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Review

Utilizing the Genetic Potentials of Traditional Rice Varieties and Conserving Rice Biodiversity with System of Rice Intensification Management

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Abstract: The genetic potentials of rice cultivars will need to be expressed to their fullest if global rice production is to be expanded enough by 2050 to meet the increased demand of the expanding population while the availability of land and water per capita dwindles. New and 'improved' rice varieties have contributed greatly to increased production over the past 50 years, but the rate of rice yield increase based on genetic changes has declined in recent decades compared with the early years of the Green Revolution. In fact, many rice consumers continue to prefer to consume 'traditional' rice varieties (referred to also as local, native, unimproved, or indigenous varieties) because of their taste, aroma, texture, and other qualities. Furthermore, many farmers prefer to cultivate these varieties because of their better adaptation to local climatic and soil conditions and their evolved resistance to endemic stresses. The practices that comprise the System of Rice Intensification (SRI), including transplanting rice seedlings at a young age, wide spacing between plants, keeping the soil well aerated rather than inundated, and enhancing soil organic matter, provide traditional rice varieties with micro-environments that are more favorable for the expression of their genetic and agronomic potentials. Interactions among rice plants, soil characteristics, water, energy, and other inputs improve the phenotypic and physiological performance of rice plants. This paper considers how the cultivation of traditional rice varieties with SRI methods can raise yields, reduce farmers' costs of production, and generate higher incomes while contributing to the conservation of rice biodiversity.

Keywords: *Oryza sativa*; system of rice intensification; traditional rice varieties; conserving rice biodiversity

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1. Introduction

By 2050, global rice production will need to increase greatly to keep up with worldwide population growth, rising incomes and demand, and dealing with persistent food deficits for millions of households. This must happen since environmental resources are becoming relatively less abundant. Improving rice production is an enormous and urgent challenge, not likely to be met just by developing and introducing 'new varieties'. The System of Rice Intensification (SRI) by modifying methods of rice crop management has shown the potential to increase rice production greatly by capitalizing upon the genetic potentials of most, if not all rice varieties, both improved and unimproved, rather than by modifying existing genetic potentials [1–3].

SRI changes the usual current methods of rice cultivation in several counter-intuitive ways, especially for irrigated cropping, but with appropriate adaptations, it can also improve upland rice production:

- Young rice seedlings, only 7–15 days old instead of 20–30 days, are transplanted singly and carefully rather than in clumps of 3–4 plants or more. This minimizes trauma to the plant roots and protects their capability to support root systems and tiller growth.

- Plant density is greatly reduced by as much as 80–90% m^{-2} via wider spacing between these single plants. This minimizes inter-plant competition and gives all plants more access to sunlight, air, water, and nutrients.
- The soil is kept moist and not mostly aerobic. Ceasing the continuous flooding of rice paddies ensures a good supply of oxygen to the roots.
- As much as possible, organic sources of soil nutrition are utilized rather than relying on inorganic fertilizers. This improves the structure and functioning of soil systems [4–6].

These modifications of currently prevailing practices enable each plant to express its genetic potential to the fullest, to grow larger and better root systems and more tillers that, in turn, produce more and heavier grains [7].

Rice is probably the most biodiverse of crops, but much of this diversity has been and is being lost to the spread of new varieties. This biodiversity is a valuable resource in itself. Many traditional varieties, evolved over millennia, are better able to cope with abiotic and biotic stresses than are other cultivars. They represent a pool of genetic resources on which further varietal development depends. Moreover, they have many qualities preferred by consumers.

SRI practices have been found to be advantageous for cultivating practically all rice varieties: old or new, traditional or modern, unimproved or improved, local or hybrid, although, as should be expected, some varieties respond more fully and favorably to SRI management than others. Thus far, the highest absolute yields obtained with SRI have been with 'improved' varieties or hybrids [8,9], although the greatest relative increases (in %) have come from traditional varieties, which start from a lower base [10].

As seen below, traditional rice varieties have shown themselves to be responsive to SRI management, expressing their genetic potential more fully than with either (a) traditional practices: transplanting older seedlings, even cutting the roots back if these are many weeks old; crowding plants together; and flooding paddy fields; or (b) modern practices that also continue flooding and rely heavily on chemical fertilizers. The latter induces greater vegetative growth that makes plants more vulnerable to lodging and more susceptible to losses from pests and diseases [11].

Traditional rice varieties are mostly photoperiod-sensitive, it should be noted, which influences their time of flowering [12]. An assessment of 324 traditional rice varieties showed a wide range of flowering time, from 65 to 124 days. The flowering stage is crucial in rice development because of the transition from vegetative to reproductive, which determines grain yield. While the management of local varieties is less standardized than with improved varieties, their consumer demand, profitability, and resilience make them worthy of consideration.

Traditional rice varieties are genotypes that are native to a certain area, having evolved there over hundreds, even thousands of generations so that they have become highly adapted to the local environment and to its characteristic biotic and abiotic stresses. 'Unimproved' varieties also often have particular grain characteristics that are valued in the local culture and communities, with particular roles in food and nutrition, for medicinal uses, for rituals, and as household items. The author knows this from personal experience in Indonesia [13].

Because many traditional rice varieties command a higher price in local markets due to consumer preferences and demand, their yield is not the only consideration that shapes farmers' planting decisions. The better price received for many local varieties, plus their lower cost of production when agrochemical inputs are forgone, makes their cultivation more profitable for farmers [14].

Also, these varieties are more resistant to abiotic and biotic environmental stresses associated with climate change, such as drought, flooding, extreme temperatures, and pest and disease attacks [15,16]. An example of this resilience is seen in Figure 1, a photograph from East Java, Indonesia, showing two adjacent rice fields after their locality had been hit first by an insect pest attack and then by a tropical storm.

Figure 1. Two adjacent paddy fields in Ngawi district, East Java, Indonesia, in 2011 after both had been exposed to a brown planthopper pest attack, followed by a tropical storm toward the end of the growing season. The field on the left, planted with an improved variety (*Ciherang*), was managed with 'modern' inputs. The field on the right, growing an aromatic traditional variety (*Sinantur*) with organic SRI methods, resisted both the biotic and abiotic stresses. It gave a yield of 8 tonnes ha^{-1}, while the field on the left produced little harvestable yield (picture provided to SRI-Rice by Ms. Miyatty Jannah, the farmer who managed the field on the right).

The field seen on the left was planted with an improved variety and given 'modern' chemical fertilizers and agro-inputs, while the field on the right, growing a traditional variety, was managed with SRI methods and organic inputs only. Despite large expenditures on inputs, the field on the left gave little yield, not covering the farmer's costs. The SRI-managed field on the right, on the other hand, with an 'unimproved variety' produced a yield more than 50% above the national average.

There is little in the published literature on traditional varieties because almost all agronomic research in the past 50–75 years has focused on 'modern' varieties. Based on my own experience with traditional rice varieties while growing up in Indonesia and upon learning how SRI management could improve their performance [13], I became curious about what contribution *Rojolele* and other local varieties could make to meeting world rice demand and whether applications of SRI could enhance their performance.

This interest led me to review the published literature, searching several rice databases, which turned up only limited literature. I contacted the SRI-Rice center at Cornell University to obtain what unpublished data it could share with me and others. So, this combination of published and unpublished sources provided the empirical basis for the following review article, which it is hoped will encourage other researchers to investigate this subject from multiple disciplinary perspectives.

My own research background is in genetics and molecular biology, so over and above my appreciation of traditional varieties for consumption, I understand their essential value for continuing varietal improvement. If the productivity of these varieties can be increased via different and better agronomic practices, this means that they have the untapped potential to increase rice production worldwide.

SRI practices have been found to reduce crop water requirements by about 25% because of the larger, deeper root systems, as well as to reduce greenhouse gas emissions when continuous flooding of rice paddies is stopped [17,18]. Under SRI management, soil organisms ranging from beneficial microbes to earthworms have more favorable conditions for growth, which enhances soil fertility [19,20]. These are additional benefits that could come from combining SRI management with traditional varieties to elicit better phenotypes from these varieties' inherent genetic potential, as discussed next.

2. Morphological Development, Physiological Characteristics, Grain Yield, and Grain Quality of Traditional Rice Varieties under SRI Management

Managing plants, water, nutrients, and soil according to SRI recommendations enables rice plants to express their genetic potential more fully, as noted above. Traditional varieties do not respond very well to current methods of 'modern' management. Crowding and flooding of rice plants constrain the growth of their roots and tillers, and the application of inorganic fertilizers and agrochemicals makes traditional cultivars more susceptible to lodging and more vulnerable to pest and disease attacks.

The innovation in crop breeding that launched the Green Revolution was the development of short-stalked cultivars of both rice and wheat. IRRI's IR8 rice variety and CIMMYT's semi-dwarf wheat did not easily fall over. Most traditional varieties, because they normally grow fairly tall, are vulnerable to lodging when given large amounts of N fertilizer. So, the strategy of the rice and wheat breeders who created the Green Revolution was to produce new cultivars that would not lodge when loaded with nitrogen.

SRI practices have been found to induce significant improvements in a number of morphological and physiological characteristics. One summary of experimental trial results has reported that these practices produce larger root systems (63% more depth, 40% more volume); 55% more root exudation; 52% greater leaf area; 30% more chlorophyll in the leaves; 40% more spikelets; and 125% greater water use efficiency.

These morphological and physiological enhancements contributed to a 48% higher yield on average from SRI vs. control plots. In the SRI plots, the number of tillers m^{-2} was 2% greater than in the control plots, even though the number of plants m^{-2} in the control plots was 6x greater than in the SRI trials [7]. Under SRI management, the plants were consistently more productive.

During the flowering and maturing stages of the rice plants, again in controlled trials, SRI leaves were found to exhibit a higher photosynthetic rate (Fv/Fm and ΦPSII), which is crucial for increasing grain yield. Even with a much lower plant population, light interception was 15% higher in SRI plots [21]. The SRI rice plants showed a high photosynthetic efficiency, similar to that of C4 plants. The leaves of these plants were thicker and displayed a greener color that indicated higher chlorophyll content with a more favorable Chl a/b ratio than found under conventional rice management.

This better leaf structure is attributable to a greater supply of nutrients from the roots to the shoots, enabling leaves to accomplish more photosynthesis. Assimilates resulting from the photosynthetic activity are delivered to the roots for their development and activity as well as to the rest of the plant. SRI practices thus support the plants' interdependent relationship between their roots and shoots in a positive feedback loop [21].

Because of their larger and stronger root systems, SRI rice plants have shown better performance in unstable climate conditions, such as resistance to soil erosion [15]. One of the most interesting effects of SRI practices is to accelerate the crop's maturation. Table 1 shows how the improved morphological characteristics and physiological activity of SRI rice plants lead to shorter rice crop cycles and more rice produced in a shorter period of time. The rice varieties are the ones most widely used in the Morang district of Nepal, not traditional varieties, as these have been mostly displaced by 'modern' varieties. However, farmers in Morang report the same effect with their traditional varieties.

Table 1. Life cycles of rice plants in Morang district, Nepal, 2007, comparing SRI with conventional farmer management [15].

Rice Varieties	(N)	Life Cycle with Conventional Methods (Days)	Life Cycle under SRI Management (Days)	Difference (in Days)
Sughanda (basmati)	12	120	106	14
Hardinath 1 (improved)	39	120	107	13
Barse 2014/2017	14	135	126	9
Bansdhar/Kanchhi	248	145	127	18
Radha 12	12	155	138	17
Swarna	40	155	139	16
Mansuli	48	155	136	19
Total/average	413	140	125	15

Source: records of the Morang District Agricultural Development Office, Biratnagar (provided by Dr. Rajendra Uprety, DADO, who collected these data).

Despite their shortened growing season and lesser number of m^{-2}, the SRI-grown rice plants produced by these farmers (N = 413) yielded 48% more grain than those that they raised in nearby fields with conventional methods, i.e., continuous flooding with older seedlings transplanted in closer proximity. That SRI panicles had more spikelets and more filled grains per panicle, plus often heavier grain weight, led to a higher harvest index. Optimizing G $\times$ E interactions under SRI management thus significantly increases rice crop production.

3. Traditional Rice Varieties under SRI Management

The diversity of traditional rice varieties is immense, with around 200,000 varieties recorded and about 40,000 currently cultivated. They manifest a wide diversity in morphological and physiological traits, growing in locations from sea level to above 2000 m elevation, in ecosystems ranging from equatorial (Indonesia) to mostly cold (Northern China), with time to maturity (crop cycle) ranging from 60 to more than 200 days. Most demonstrate some resistance to diseases and pests as well as greater tolerance to environmental stresses, such as drought, salinity, flood, heat, and low temperature.

The grain characteristics of traditional varieties show great diversity, with grain colors ranging from black to white, with purple, red, and various shades of yellow and amber in between. This variability is shown in Figure 2. Grain length varies from 3.5 to 14 mm, with grains classified as round, bold, and slender, as seen in Figure 3. Grain breadth ranges from 1.9 to 3 mm. Some varieties are aromatic, and others are non-aromatic; some are glutinous (sticky), and others are not. (This is not to be confused with containing gluten, a protein found in the grains of wheat and some other cereals; all rice varieties are gluten-free).

(**A**) (**B**) (**C**) (**D**)

Figure 2. Different hull colors of traditional rice varieties: (**A**) *Kalajeera*; (**B**) *Gangabaru*; (**C**) *Sadamota*; (**D**) *Laldhan* [22].

Figure 3. Grades of grain (**left** to **right**): round (*Malheria*); bold (*Sikhar*); slender (basmati) [22].

In recent decades, many improved and hybrid rice varieties have been developed and released by government researchers and companies to be adopted by farmers. These varieties have been bred mostly for their higher yield rather than for other traits, so they are not recognized for their particular qualities, such as taste, texture, aroma, or color. This has prompted a number of organizations to start programs to promote the conservation of traditional rice varieties, which have been found to respond well to SRI management.

The state of Odisha in India, formerly known as Orissa, is reputed to be one of the centers of rice domestication from as many as 5000 years ago [23]. With the advent of 'modern' varieties, probably over 10,000 'native' varieties have already been lost. For almost two decades, Dr. Debal Deb of Virhi, based in the Rayagada district, has been conserving traditional rice varieties, now over 800 [24]. Some of his accessions are reviewed in Appendix A.

Also in Odisha state, the NGO Sambhav has made collecting and conserving indigenous varieties one of its missions, also evaluating their performance under SRI management. Sambhav has over 700 native varieties of rice in its seed bank, and it has developed a novel participatory strategy for conserving these varieties by obtaining individual farm families to 'adopt' an old variety in perpetuity so that it is planted and grown anew each year, rather than being simply stored in a vault [25]. The results of growing 99 of these conserved varieties with SRI methods, reported in Appendix B, can be summarized as follows.

All of the varieties tested yielded more than 5 tonnes ha^{-1} under SRI management, which is well above the all-India yield of 4.1 tonnes ha^{-1}, an average that considers all varieties and yields together. Three of the traditional varieties gave very high yields under SRI management, producing 9 to 11 tonnes ha^{-1}, which is considerably more than twice the national average, while another 11 varieties yielded in the range of 8+ tonnes ha^{-1}, and 15 varieties had yields in the range of 7+ tonnes ha^{-1}. Four of the latter varieties were aromatic, which, as a rule, are lower-yielding but command a higher market price kg^{-1}. Thirty-six varieties, five of them aromatic, gave yields of 6+ tonnes ha^{-1} with SRI crop management, and another thirty-four varieties (4 aromatic) produced 5+ tonnes ha^{-1}.

In India, PRADAN, a national NGO based in New Delhi, has been promoting SR management to farmers in more than eight states to increase their rice productivity. Under SRI methods, many local rice varieties have been found to perform remarkably well [14].

- One local variety, *Kumlichudi*, for example, which has reddish-yellow grains, produced a yield of 9.2 tonnes ha^{-1}, with 40–50 tillers per plant, long panicle length (28 cm), and the number of filled grains panicle^{-1} reaching 275 [26].
- A red rice variety, *Adanbargi* achieved 8.8 tonnes ha^{-1} in just 95 days, with up to 35 tillers plant^{-1}, long panicles (27 cm), and more grains panicle^{-1} (225).
- *Mansuri*, a popular rice variety with bold grains, showed a yield of 8.4 tonnes ha^{-1} in 120 days, with 50–60 tillers plant^{-1}, panicle length of 25 cm, and more grains panicle^{-1}, up to 285.
- A black rice variety, *Kajri*, with a crop cycle of 135 days, gave a yield of 8 tonnes ha^{-1} under SRI, with 45 tillers plant^{-1}, long panicles (25 cm), and more grains panicle^{-1} (290). These are all very impressive performance parameters.

In the Philippines, SRI management of a popular aromatic traditional rice variety, *Azucena*, has been quite successful in upland areas, giving 40% higher yield than with usual farmer methods. An NGO in Negros Province, BIND, conducted trials in the mountain areas of Sitio Sutay municipality, evaluating SRI practices adapted for unirrigated (rainfed) rice production. *Azusena* seedlings were planted at several different distances to ascertain what would be the best spacing (plant density) for the local growing conditions. It turned out that 20 × 40 cm spacing, 10 plants m^{-2}, gave the best results, with an average yield of 7.7 tonnes ha^{-1}, tiller number 9.85 $hill^{-1}$, panicle length 29.8 cm, and 338 grains $panicle^{-1}$ [27]. Such results would be good for any cultivar, let alone an unirrigated traditional variety.

In Sarawak, Malaysia, under a WWF conservation initiative, a dozen farmers started growing their local rice variety *Adan* with SRI methods in 2017; within five years, this number had grown to 53 farmers [28,29]. *Adan* rice has a long history for the Lun Bawang people in this location, as it is the main ingredient in their culinary culture. Due to their location near forested areas in Sarawak, adopting the SRI methodology creates advantages for both the farmers and for local ecosystems by reducing pressure to convert forest areas to rice fields. Furthermore, SRI reduces the negative impact on the environment of agrochemical use (synthetic fertilizers and pesticides). By cultivating *Adan* rice under SRI management, the farmers obtain a higher yield and income, which gives them an incentive to cooperate in environmental protection.

A number of traditional rice varieties that tolerate salinity and submergence in water are also being grown with SRI practices. With SRI management, *Bahurupi*, which is saline-tolerant up to 6 mS cm^{-1} salinity, can give a yield of 5.6 tonnes ha^{-1}, several times more than what is now produced from these soils with farmers' usual methods. *Chamormoni*, which is grown in the Sundarbans of West Bengal in India, can tolerate salinity as well as submergence in 1.5–1.8 m of standing water for about a month. *Jalkamini*, which originated in the 24 Parganas area of West Bengal, and *Champaisiari*, a local variety of the Mahanadi basin in Odisha state, both grow to about 5 m height to float on the floodwater surface where their leaves can carry out photosynthesis. With SRI practices and planting young seedlings before the flooding begins, these varieties grow more erect and are resistant to lodging in windy and stormy conditions because of their stronger culms and roots and wider spacing under SRI management [30].

In southern Iraq, adopting SRI practices is found to increase the grain yield of a popular local Jasmine rice variety by up to 50%, while also reducing the crop's water requirements and lowering production cost. This provides benefits to farmers by enhancing their income and to the country by improving environmental quality [31].

Jasmine rice is an aromatic and long-grain variety native to Thailand with a soft texture. Its floral aroma results from the evaporation of the aromatic compound 2-acety-1-pyrroline. Because of these grain quality traits, Jasmine rice has high demand from consumers and commands a good market price. With SRI management, the yield of Jasmine rice in Iraq can be raised to 7 tonnes ha^{-1}, with panicle length up to 22 cm, and with more filled grains $panicle^{-1}$ (average of 142).

Pandan Wangi is one of the most popular aromatic traditional rice varieties in Indonesia. When grown under SRI management, the grain yield can be increased up to 78% [32]. The fragrant aroma of *Pandan Wangi* is similar to that of pandan leaves, which makes its eating more pleasurable. The appearance of *Pandan Wangi* grains as short, round, and transparent attracts consumers, and its excellent taste, together with tender texture and moistness, gives it a combination of stickiness and fluffiness that fetches a higher price in the market. With SRI management, not only is the yield increased, but there are water savings of 50% and a decrease in greenhouse gas emissions.

Several other traditional rice varieties, such as *Mentik Susu*, *Mentik Wangi*, *Rojolele Gepyok*, and *Rojolele Genjah,* are also beginning to be cultivated with SRI practices [33]. The productivity of these varieties is increased by up to 50%, supported by longer roots, stronger stems, productive tillers, thicker and greener leaves, longer panicles, heavier grains, and more biomass.

In Crawak village in East Java, Indonesia, as seen in Figure 1, a traditional aromatic variety *Sinantur* cultivated with organic SRI methods in the summer of 2011 showed impressive resistance to a brown planthopper attack and then resistance to lodging during a tropical storm, giving a yield of 8 tonnes ha^{-1}. A 'modern' variety rice crop (*Ciherang*) in the adjacent field succumbed to both hazards. In West Africa, several indigenous rice varieties of *Oryza glaberrima*, a rice species closely related to *Oryza sativa* which has Asian origins, have been found to produce almost twice as much yield by practicing SRI rather than with current rice crop management [34].

SRI has also been applied in the cultivation of black rice, an heirloom variety that has high levels of antioxidants due to anthocyanin pigment in the grain. Compared to other rice varieties, it also contains elevated concentrations of vitamins A and B, iron, fiber, protein, and vital amino acids. Because of its high concentration of antioxidants that can protect the human body from damage by free radicals, black rice offers health advantages such as the reduction in atherosclerosis, diabetes, cancer, and other chronic diseases. This makes it popular with health-conscious consumers.

There are many varieties of black rice, including black japonica rice, black glutinous rice, Italian black rice, and Thai black jasmine rice. Due to high demand from consumers, there is considerable scope in many countries for increasing black rice production and sales by practicing SRI for economic and environmental as well as for health gains [35].

In Nepal, the mountainous region of Bajhang district has an elevation of over 7000 m, a short growing period, and poor soil fertility. Two traditional rice varieties being grown there with SRI methods were evaluated, including *Hansraj* basmati, an aromatic rice with premium export qualities, and *Thapachini*, a popular local rice variety [36]. With SRI methods, *Hansraj*'s yield is increased by up to 62% compared to conventional methods. In the market, it has the brand name of Jorayal Basmati, which has high consumer demand. The *Thapachini* yield increase with SRI practices was 91%. These traditional varieties under SRI management had a higher number of tillers plant^{-1}, longer panicle length, more filled grains panicle^{-1} with fewer unfilled grains.

Productivity and profitability of traditional rice varieties are also influenced by the age of seedlings at transplanting, contributing to more tillers plant^{-1} and grain yield. In South India, eight traditional rice varieties were evaluated for the effect of seedling age on rice productivity under SRI management [37]. With SRI practices, transplanting 15-day-old seedlings of all these varieties resulted in more favorable components of yield like a number of productive tillers, total spikelets, filled grains panicle^{-1}, and 1000-grain weight. Some specific findings include the following:

- *Njavara*, a medicinal rice variety that is susceptible to lodging, has been found to be less susceptible to this when grown with SRI methods.
- *Kavuni*, used for medicinal purposes due to the antioxidant activity of its natural anthocyanin pigment ranging from red to black coloration, responded very positively to these methods.
- Several of the varieties evaluated—*Nootripathu*, *Norungan*, *Kuruvaikalanjiyam*, *Kuliyadichan*, and *Chandikar*—are known to be drought-tolerant. This will become ever more important as water limitations for growing rice become more severe.

Basmati rice is one of the leading agricultural export commodities for India. Increasing its yield, quality, and profitability will benefit farmers as well as exporters and the national economy. The large rice-exporting company Tilda began promoting SRI practices in Haryana state because of grain quality as well as yield considerations. It has been reported that SRI-grown basmati rice not only has greater resistance to lodging and rice blast disease but also has fewer immature and broken grains when being milled [38].

Two basmati rice varieties, *Geetanjali* and Pusa Basmati-1, were cultivated with SRI methods in the coastal area of eastern and southeastern Odisha state. Both varieties responded well to the effects of SRI management—wider spacing, organic nutrient management, and young age of seedlings—with higher tiller number, greater panicle length, and more filled grains panicle^{-1} [39].

In 2023, seven Indian traditional rice varieties were cultivated under SRI practices in Tamil Nadu state [40]. *Thanga samba* showed the best performance under SRI with a grain yield of 6.5 tonnes ha^{-1}, which would be respectable for most improved varieties. It exhibited greater panicle weight and straw yield, as well as the highest net economic return. In comparison to cultivation with conventional methods, SRI-grown traditional varieties showed a high benefit/cost ratio, 2.2:1, with one variety having a calculated ratio of 2.6:1. As would be expected, there was some variance in how well the different varieties responded to SRI management, but the components of yield measured and compared were quite consistently positive.

4. Conclusions

This review considered what evidence can be found in the published agricultural literature on the effects of practicing SRI with traditional rice varieties from several countries. Possibly, there have been some negative effects of SRI management with these varieties that have not been reported. But the published record is very encouraging, indicating that combining SRI management with traditional/native/local/indigenous rice varieties can be both productive and profitable.

SRI practices for managing seeds, plants, soil, water, and energy enable rice plants of most varieties to express their genetic potential more fully. This effect appears to be most important for traditional rice varieties that are inhibited by practices of high plant density, continuous flooding, and reliance on chemical fertilizers, herbicides, and insecticides. These varieties are in danger of being lost under the pressures of new varieties and 'modern' practices, some of which are promoted directly or indirectly by governments (via subsidies for fertilizer, free water, and low or no charges for electricity to operate tubewells). Under eco-friendly management, traditional varieties can accomplish high productivity and more robust phenotypes from the given genotype and thus become economically competitive with 'improved' varieties.

Understanding SRI practices and their effects, not just on rice plants but on the soil and soil biota, is important for improving current rice breeding programs that aim to feed increased human populations. Plants need to be seen not just as vegetative organisms but as holobionts, i.e., composites of plant and microbial life forms [41]. Under SRI management, traditional rice varieties that enjoy higher consumer preference and better prices can be grown profitably by farmers, and this is also good for the natural environment. Such management can achieve maximal phenotypic expression of traditional varieties' genetic potentials and can also help to conserve the complex gene pool that rice species have built up and differentiated over many thousands of years.

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Appendix A

Characteristics of Indian traditional rice varieties that yielded >6 t ha^{-1} under SRI management, reported according to ascending yield ha^{-1}.

Table A1. Characteristics of Indian traditional rice varieties that yielded >6 t ha^{-1} under SRI management, reported according to ascending yield ha^{-1}.

Variety Name	Habitat	Duration (Days)	Tillers Plant^{-1}	Panicle Length (cm)	% Fertile Panicles	Grains Panicle^{-1}	Grain Yield (t ha^{-1})	Stress Tolerance	Grain Grade	Special Features; Farmer Assessments
Lohondi	Lowland	150	17	25	90	200	6.0	1	2	1, F2; No need to parboil
Rongochuri	Lowland	120	40	18	38	120	6.2	1, 3, 4	2	1, F1; Good for making *biryani*; grains elongate during cooking
Kalinga	Medium upland	90	25	20	90	200	6.2	1	2	1; Summer season paddy; price Rs 10 kg^{-1}
Jhumpuri	Lowland	160	32	30	93	290	6.2	1	2	1; Straw is strong; this variety is alternated with *Champaisiari* to avoid weeds
Asamchudi	Lowland	135	25	27	100	385	6.2	1, 3, 4	2	1; High satiety; good for rice porridge and rice beer (*landah*)
Ramipareva	Medium upland	130	15	25	100	346	6.2	3, 4	2	1, 2, 3
Puiri Lochai	Medium upland	125	43	24	100	275	6.2	1, 3, 4	2	1; Low price in market, Rs 12.5 kg^{-1}
Jeeraphul	Lowland	150	50	25	90	200	6.4	1	2	1, F2; No need to parboil
Tulsibas	Medium upland	135	21	29	13	355	6.5		2	F2; Good price in market, Rs. 50 kg^{-1}; ratooning possible
Bandiluchai	Lowland	135	23	NA	100	390	6.7	1, 3, 4	2	1, 3, 4; Good for rice porridge; grains that elongate during cooking
Sopori	Lowland	150	45	25	40	140	6.9	3, 4	3	F1; Good for *Pitha* making; tastes sweet
Champaisiari	Lowland	160	35	32	95	320	7.0	2 (30 d)	2	1; Tasty; preferred by the poor
Jauphul	Medium upland	145	70	19	100	280	7.0	1, 3, 4	2	1, F2; Good price in market, Rs. 50 kg^{-1}
Sarogotora	Medium upland	135	26	29	23	350	7.0		3	1; Fine non-scented rice; its short straw length makes it suitable as fodder
Mourikhas	Lowland	140	22	30	18	345	7.0		2	F2; Good price in market, Rs 50–55 kg^{-1}
Khajurcheri	Medium upland	128	25	25	NA	245	7.0		3	1; Fine non-scented rice; good both raw and parboiled; cross-pollinating variety
Dhaniaphul	Lowland	140	45	25	90	330	7.2		1	1
Bhataphul	Medium upland	95	25	28	100	300	7.2	1, 3, 4	1	1, F2

Table A1. *Cont.*

Variety Name	Habitat	Duration (Days)	Tillers Plant^{-1}	Panicle Length (cm)	% Fertile Panicles	Grains Panicle^{-1}	Grain Yield (t ha^{-1})	Stress Tolerance	Grain Grade	Special Features; Farmer Assessments
Birholi	Medium upland	95	25	28	100	300	7.2	1, 3, 4	1	1, F2
Kumdhen	Lowland	110	25	25	100	250	7.4	1	2	1, F1
Lal Lochai	Medium upland	125	33	23	100	250	7.4	1, 3, 4	2	1; Rice price in market is only Rs 12.5 kg^{-1}
Kalajeera	Lowland	145	20	25	100	NA	7.4		1	1, F2
Lalmokro	Lowland	135	15	27	100	271	7.5	1, 3, 4	2	1, 2, 3
Latamohu	Lowland	160	43	30	97	250	7.6	1, 3, 4	2	1, F1; Tasty
Kalachampa	Medium upland	150	37	34	85	327	7.6	1	2	1
Kajri	Lowland	135	45	25	90	285	8.0		2	1
Kurlubuti	Lowland	135	19	26	100	271	8.0	1, 3, 4	2	1; Good for rice porridge; less breaking of grains during milling
Radhatilak	Medium upland	135	21	29	17	345	8.0		2	1, F2; Good price in market, Rs 50 kg^{-1}
Mahsuri	Lowland	125	55	25	90	285	8.4		2	1; Tasty, Rs 10 kg^{-1}
Adanbargi	Lowland	100	35	28	90	225	8.8	1, 3, 4	2	1
Agnilal	Medium upland	130	16	26	11	220	9.0	4 *	2	1, 5; Good for pregnant women
Red 1009	Medium upland	135	27	25	22	232	9.0		2	1, 2, 3; Strong straw, can be used for thatching and growing mush-rooms
Laluchura	Medium upland	130	25	29	18	245	9.0		2	1, 2, 4; Bold variety; preferred by economically weaker sections; straw is good for thatching
Kanchan Safri	Medium upland	110	80	28	90	275	9.2	1, 3, 4	3	1
Kumlichudi	Lowland	120	45	28	90	275	9.2	1, 3, 4	2	1
Sungibaram	Lowland	130	21	29	18	285	10.0	4 *	2	1
Bashabhog	Medium upland	120	43	32	90	350	10.4	1	2	1, F2
Talomuli	Medium upland	130	31	30	18	280	11.0	1, 3	2	1, 4

Stress tolerance: 1 = Drought; 2 = Flooding 3 = Pests; 4 = Diseases; Grain type: 1 = Round; 2 = Bold; 3 = Slender; F1 = Light-scented; F2 = Strong-scented/aromatic; Special features: 1 = Good for daily cooking, 2 = Puffed rice, 3 = Rice flakes, 4 = Popped rice, 5 = Medicinal uses; * Against rice blast. These data were sourced from Banerjee and Sundharpahari (2013) [22].

Appendix B

Traditional rice varieties (N = 99) cultivated under SRI by the NGO Sambhav in Odisha state of India, reported by yield ha^{-1}.

Table A2. Traditional rice varieties (N = 99) cultivated under SRI by the NGO Sambhav in Odisha state of India, reported by yield ha^{-1}.

Yield (in Tonnes ha^{-1})	Number of Varieties	Traditional Varieties Evaluated with SRI Management
≥11	1	Talamuli
≥10	1	Surangibaran
≥9	1	Agnilal
≥8	11	Laghu Pathara, Runja Manika, Dilip Mota, Sita Sal, Radha Tilak, Birai, Gopal Bhog, Sunapan, * Sana Bhata Dhan, Morikhas, Ketaki Champa
≥7	15 (4 aromatic)	Nandika, Khajur Cheri, Bhainspat, Banamal, Mayurkantha, Narayan Kamini, Lathisal, *Karpurakeli*, *Govind Bhoga*, Banspatri, *Samalai Bhog*, Saragtara, Debrani, Ajirbana, *Ketakijoha*
≥6	36 (5 aromatic)	Barhagali, Andharchaki, Dandabalunga, Nadiaphula, Mugudi, Hari Shankar, Kolajan, Barapanka, Kalabarni, Kajal Kanhei, Kukudamunda, Ghios, Bhaluki (no. 2), Badagandamala, Jagatsinghpur Basmati, Saru Chinamali, Sunasari, Meghamala, Kalakanhu, Katrangi, *Gangabali*, Baramasi, *Tulsi Mukul*, Chamormoni, Batakalama, Kanakchur, Kuja, Kuji Patali, Jalendri, Rahaspanjar, *Matabhog*, Panicheri, *Kalajeera*, *Basbhog*, Doddaberunelu, Banglapatnai
≥5	34 (4 aromatic)	Banapuri, Kankhri, Bhalu Dubraj, Ramsal, Kerandi, Ramigali, Laghu Bhutia, Lim Dhan, Gedi Kanhei, Alsikiba, Raghusal, Nadiajodi, Badanali, *Kalonunia*, Dhusura Bhutia, Silkote, Balabhadrabhog, Baikani, Nalipakhia, *Mugajai*, Dudh Kalama, *Jawaphul*, Kalakadam, Geleigeti, Chudi, Kadalia Champa, Bhelian, Ganagabali (no. 2), Tulsa, Raniakhanda, Kajalamali, Jhingesal, Dhaniaphual, *Tulsibasa*, Khaw Dam

* A deep-water traditional rice variety. *Italicized names* are aromatic rice varieties. Data sourced from Ms. Sabarmatee Tiki, executive director, Sambhav, Rohibank, Odisha, India, provided to SRI-Rice, Cornell University, and shared with the author with permission.

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