Hand Book of Agriculture & Plant Sciences

Editor

Dr. Dwaipayan Sinha

Education is Most Powerful Weapon

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Hand Book of Agriculture & Plant Sciences

By : *Dr. Dwaipayan Sinha*

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their efforts in writing wonderful chapters and highlighting the issues related to the theme of the book. I also express my thanks to all the reviewers who have given their vital inputs for the betterment of the scientific contents of the book. I convey my heartiest thanks to Mr. Sanjeev and all the team members of ABS Books, New Delhi for accepting the proposal and making the venture successful from a publication point of view. Finally I thank my parents and family members for their generous support during the entire work.

Dr. Dwaipayan Sinha

Foreword

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I am extremely happy to present and introduce the book entitled. "Handbook of Agriculture and Plant Sciences", edited by Dr. Dwaipayan Sinha, one of the most sincere students whom I have taught in my almost four decades of teaching career. I am sure that it will also convey same impression of the Editor as of mine to the readers. The book has chapters on a variety of contemporary topics, which are of prime importance in both the related themes included in the title. These have been contributed by his erstwhile class fellows, present colleagues and also at least one of his former teachers.

The book is divided into three sections, each of which deals with a specific theme. Section I dealing with Agriculture and Sustainable development highlights the role and importance of biofertilzers in sustainable development, introduces the readers to menace of heavy metal in agricultural soils and bioremediation methods which could be applied to minimize this problem and provides a broad overview of agriculture in near future. Section II is focussed on nutraceuticals from indigenous rice varieties and endophytic bacteria, thus also highlighting the importance of the latter which have drawn a lot of attention as the important associates of plant and sources of bioactive molecules earlier considered to be the metabolic products of the plants during the last decade or so. The last section justifiably largest of the three encompasses different aspects of medicinal plants. These are different groups of plants as source of phytomedicine or plant-derived phytochemicals as antiviral and antidibetic agents.

Though the topics included in the book do not represent all the important aspects which would fall under the title as general as Agriculture and Plant Sciences, selection of the included topics is such that these will attract the attention of not only students, teachers and scientists practicing these ,two disciplines, but also public in general. Such books though not comprehensive, serve a very important purpose of making the professionals as well amateurs aware of the important developments in the chosen topics which have taken place in recent times, along with providing projections for the future.

(Prof.) Shashi B. Babbar
Dated: March 20, 2021
Place: Delhi

Preface

Plants are a fascinating group of plants that have been dominating the earth for 400 million years. During evolution, they have undergone series of evolutionary changes to suit themselves with the surrounding environment. These evolutionary changes not only included morphological changes to suit varied climatic conditions but also armed with intricate physiological changes to synchronize with the former and fortify better adaptability. These physiological changes of the plant later proved to be of immense help to the humans who evolved much later somewhere between 6 million to 2 million years ago. The physiological and biochemical evolution of the plants with the synchronous origin of various taxa resulted in the formation of numerous biochemical pathways producing a large number of secondary metabolites whose one primary aim is to protect the plants from herbivores and insect which in the due course of evolution became an integral part of the food chain. However, the secondary metabolites also proved to be of immense use to humans since antiquity who unknowingly since prehistoric times used plants for their food and medicine. It is only in the past hundred years or so, people became aware of the chemical constituent of the plants and started exploring their various beneficial properties. The agricultural activities also coevolved with human civilization and with the increase in population, higher yield along with protection of crops from pathogen attack became a necessity. This lead to the formulation of fertilizers which consequently paved the way for biofertilizers with a fewer side effects on humans and animals but with a more green approach towards fertility enhancement. With the advent of industrialization the menace of pollution cropped up and presently this pollution is encroaching soil water and air. This is having a deleterious effect on the ecosystem concerning human and animal health and also agricultural productivity. Thus keeping this in mind the scientific community was determined to remediate the polluted sites with the help of biological agents in which the plants and microbes played an important role. This provided major protection to agriculture from contamination thereby sustaining productivity. Thus, an attempt is made to highlight the progress and advances in the field of agriculture and plant science. Thus A handbook of Agricultural and Plant Sciences is an attempt to compile information related to the field of agriculture and plant science. The main purpose of the book is to provide relevant information to the readers on aspects largely cantered on plants. The book is divided into three sections namely agriculture and sustainable development, plants and microbes as nutraceutical agents, and medicinal potential of plants. Selected chapters in relevance to the sections have been accommodated to provide an overview. The first section deals with various aspects through which crops can be fortified through bio fertilization and also decontamination of polluted lands. The world population is presently stressing upon consumption of foods from natural sources as consumption of fast food with artificial agents is leading to the onset of several diseases. This has led to a group of foods that confers nutrition as well as a medicinal benefit at the same time. They are presently termed and considered nutraceuticals. The second section of the book deals with the nutraceutical potential of plants and microbes which are symbiotically associated with plants. The third section is also related to the second one concerning the medicinal importance. This section encompasses the medicinal importance of plants. Plants as antiviral agents have been accommodated because of the current pandemic situation. The section also contains a chapter on the ant diabetic potential of plants and also the medicinal importance of gymnosperms and bioactive potentials of bryophytes which adds up to the variation in chapters focusing on the medicinal aspect. The book is also accompanied by several tables within each chapter which gives a clear and systematic description of the theme that is discussed upon. The book is an academic venture and would benefit the scientific community and readers who are interested in the field of plant sciences.

Dr. Dwaipayan Sinha

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Agronomic and Nutraceutical Properties of Indigenous Rice Varieties

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Introduction

Around 12,000 years ago, Neolithic people began domestication of several plants and animals, and marked the Agricultural Revolution, which not only created new species of animals (like dog and horse) and plants (like rice and wheat) that never existed before, but also created thousands of animal breeds and crop landraces (Diamond, 2002; Doebly et al., 2006; Larson & Fuller, 2014). The cultivated rice (*Oryza sativa* L.) was domesticated through careful selection from ancestral *Oryza rufipogon in China* (*O. sativa* ssp. *japonica*) around 12,000 years ago and in India (*O. sativa* ssp. *indica*) about 10,000 years ago (Fuller, 2011; Sweeny & McCouch, 2007). Over millennia, indigenous farmers created thousands of rice landraces through careful selection and breeding experiments. Until 1970, over 110,000 landraces of rice is estimated to have existed in India (Deb, 2019*a*).

Crop genetic diversity is the foundation for adaptation to different environmental conditions, such as drought, seasonal floods, soil salinity and resistance to crop pests and pathogens (Vaughan & Chang, 1992; Bellon, 2017; Deb, 2017). Since the onset of the Green Revolution in the late 1960s, however, the wealth of crop genetic resources has been squandered by the process of agricultural industrialization, which is geared to homogenization of the genetic base, truncation of agro-ecosystem complexity, and linking food production to external industrial inputs (Deb, 2004; 2017; 2019*b*). This has undermined food sovereignty of farmers and a deepening food insecurity, both on the farm and the national levels (Deb 2019*b*). During the period from 1970 to 2000, more than 90% of the indigenous rice landraces has disappeared from farm fields in India (Deb, 2019*a*).

The process of rice genetic erosion in Bengal is paradigmatic. An estimated 15,000 folk landraces are reported to have been cultivated in undivided Bengal in the 1940s (Bashar et al., 2004). According to unpublished records of West Bengal State Rice Research Station, Chuchura, West Bengal, farmers used to grow ca. 5,556 landraces until the late 1960s; of these, 3500 varieties were shipped to International Rice Research Institute in the Philippines during the period from 1975 to 1983 (Deb, 2005; Deb, 2019). Since the late 1960s, with the advent of the Green Revolution, thousands of traditional landraces have been replaced with a handful of high yielding varieties (HYVs) and hybrid crops in all Indian States (Thrupp, 2000; Gao, 2003; Nelson et al., 2019). Bangladesh also has witnessed a similar process of erosion of rice genetic diversity. In the 1970s, about 7000 *rice varieties* in Bangladesh were replaced by modern HYVs (Thrupp, 2000), and further hundreds disappeared in the following decades. Most of the old landraces of Bengal, from both sides of the international border, are now available only in a few gene banks, not in the hands of farmers (Vengadessan et al., 2016; Deb, 2017). As of date, less than 700 folk varieties in Bangladesh, and ca. 400 in West Bengal are extant on farm fields (Deb, 2017; Deb, 2019*a*). Currently, less than 6000 varieties are being cultivated on farms in all the States of India (Deb 2019*a*).

Conservation Efforts

In spite of the advices from FAO and IPGRI scientists (Vaughan & Chang, 1992; Jackson, 1995; FAO, 2002; Bellon et al., 2017) on conservation of rice genetic diversity for improving crop productivity and food security, the overall efforts of conservation of genetic diversity has so far remained confined to collection and preservation of germplasm accessions in national and international gene banks. However, because the germination potential of rice seeds in gene bank storage expires after ca. 35 years, a large proportion of the gene bank accession is dead. In addition, the accessions of these gene banks remain out of access for farmers, although seed companies have easy access to the germplasm (Deb, 2019*a*). Barring rare initiatives of a few officials, the Directorate of Agriculture does not have a statutory agenda to conserve and popularise indigenous crop genetic diversity. After 2011, a few States began promoting a handful of heirloom rice varieties among farmers with a lure of premium price. However, premium price tagging of a few special varieties may act against conservation, because the varieties that cannot fetch a good price are soon abandoned.

The extinction of indigenous rice varieties is not only disastrous to food security, but also implies erosion of local food cultures. The traditional cultural values associated to the local landraces have largely disappeared from the modernized farmer communities, so that farmers willing to grow a few heirloom rice varieties regardless of high market price are themselves a “rare species”. In the absence of both cultural motivation and financial incentive, folk rice landraces are rapidly disappearing from farmers’ fields.

Vrihi folk rice seed bank (www.cintdis.org/vrihi), established in 1997, is the largest open source seed bank of extant folk rice varieties in India, with an accession of 1440 landraces, many of which are no longer cultivated by any farmer in the country, nor exist in the gene bank of the National Bureau of Plant Genetic Resources. Several of these landraces are critically endangered, surviving in single farms. Vrihi cultivates every landrace of its accession every year; maintains its genetic purity by preventing cross-pollination between varieties on neighbouring plots, and by ‘rouging’ of the off-types, based on matching of 56 morphological characters; and distributes the seeds after harvest among farmers for free. Vrihi’s documentation of folk rice varieties (Deb, 2005) constitutes the only published record of detailed agronomic and morphological characters of 416 Indian rice landraces.

Folk Rice Varieties and Traditional Knowledge

Traditional farmers developed, bred, and maintained different folk varieties that were fine tuned to the local soil and climatic conditions. Until the advent of industrial agriculture at the behest of the statutory institutions and seed industry, most of the marginal farmers used to remember the unique agronomic properties and cultural uses. The traditional knowledge related to folk rice varieties consisted of the following.

Adaptation to Soil and Climatic Conditions

Different landraces are adapted to different local climatic and soil conditions. Different genes for resistance to pests and pathogens are found in a large number of local landraces, which are the greatest arsenal for breeding improved cultivars. Hundreds of farmer landraces are capable of withstanding too much rain, too late rain, too scanty rain, prolonged inundation, and soil salinity – properties which are conspicuously absent in modern HYVs (Deb, 2000; 2005; 2017). These are also the traits that transgenic research is aspiring to incorporate in modern rice genome. Many of these landraces from Vrihi's accession have rescued hundreds of farmers from droughts, cyclones and sea water incursion in coastal farms over two decades. All these landraces were developed by serendipitous selection and breeding experiments by unknown farmer-breeders to ensure food production across a range of environmental vagaries. Indian folk rice landraces can be classified into 5 categories according to the topography and physical characters of the land of their cultivation, as given in Table 1.

Cultural Values

Apart from agronomic properties, different other qualities of rice also have different cultural values in all food cultures. The presence of 2-acetyl 1-pyroline, the substance which gives aroma, and the amylose content that determines the degree of stickiness in cooked rice are important in local culinary delicacies. Different landraces are preferred for crisped rice, puffed rice, beaten rice, as well as for making rice pudding and other sweets. For instance, Raghusal, Dahar nagra, Nalpai, Moul, etc. are preferred for crisped rice; Manik kalma, Nikunja, Katki nona and Chandrakanta are preferred for beaten rice; Lakshmichura, Jhinga-sal and Patnai are preferred for puffed rice (Deb, 2000; Deb, 2005). A special Bengal rice sweet, *Jaynagarer moa*, was traditionally made from the puffed rice of Kanakchur in South 24 Parganas district of West Bengal. As this landrace is no longer in cultivation on modern farms, the special aroma of this delicacy is lost in modern versions of *Jaynagarer moa*. Until the 1990s, Jamainadu and Jamai-sal were grown in a few villages only to make a special treat for the son in law (*jamai*) on the jamaisasthi ceremony in summer (Deb, 2005).

Visual aesthetics is another driver of selection and breeding of different landraces with gold, brown, purple, and black hull, purple apex, black and red awn, purple, brown and black pericarp, and so on (Deb, 2017). Many farmers in Eastern India take pride in the beauty of the wing-like extensions of sterile lemma in Moynatundi of southern Odisha and Ramigali of Chattisgarh (Deb, 2019*a*).

Medicinal Values

Many rice varieties are known to have a range of folk medicinal uses. For instance, Laicha rice from Chattisgarh and Nyavara from Kerala are medicinal rice, used in treating chronic gastritis and peptic ulcer for a long time. Nyavara is also traditionally valued in treatment of neurotic disorders. Pichchavari, Neelam samba and Karthigai from Tamil Nadu, Dudheswar from West Bengal, Jongasrihati from Bihar, Maharaji and Bhejri from Chhattisgarh, are believed to increase lactation in women after childbirth. Kelas and Bhutmoori from West Bengal are prescribed to cure peri-partum anemia in women (Das et al., 2000; Deb, 2017; Deb, 2019*a*). Parmai-sal has nutritive properties for improving general health, and traditional medicine prescribed Kabiraj-sal as diet for convalescing patients. Garib-sal, used in folk medicine to cure gastroenteric infections, is the only rice variety so far known to science to contain silver in its grains (Deb et al., 2015; Sen Gupta et al., 2017); the high amount of silver on the pericarp of its grains likely serves to kill gut pathogens (Kyaw et al., 2017; Sen Gupta et al., 2017). Other south Indian varieties namely Mappillai samba is reported to have medicinal values like anti-diabetic and anti-cancerous properties, containing steroidal bioactive compounds and anti-oxidants (Sulochana et al., 2015). In Bihar and Jharkhand, rice paste of Karanga variety is fed to patients suffering from dysentery. The starchy water of Bora variety of Assam is used for jaundice patients (Rahman et al., 2006). In Karnataka, the red paste of Akkacchu variety is used as ointment for skin allergies (Hegde et al., 2013).

Biochemical Properties of Grains of Folk Rice Varieties

All the folk rice varieties in Vrihi's accession are assessed for their nutritional properties through quantification of carbohydrate, protein, lipids and micronutrients like vitamins, metals and secondary metabolites. A recent collaborative mapping of metabolites in various rice landraces using DESI-MS revealed an invariable distribution of choline, sugar molecules, linoleic acid, gluconic acid, phospholipid intermediate molecules on the rice grain surface (Suganya et al., 2019). This study reports an accumulation of sucrose and gluconic acid in the endosperm of Garib-sal, Gazepxali, Kataribhog, Kala nuniya, Radhatilak and Tike churi varieties. SEM-EDS (Scanning Electron Microscopy-Energy Dispersive X-Ray Spectroscopy) showed that chromium is dispersed on the surfaces of the bran and the embryo of Garib-sal rice. Fatty acids such as linoleic acid or omega-6-fatty acid, isoschaftoside and C-glycosylflavonoids are localized in the starchy endosperm of Gazepxali, Kataribhog, Kala nuniya and Radhatilak varieties. Moreover, two components of lipid γ-oryzanol, oryzanol A (cycloartenylferulate) and oryzanol C (24-methyl cycloartenylferulate) have been mapped in the bran of these varieties (Suganya et al., 2019).

Garudan samba, an important folk rice variety from Tamil Nadu also contains medicinally important compounds like caryophyllene, ethyl oleate, squalene, γ-tocopherol, lup-20(29)-en-3-ol, acetate, and phyto-sterols like campesterol, stigmasterol and ß-sitosterol (Sulochana et al., 2016). Some varieties such as Tulsa, Khasdhan and Tulasi contains high quantity of omega-3 fatty acids (Ray et al., 2014). Volatiles such as hexanol, 2-heptanone, furan-2-pentyl, 1-hexanol, 1-octen-3-ol were identified in 12 folk rice varieties conserved at Basudha (Ray et al., 2016).

Macronutrients in Rice Varieties

Since rice is always consumed as cooked, we are examining macronutrient contents of cooked rice. In Table 2, we present a representative sample of 15 traditional varieties, accessed from Basudha and other authors, for their nutritional properties through quantification of macronutrients such as total starch, total protein and total lipid.

Starch

Rice grains contain starch as the principle component. Starch content in modern cultivars ranges from 80 to 90 % (Deepa et al., 2010). However this content is variable in different landraces. In Indica varieties, there are very few investigations on macronutrient content. Fauziya et al., (2015) examined *Indica* varieties for starch content alone. Landraces from Jharkhand such as Dahiya, Danigoda, Karheni and Neta contain total starch ranging from 42.2% to 62.03 %. Uncooked rice of C14, W01 varieties contain >25% of starch, while after cooking, the soluble starch content increases to >30%, which indicates an increase in starch content after cooking. This may be due to the fact that, cooking causes swelling of complex starch granules which fragments the starch chains and converts much of the resistant starch into soluble starch (Deepa et al., 2010). Representative varieties are shown in Table 2.

The presence of labile starch in traditional varieties is a significant factor of nutrition. As reported in our previous study, varieties like Parmai-sal have a high amount of labile starch in addition to antioxidants and micronutrients (Deb, 2019*a*).

Total Protein

Among cereals, rice has a very low content of proteins. A study of evaluation of total protein of 17 rice landraces from Assam, such as Borchakua, Bora chakua, Lahichakua reported total protein content ranging between 0.08% and 15.41% (Das et al., 2018). Total protein protein content of uncooked grains of 15 folk landraces from Kerala ranges from 5.3% to 11.8% (Pillai et al., 2020). So far there is no published data available for protein contents in cooked rice. Our ongoing investigation at Basudha Laboratory reveals that some uncooked varieties contain total protein ranging from 5% to 7%, whereas after cooking, the protein contents of the same varieties decreases to <1% (Datta et al. (in preparation). Total protein content of cooked and uncooked rice grains from representative landraces is given in Table 2.

Total Lipid

Total lipid content of 15 indigenous varieties from Kerala such as Cheruvellari, Chettadi, Kuttadan, Vellari, Kanchana ranges between 21.9 and 47.8 mg/g (Pillai et al., 2020). So far there is no published record of lipid contents in cooked rice. Our ongoing work at Basudha Laboratory indicates that total lipid content decreases after cooking. However, some landraces, such as M17 and W01, do not show any significant difference in total lipid contents before and after cooking (Table 2). Highest amount (>35 mg/g) of total lipid content was recorded in uncooked grains of K05 and K50. In cooked samples, the highest amount of crude lipid was seen in V01.

Micronutrients in Rice

All the varieties stored at Basudha farm are analyzed for micronutrients which include nutritionally important heavy metals, total phenolic content (TPC), total flavonoid content (TFC), antioxidant activity and B vitamins.

Nutritionally Important Metals

Pigmented rice varieties are considered more nutritious and are found to be rich in iron, zinc, calcium and magnesium (Savitha & Kumari, 2016). Anandan et al. (2011) examined 92 folk rice varieties with known medicinal properties, including Kalabhat, Nyavara and Norungan, for contents of Fe and other metal micronutrients. Deb and coworkers (Deb et al., 2015; Sen Gupta et al., 2017), using inductively coupled plasma mass spectrometry (ICPMS), examined the contents of 12 metals in over 500 folk rice landraces, which was never examined before. Representative samples of 26 landraces of Basudha and from other authors, containing high amounts of Fe, Cu, Zn and Mn are given in Table 3. Das et al. (2018) reported Fe content ranging from 1.04 to 643.5 mg/100g in the grains of 17 varieties from Assam. Mudoi & Das (2019) analyzed Fe, Zn and Mn contents in 16 landraces from Assam. Longvah et al. (2020) analyzed Fe, Zn, Cu and Mn contents of 32 landraces from Meghalaya and Pillai et al. (2020) examined 15 landraces from Kerala.

Total Phenol and Total Flavonoid Content

Traditional varieties contain a good amount of therapeutic phytochemicals and antioxidant compounds. Considerable amount of phenolic compounds such as ferulic acid, caffeic acid, gallic acid, 4-hydroxybenzoic acid and vanillic acid has been identified in 32 folk rice varieties of Basudha (Ray et al., 2018). TPC of 20 folk rice of Karnataka such as Anandi, Kagisaale, Gajagunda, Nagabatta etc. was estimated, which ranges between 47.8 and 160.7 mg GAE/100g dry weight (Muttagi & Ravindra, 2020). TFC of 16 folk varieties of Assam including Betu, Biroi, Dal bao, Kolaguni, Kotiabao ranges from 252.1 to 1000.8 mg QE/100 g dry weight (Mudoi & Das, 2019). Rajendran et al. (2018) examined 10 landraces, and reported TPC, ranging from 10.2 to 43.2 mg/100g and TFC, ranging from 2 to 7.2 mg/100g.

Our ongoing investigation of 1440 landraces indicates a wide range of both TPC and TFC in cooked rice. TPC and TFC of 21 representative samples of Basudha and other authors are given in Table 4. The uncooked grains of W01, V01, K05, with pigmented pericarp, have TPC of >110 mg GAE/100 g dry weight. After cooking, their TPC decreases to <50 mg/100 g. Similarly, TFC was high (>390 mg QE/100 g dry weight) in uncooked grains of C14 and

W01, whereas after cooking, the TFC decreases to <50 mg/ 100g (Mondal et al. communicating). Upon cooking, the hydroxyl group of phenolic compounds transforms into smaller molecules, leading to a deterioration of phenolic and flavonoid compounds (Saikia et al., 2012; Patras et al., 2010).

Antioxidant Activity

A small number of workers have reported antioxidant activities of folk rice varieties. Rajendran et al. (2018) reported that the reducing power of 10 folk rice varieties ranges between 112.1 and 231 µM AAE/100g and radical scavenging activity ranges between 284.8 and 897.1 µM AAE/100 g dry weight. The scavenging activity ranging between 257.9 and 800.3 µM AAE/100 g dry weight was further reported in uncooked grains of 20 landraces from Karnataka (Muttagi & Ravindra, 2020).

Folk rice varieties from Basudha's collection consists of pigmented varieties such as Kelas, Bhutmoori, Ghasraiz etc. (Deb, 2005), which are replete with antioxidants (Ray et al., 2014). Our ongoing investigation shows the radical scavenging activity of these landraces ranges between 441.5 and 2096.5 µM AAE/100g, and reducing power ranges from 2327.1 to 18422.9 µM $FeSO_4$/100g after 6 hours of extraction with methanolic water (Ray et al., 2021; Mondal et al., 2020). Our analysis shows that antioxidant activities dramatically decrease after cooking (Table 5). The cooking process breaks down the cell matrix and facilitates the bound phenolics to release and then transform into free phenolics, which eventually decompose under high temperature. The pyrylium ring of anthocyanin opens upon cooking, which causes the cleavage of glycoside linkage, resulting in the formation of a colorless chalcone structure which eventually slows down the antioxidant activity (Saikia et al., 2012).

B Vitamins

Reports of B vitamins of medicinally important folk rice varieties, namely, Njavara from Kerala and Jyothi from Karnataka (Deepa et al., 2008) and 32 folk rice varieties from Meghalaya (Longvah et al., 2020) are available in published literature. Our ongoing work on 1440 landraces indicates the presence of considerable amount (1.18 mg/g) of thiamin in K50; high concentration (>3 mg/g) of Pantothenic acid in C14 and K131 and of Pyridoxine (1.07 mg/g) in V01. Selected B vitamin contents of representative folk rice varieties, assessed by Basudha's workers and other authors are shown in Table 6.

Discussion

Food security involves total nutritional assurance and easy access to healthy food. Food security is strengthened by the yield stability of the crop, and zero (or near-zero) dependence on external inputs for crop production (Deb, 2019*b*). All traditional crop landraces have greater yield stability over long term than modern cultivars (Cleveland et al., 2007; Deb, 2017). Furthermore, crop landraces out-yield all modern cultivars in marginal farm conditions (Ficiciyan et al., 2018; Deb, 2019*a*), ensuring food security of poor and marginal farmers, who can remain independent of external inputs. In the face of climatic vagaries like too much rain, too scanty rain, too late rain, flash floods and sea water incursion, drought tolerant, flood tolerant and salinity tolerant landraces are the best bet for farmers (Table 1).

Crop loss due to pest and disease outbreaks is a frequent experience of most farmers, who cultivate modern HYVs. Employment of rice genetic diversity, incorporating resistant genotypes in rice fields is a traditional and effective method of disease control (Bottrell & Schoenly, 2012; Gallet et al., 2014; Raboin et al., 2012; Zhu et al., 2000). Numerous traditional varieties have been reported to have resistance to various pests and pathogens like worms, virus, bacteria and fungi (Vasudevan et al., 2014; Deb, 2020). Varieties such as Kalonunia, Kalanamak, Kartik-sal and Tulsi manjari are resistant to blast. Bishnubhog and Rani kajal are blight resistant (Deb, 2017; 2019*a*). A recent meta-analysis shows that polyculture of rice with different landraces builds trait heterogeneity, which suppresses pest incidents, by regulating effects on arthropod diversity on several trophic levels in agroecosystems, and reduces damage by generalist herbivores (Koricheva & Hayes, 2018).

Most of the landraces do not require irrigation in excess of normal rainwater, nor any agrochemical inputs. In addition, farm saved folk variety seeds obviate the need of periodical purchase of seeds from seed suppliers. Thus, cultivation of these landraces ensures yield stability and can establish farmers' sovereignty over their materials and means of food production.

Cultivation of multiple cropping, involving rice, maize, millets and legumes, is known to reduce pest pressure (Lin et al., 2011; Yao et al., 2012), and integrated farming including domesticated animals also provides for all dietary micronutrients including iron, zinc and vitamins. In the absence of appropriate agro-biodiversity on modern farms, biofortification of HYVs of rice with micronutrients like folic acid, vitamin A, iron and zinc is being promoted as a means to ensuring nutrient security. However, biofortification has little or no observable effects on health of patients with anemia and vitamin A deficiency if intestinal infections like diarrhoea and dysentery persist in the consumer population or if the diet is deficient in zinc and polyglycerols (Castenmiller & West, 1998; Nutting et al., 2002). Thousands of folk rice varieties need to be sought for providing enhanced nutrition in terms of micronutrients (Deb et al., 2015; Sen Gupta et al., 2017), which also have a clear edge over artificially biofortified rice.

With a single focus on increasing grain yield by modern breeders, many traditional varieties were disdained, although they are having various micronutrients, which are found at negligible levels in modern varieties. Our on-going study on folk rice varieties, conducted at Basudha Laboratory for Conservation (http://cintds.org/labotatory/) indicates substantial contents of micronutrients in traditional varieties (Table 3, Table 6). At least 80 traditional rice varieties showed iron content in the range of 20 to 151 mg /kg, which is 2 to 15-fold higher than that in genetically modified iron-fortified rice IR-68144-2B-2-23 (9.8 mg/kg) (Deb et al., 2015). Similarly, considerable amount of pro-vitamin A is found in the bran of a number of landraces of Malaysia, Thailand, Vietnam and the Philippines (Frei & Becker, 2004; 2005), and some Indian landraces with brown and black pericarp (Renuka et al., 2016; Roy & Deb, mss in preparation). It is feasible and scientifically more sensible to make these rice varieties widely available for regular consumption throughout the country, especially among the rural poor, than to invest in developing and importing transgenic vitamin A-enriched rice.

There is crucial need for detailed research in indigenous rice landraces for a deeper understanding of the diverse nutraceutical properties of rice landraces. While folk crop varieties are usually not on any priority list of agronomic research and development agenda, available literature and our on-going research indicate that most of the folk rice varieties are superior to any modern rice cultivar, in terms of nutritional and therapeutic properties. An obvious policy recommendation that transpires from the data presented here, drawn on different published as well as ongoing research findings, is that it is imperative to conserve and promote consumption of folk rice varieties, particularly in marginal environmental conditions. Widespread cultivation in order to enhance availability and accessibility of nutritious folk rice varieties would be a scientifically more reasonable means to ensure food and nutritional security of the masses, than instituting and investing in expensive and capital intensive extraneous biofortification programs.

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Table 1: Representative Rice Landraces Adapted to Marginal Environmental Conditions

Rainfed upland	Rainfed medium land	Lowland	Deepwater	Saline
Ashu	Bans phul	Agni-Sal	Bajal	Kalo nuniya
Bhutmoori	Betichikon	Bara kalma	Banya-sal	Karpur kranti
Chakramala	Kali jira	Kalomanik	Hugli	Korgut khari
Gorah	Lahia	Koya badam	Jal kamini	Lalgetu
Guruji	Lahara	Malabati	Kumrogorh	Matla
Jirkudi	Lotal	Nona baran	Lal jabra	Nona bokra
Kali ashu	Moynagiri	Rani kajal	Lakshmi dighal	Nona khirish
Kalomanik	Patnai	Sada chamor	Pantara	Pokkali
Kelas	Sapra	Sindur mukhi	Paniduba	Surakuruvai
Kinari	Tulsimukul	Sita-sal	Sada jabra	Tal mugur

Source: Deb, 2000; Deb, 2005

Table 2: Total starch, protein and lipid content of cooked and uncooked folk rice varieties

Landraces/ Basudha Accession Code	Uncooked rice			Cooked rice			Reference
	% Total starch	% Total protein	Total lipid (mg/g)	% Total starch	% Total protein	Total lipid (mg/g)	
Thekkan	-	5.3	37.2	-	-	-	Pillai et al., 2020
Vellari	-	7.9	37.2	-	-	-	Pillai et al., 2020
Kanchana	-	7.9	21.9	-	-	-	Pillai et al., 2020
Thavalakannan	-	11.8	47.8	-	-	-	Pillai et al., 2020
C14	25.1	4.7	22	35.5	0.6	8	Datta et al. (MS in preparation)
K05	13.2	3.4	40	25.7	0.9	8	Datta et al. (MS in preparation)
K10	23.3	5.5	12	26.3	0.6	8	Datta et al. (MS in preparation)
K131	13.8	1.9	22	29.7	0.6	8	Datta et al. (MS in preparation)
K39	24.2	0.5	14	26.5	0.3	8	Datta et al. (MS in preparation)
K50	19.6	7.5	38	20.1	0.7	16	Datta et al. (MS in preparation)
M17	15.6	5.8	16	31.8	0.6	16	Datta et al. (MS in preparation)
P40	13.5	2.4	10	13.6	0.5	8	Datta et al. (MS in preparation)
V01	26.1	1.3	22	27.7	0.9	20	Datta et al. (MS in preparation)
W01	28.5	0.9	10	36.7	0.3	10	Datta et al. (MS in preparation)
BPT 5204#	27.6	2.3	14	-	-	-	Datta et al. (MS in preparation)

 # - Modern cultivar

Table 3: Nutritionally important metal content in grains of selected folk rice varieties

Landraces/ Basudha Accession Code	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Reference
Kalabath	39.2	26.8	7.1	5.7	Anandan et al., 2011
Pusa Basmati 1	29.9	33.3	7.1	8.3	Anandan et al., 2011
Norungan	24.2	31.4	10.6	11.8	Anandan et al., 2011
Kelas	34.6	44.9	2.9	44.9	Deb et al., 2015
Kurai	54.4	23.0	1.8	27.9	Deb et al., 2015
Kabiraj-sal	31.4	20.3	0.4	28.3	Deb et al., 2015
Champa	25.7	27.5	7.2	43.1	Sen Gupta et al., 2017
Baid dhusuri	150.8	21.7	2.8	232.4	Sen Gupta et al., 2017
Dudhe bolta	130.9	24.8	0.7	26.0	Sen Gupta et al., 2017
Garib-sal	11.9	155.3	19.3	35	Sen Gupta et al., 2017
Kundapullan	28.9	32.8	3.0	47.8	Sen Gupta et al., 2017
Kali shankar	20.2	27.9	1.9	43.3	Sen Gupta et al., 2017
Madraraj	56.3	23.6	3.8	38.7	Sen Gupta et al., 2017
Pusabadh	20.9	31.5	7.4	49.1	Sen Gupta et al., 2017
Bhutmoori	24.4	38.5	7.8	27	Sen Gupta et al., 2017
Ghasraiz	21.9	0.9	0.0	36.8	Sen Gupta et al., 2017
Biroi	38.7	63.1	-	37.2	Mudoi & Das, 2019
Boga buni	55.5	121.6	-	6.5	Mudoi & Das, 2019
Ixojoy	60.9	52.2	-	28.1	Mudoi & Das, 2019
Gopalbhok	9.2	19.7	2.7	47.7	Longvah et al., 2020
Jahagipok	10.6	23.8	2.5	42.8	Longvah et al., 2020
Maigothi	21.8	19.3	3.3	24.8	Longvah et al., 2020
Cheru vellari	32.4	26.4	5.9	33.6	Pillai et al., 2020
Chettadi	19.4	34.1	6.2	29.1	Pillai et al., 2020
Gandhakasala	29.2	29.6	3.9	34.8	Pillai et al., 2020
BPT 5204#	8.9	37.9	12.9	34.1	Sen Gupta et al., 2017

 # - Modern cultivar

Table 4: Total phenol content (TPC) and total flavonoid content (TFC) of cooked and uncooked folk rice varieties

Landraces/ Basudha Accession Code	Uncooked rice		Cooked rice		Reference
	TPC (mg GAE /100 g)	TFC (mg QE/100 g)	TPC (mg GAE/100 g)	TFC (mg QE/100 g)	
Kala namak	43.2a	7.2	-	-	Rajendran et al., 2018
Poongar	10.2a	2.2	-	-	Rajendran et al., 2018
Ixojoy	762.5b	252.1	-	-	Mudoi & Das, 2019
Dal bao	2215.7b	1000.7	-	-	Mudoi & Das, 2019
Jul bao	1145.1b	466.1	-	-	Mudoi & Das, 2019
Kolaguni	1850.9b	647.7	-	-	Mudoi & Das, 2019
Nagabatta	47.8a	-	-	-	Muttagi & Ravindra, 2020
Kagisaale	98.2a	-	-	-	Muttagi & Ravindra, 2020
Karimundaga	160.7a	-	-	-	Muttagi & Ravindra, 2020
Gajagunda	152.3a	-	-	-	Muttagi & Ravindra, 2020
C14	105a	451.6	22.2	36.3	Mondal et al., 2020
K05	98.7a	90.8	15.7	27	Mondal et al., 2020
K10	32.2a	79.1	3	20	Mondal et al., 2020
K131	21.5a	48.9	0.7	23.3	Mondal et al., 2020
K39	31.3a	40.7	0.8	19.5	Mondal et al., 2020
K50	15.2a	14.9	1.7	26.5	Mondal et al., 2020
M17	68a	327.1	37.3	43.3	Mondal et al., 2020
P40	51.8a	67.5	14.2	37.7	Mondal et al., 2020
V01	153.3a	134.6	42.8	65.2	Mondal et al., 2020
W01	115.5a	396.9	18.8	40	Mondal et al., 2020
BPT 5204#	29.5a	34.3	-	-	Mondal et al., 2020

a -Gallic acid equivalent; b-Catechol equivalent; # - Modern cultivar.

Table 5: Antioxidant activity of cooked and uncooked folk rice varieties

Landraces/ Basudha Accession Code	Uncooked rice		Cooked rice		Reference
	DPPH radical scavenging activity(µM AAE/100 g)	Ferric reducing antioxidant power (µM/ FeSO4 /100 g)	DPPH radical scavenging activity (µM AAE/100 g)	Ferric reducing antioxidant power (µM FeSO4/100 g)	
Kala namak	897.1	231a	-	-	Rajendran et al., 2018
Salem sannam	284.8	112.1a	-	-	Rajendran et al., 2018
Kagisaale	622.5	-	-	-	Muttagi & Ravindra, 2020
Gajagunda	703.8	-	-	-	Muttagi & Ravindra, 2020
Karimundaga	800.2	-	-	-	Muttagi & Ravindra, 2020
Gandhasaale	313.1	-	-	-	Muttagi & Ravindra, 2020
C14	2,016.5	18,422.9b	776.5	7,834.6	Mondal et al., 2020; Ray et al., 2021
K05	871.5	9,133.9b	681.5	7,214	Mondal et al., 2020; Ray et al., 2021
K10	1,566.5	3,607b	836.5	1,687.1	Mondal et al., 2020; Ray et al., 2021
K131	961.5	2,811.9b	861.5	2,191.4	Mondal et al., 2020; Ray et al., 2021
K39	441.5	2,676.2b	341.5	2,656.8	Mondal et al., 2020; Ray et al., 2021
K50	646.5	2,327.1b	526.5	1,842.3	Mondal et al., 2020; Ray et al., 2021
M17	1,556.5	15,882.5b	871.5	9,424.8	Mondal et al., 2020; Ray et al., 2021
P40	586.5	6,787.4b	566.5	5,332.9	Mondal et al., 2020; Ray et al., 2021
V01	2,096.5	16,599.9b	1,421.5	10,898.6	Mondal et al., 2020; Ray et al., 2021
W01	2,066.5	14,835.3b	1,501.5	8,183.6	Mondal et al., 2020; Ray et al., 2021

a- Ascorbic acid equivalent; b- Ferrous sulphate equivalent.

Table 6: B vitamins of uncooked folk rice varieties

Landraces/ Basudha Accession Code	Thiamin (mg/g)	Riboflavin (mg/g)	Niacin (mg/g)	Pantothenic acid (mg/g)	Pyridoxine (mg/g)	Reference
Njavara	0.005	0.0007	0.073	-	-	Deepa et al., 2008
Jyothi#	0.003	0.005	0.071	-	-	Deepa et al., 2008
Gopalbhok	0.0026	0.0007	0.03	0.03	0.0005	Longvah et al., 2020
Jahagisim	0.002	0.0006	0.03	0.03	0.001	Longvah et al., 2020
Khisore	0.002	0.0006	0.02	0.02	0.0006	Longvah et al., 2020
C14	0.7	0.0	0.03	3.28	0.09	Roy et al., 2020
K05	0.0	0.03	0.38	0.0	0.0	Roy et al.,, 2020
K10	1.02	0.16	0.19	0.93	0.11	Roy et al.,, 2020
K131	0.93	0.32	0.13	3.27	0.09	Roy et al.,, 2020
K39	1.06	0.21	0.08	0.54	0.1	Roy et al.,, 2020
K50	1.18	0.31	018	1.56	0.21	Roy et al.,, 2020
M17	0.43	0.07	0.09	0.5	0.02	Roy et al.,, 2020
P40	0.99	0.25	0.13	0.73	0.14	Roy et al.,, 2020
V01	0.0	0.0	0.27	0.0	1.23	Roy et al.,, 2020
W01	0.73	0.3	0.14	1.07	0.12	Roy et al.,, 2020
BPT 5204#	0.37	0.02	0.05	0.0	0.0	Roy et al.,, 2020

#- Modern cultivar

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