasula V. Seshu. 2017. Networking a Pivotal Strategy for Rice Genetic Improvement. *Journal of Rice Research*, 10: 1-8.
2. Kemparaju KB, MS Ramesha, K Sruti, AS Hari Prasad, RM Sundaram, P Senguttuvel and P Revathi. 2018. Breeding strategy for improvement of rice maintainer lines through composite population for short term diversity. *Journal of Rice Research*, 11: 27-30
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Book

Subba Rao LV, Shobha Rani N, Chiranjeevi M, Chaitanya U, Sudharshan I, Suneetha K, Jyothi Badri and Dipal R Choudhary 2013 DUS Characterization of Rice Varieties. Directorate of Rice Research, Rajendranagar, Hyderabad-500 030, AP, India. 524 pp

Figures: Photographs and drawings for graphs and charts should be prepared with good contrast of dark and light. Figure caption should be brief specifying the crop or soil, major variables presented and year. Give careful attention to the width of lines and size, and clarity of type and symbols.

Tables: Tables are used for reporting extensive numerical data in an organized manner and statistically analyzed. They should be self explanatory. Prepare tables with the word-processing tables feature and tabs or graphics boxes should not be used. Table head should be brief but complete and self contained. Define all variables and spell out all the abbreviations. An exponential expression (eg. x 10^3) in the unit's line is often needed to keep length of the data reasonably short, and referenced with an explanatory note. Unless otherwise required, two decimal place values are suggested.

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