Journal of Stress Physiology & Biochemistry, Vol. 21, No. 2, 2025, pp. 239-256 ISSN 1997-0838

REVIEW

OPEN ACCESS

Review Study on the Maintenance of Improved Crop Varieties for Protecting Their Popularity in Seed Multiplication Systems

Sabyasachi Patra

[1] P.N. Bhaduri Crop Research and Seed Multiplication Farm (PNBCRSMF), Department of Botany, The University of Burdwan, Burdwan-713104, East Burdwan, India

*E-Mail: sabya1983@gmail.com

Received December 15, 2024

Improved crop varieties are the result of important plant breeding techniques, have several benefits, such as higher yields, resistance to pests and diseases, and endurance under adverse conditions like salinity and drought. These varieties are losing their uniqueness and health if they are not properly maintained. This is mostly caused by contaminating and degrading factors, such as genetic drift, outcrossing, volunteer plants, mutation, environmental stressors, and diseases spread by seeds. Proper seed management during seed multiplication can prevent this degeneration. This review study aimed to keep better varieties in seed multiplication systems. It looks at the significance of genetic purity and the variables that influence it. A thorough discussion of the techniques for preserving genetic integrity, including roguing, isolation, and seed certification. It is also stressed that policy support is needed for farmer education, seed certification, and research to preserve the benefits of these varieties. This evaluation offers valuable insights into the optimal management procedures during seed multiplication to guarantee that enhanced crop varieties continue to be useful instruments for boosting agricultural productivity and food security. It accomplishes this by undertaking a detailed examination of current practices and advances.

Key words: Seed generation, Genetic purity, Seed-borne disease, Seed certification, Regulation

Maintaining sustainability and resilience against diverse biotic and abiotic pressures is a persistent problem for the agricultural industry, as noted by Roberts and Mattoo, (2018). This is in addition to satisfying the world's food requirements. To overcome these obstacles, improved varieties of crops that have been created through intensive research and breeding programs are essential. These cultivars provide increased productivity, protection against pests and diseases, and flexibility in a range of environmental circumstances. They are therefore essential to both food security and current farming techniques. The sustained performance of these improved varieties of crops is critical to their success, and this performance is dependent upon the efficacy of seed multiplication approaches (Louwaars, 2007). The process of multiplying seeds involves going from breeder seed to foundation seed and then to certified seed that farmers can plant. This method has to maintain the seeds' genetic purity, health, and vigour while preserving the desirable traits that distinguish improved varieties from traditional ones. To guarantee farmers have access to crop varieties and adaptations as well as the freedom to obtain seed on demand, seed systems play a crucial role. Since seed security is closely related to food security and resilient livelihoods in general, seed systems are essential, especially in alleviating stress caused by climate change (Monica & Astrid, 2016). According to studies, most farmers, particularly in developing countries such as Africa, reported that home-saved seed was their most important source of seed, with only 2% obtaining certified seed. One of the reasons for the low output of seeds in the smallholder agricultural sector has been identified as land scarcity (CIAT *et al*., 2009). The farmer seed supply is hesitant to change, despite the development of new varieties of crops (Jean *et al*., 2007).

To address these issues, many developing-country seed companies generally partner with small-scale seed producers who either NGOs/GOs or farmer associations support. This strategy is increasingly being used in several countries, including Ethiopia, Malawi, Kenya, and Uganda (Jean *et al*., 2007).

Reasons for the Maintenance of Improved Crop Varieties

The resistance of improved varieties of crops to diseases and pests is one of their main benefits. This resilience lowers production costs and the environmental effect by reducing the demand for chemical pesticides. It is crucial to safeguard these resistance genes through rigorous seed multiplication to stop disease and insect infestations that could destroy crops and cause large financial losses. Technological and scientific developments between the 1940s and 1970s brought about a new wave of agricultural practices that allowed farmers to significantly boost crop yields. The movement became recognized as the "Green Revolution (GR; Borlaug and Dowswell., 2005). The first significant breakthrough of the Green Revolution was the development of new semi-dwarf wheat cultivars that were high-yielding, resistant to disease (mostly stem rust), and spread to other crops (Dubin and Brennan, 2009). The practice of monoculture and the substitution of contemporary techniques and technologies for conventional agricultural methods, such as the widespread application of agrochemicals (chemical fertilizers, herbicides, and pesticides), labour mechanization, and a significant expansion around irrigated cropland, were other important aspects of the Green Revolution (Evans, 1998).

There is a close correlation between market demand and crop attributes including taste, size, and shelf life. Higher prices and greater profits for farmers can be obtained via improved varieties that cater to customer tastes. By retaining these characteristics, farmers can continue to produce crops that live up to market demands, promoting both customer happiness and economic viability. Accordingly, A portion of the first selection criteria in varietal development projects is based on the visual qualities of rice grains, which are important screening attributes that influence customers' purchasing decisions (Adair *et al*., 1966; Tomlins *et al*., 2007). The length is the primary determinant of grain size. However, the length-to-width ratio determines the grain shape (Graham, 2002). There is no standard method for classifying rice samples according to their shape and size in different markets and countries (Codex Alimentarius Commission, 1995; Dela Cruz & Khush, 2002). The breeding system of International Rice Research Institute (IRRI) employ the following routine classification system: short rice grain (5.50 mm), medium/intermediate rice grain (5.51–6.60 mm), long rice grain (6.61–7.50 mm), and very long rice grain (> 7.50 mm). The percentage of chalky grain determines the grain's classification: none (0%), tiny (< 10%), medium (10–20%), and large (> 20%). (Ikehashi & Khush, 1979; Dela Cruz & Khush, 2000]. The effects of rice's intrinsic and extrinsic quality attributes on market prices have also been studied using the hedonic pricing model (Abansi *et al*., 1992; Unnevehr, 1986); the findings suggest that varietal improvement programs shouldn't be restricted to yield-enhancing traits alone. More sustainable agricultural methods are frequently facilitated by improved crop varieties. For example, cultivators can use less water and fertilizer when using varieties with higher nutrient use efficiency and drought tolerance. Considering resource constraint and climate change, maintaining these characteristics is crucial for advancing environmentally sustainable agriculture. Given its capacity to meet the goals of reducing the yield-scaled impacts of farming and increasing the yield gap, high-yielding rice varieties have attracted increasing attention from researchers in developing nations (Chen *et al*., 2014; Yamano *et al*., 2016; Yuan *et al*., 2021; 2022).

To get a greater predicted yield, however, the replacement of traditional rice cultivars with high-yielding varieties may raise the requirement for production inputs (such as fertilizers and machinery) (Chen *et al*., 2021; Darzi-Naftchali *et al*., 2017). To highlight potential successes and compromises between the goals of overall sustainability and food security, more data from actual farms is required regarding the comparison of variety substitution's effects on the environment (e.g., traditional vs. high-yielding rice cultivars), based on a life cycle assessment of all production inputs and outcomes (Alhashim *et al*., 2021; Garnett, 2014; Guinée & Heijungs, 2011, Heijungs *et al*., 2009).To keep the lines intact and retain their desired traits and original genetic makeup for future generations, maintenance breeding is crucial. The study of the significance of two techniques inside and the ability to spot slow or dramatic changes are made possible by maintenance through sib mating and selfing (year to row) throughout generations. According to Nally *et al*. (2016), it aids in boosting rice crops against biotic and abiotic stress; maintenance breeding for disease resistance is one method to increase food supply without raising production potential. Significant time, financial, and scientific resources must be committed to the breeding of improved cultivars. By keeping these cultivars alive, we can make sure that the money and resources used to develop them are not lost. Additionally, it maintains the genetic progress accomplished, which can serve as a basis for further breeding initiatives. Maintaining PGR diversity is essential for both genetic improvement and crop variety development.

The extinction rate of plant species is currently surging, and anthropogenic activities and climate change are causing life on Earth to experience its sixth mass extinction event, which might result in ecological breakdown (Teixeira & Huber, 2021).

The Leipzig Declaration (Leipzig Declaration, 1996) placed a strong emphasis on preserving seed and planting material in order to prevent genetic susceptibility and food shortages in unfavorable circumstances. Plant species with a broad gene pool, including wild species, landraces, breeding stock, etc., may have the means to adapt to harsh climates and survive them (Varaprasad & Sivaraj, 2010). For the sake of future generations' food security, these priceless resources must be secured and used sustainably. Plant breeders should have easy access to genetic resources in order to continuously produce new crop varieties. PGRs are a valuable source of genes resistant to insects, diseases, and other pests and diseases, which can be used to create more resilient and enhanced crop types. PGRs have contributed significantly to the creation of crop varieties that are adaptable to the current climate change situation, hence enhancing food security (Hammer & Teklu, 2010). Crop varieties with improved yield and quality attributes and resistance to biotic and abiotic stressors, such as diseases, insect pests, flooding, salinity, and drought, are being produced with the use of PGRs. PGRs are also used in poor nations to produce a wider variety of crops. PGRs are increasingly needed to develop new crop varieties, including cereals, legumes, fruits, vegetables, and ornamentals (Hammer & Teklu, 2010). Modern agriculture depends heavily on maintaining of improved crop varieties. Employing several seed generations, it guarantees that the advantages of these cultivarslike increased yields, resistance to disease, adaptation, and marketability—remain intact. The agricultural community can maintain the efficacy and appeal of these improved varieties by tackling the problems posed by genetic drift, outcrossing, and environmental pressures. In addition to promoting sustainable farming methods, which are critical for the planet's long-term health, this also aids economic stability and food security.

Challenges for the Maintenance of Improved Varieties of Crops

Several major obstacles must be overcome to maintain improved varieties of crops across consecutive generations of seed multiplication. In the end, these difficulties may have an impact on the varieties' acceptance and efficiency in farming systems by compromising their genetic purity, general health, and overall performance. The key challenges include:

Genetic Drift:

Random variations in allele frequency between generations within a population are referred to as genetic drift. Genetic drift can cause the gradual loss of certain features that characterize an enhanced variety during the seed-multiplying process. Plant populations having unique genetic constitutions are known as cross-pollinated crop species and multi-line variants. Therefore, in the process of maintaining these varieties, the generation that results will not accurately represent the whole range of gene combinations found in the original variety's genotype if a small number of gene combinations are excluded owing to incorrect sampling. Such a population abruptly loses the genetic equilibrium that was expected to exist (Nagel *et al*. 2019). Crops can naturally undergo small genetic changes over time, even in isolated fields. The crop's purity may be compromised by this slow genetic drift if it results in changes to its traits (Gereziher Teame *et al*., 2017). To find any changes, ongoing genetic testing and observation are necessary. Genetic drift can also be resisted by regulated breeding programs that preserve a diversified genetic pool. Crop kinds that contain contaminants can be identified with the aid of genetic testing methods. DNA sequencing and polymerase chain reaction are two methods for confirming genetic purity (Ratna *et al*., 2015). rigorous measures, such as keeping foundation and breeder seeds under rigorous supervision and guaranteeing modest effective population sizes during seed multiplication, are necessary to reduce genetic drift.

Outcrossing:

When pollen from a different variety or species fertilizes the flowers of an improved variety, this process is known as outcrossing or cross-pollination. Multiple environmental stresses acting in together are endangering animal pollination of both wild and farmed plant species (Schweiger *et al*. 2010). Plant-pollinator interactions have been demonstrated to be adversely affected by invasive species (Memmott and Waser 2002; Bjerknes *et al*. 2007), pesticide use (Kremen *et al*. 2002), changes in land-use, such as habitat fragmentation (Mustajarvi *et al*. 2001; Aguilar *et al*. 2006), and agricultural intensification (Ricketts *et al*. 2008). Pollination control approaches, such as bagging flowers or adopting male-sterile lines, are effective strategies. Other strategies include temporal isolation (planting at various times to minimize overlapping flowering periods) and physical isolation of seed multiplication fields. To lessen the chance of cross-pollination, farmers can establish buffer zones or isolation zones between various crop species. This entails keeping a physical distance between crops whose genetic characteristics are incompatible.

Seed-Borne Diseases:

"Seed-borne diseases" are infections caused by pathogens that transmit through seeds, heavily impairing plant quality and yield. Some strategies to manage seed-borne infections include using disease-free seed stock, treating seeds with fungicides or hot water, and implementing stringent field hygiene protocols to minimize contamination. When genes from different species are included to introduce disease or pest resistance, genetic purity may be compromised (Tewodros Mesfin *et al*., 2009). Researchers are looking into alternatives like traditional breeding techniques that preserve genetic integrity to produce resistance, or the use of biocontrols, which are naturally occurring enemies of pests. It is possible to identify externally transmitted seed-borne fungus by using the washing approach (Verma and Lahori, 2004). Such example are flag smut of wheat (*Urocystis tritici*), downy mildew of soyabean (*Peronospora manshurica*), blast of paddy (*Pyricularia oryzae*), smut of pearl millet (*Tolyposporium penicillarie*).

Environmental Stress:

Modifications to the soil, temperature, precipitation patterns, and other environmental factors can have an impact on the stability and performance of enhanced cultivars. In a climate change scenario, producing and using high-quality seeds can be crucial to generating high yields. However, because these pressures have a negative impact on plants, producing high-quality seeds under different abiotic stresses requires extra attention. Abiotic stressors impact crop plants at all levels, from morphology to the molecular (Fahad *et al*., 2017), limiting yield and quality. Nonetheless, plants exhibit a few strategies, such as stress avoidance, escape, and stress tolerance, in response to the pressures. Plants experience molecular, cellular, and physiological alterations in response to stressors and learn to adapt to them. To ensure food security, one of the essential elements of plant studies is an insight view of such changes. A deeper comprehension of how plants react to stressors can aid in the development of numerous stress-reduction tactics. To lessen these impacts, cultivators can use stress-tolerant rootstocks, controlled environment agriculture (CEA) for seed production, and variety development with increased environmental adaptability.

Regulatory and Certification Challenges:

Variations in seed quality and genetic purity standards might result from inconsistent or insufficient regulatory frameworks and certification procedures. It was noted in the 20th century that mechanical mixing and genetic contamination caused newly created crops cultivars or varieties to lose their uniqueness. In order to solve this issue, a group of breeders and agronomists started going to progressive producers' fields to advise them on safety measures to take in order to prevent mechanical mixes and maintain the seed's genetic purity, or true to type. Field inspections became commonplace as a result of this campaign. Field inspection was considered by crop scientists and growers/farmers as a potentially helpful method for preserving the genetic purity of crop varieties/cultivars. Though there are some restrictions on producing seeds or crops in ecosystems that are impossible to completely regulate, thinking has evolved about the appropriate limits for mechanical mixes and genetic contamination, among other things. The International Crop Improvement Association (ICIA) was founded in 1919 when officials from the USA and Canada convened in Chicago, Illinois, to address these real-world issues brought on by nature. The contemporary era of seed certification began with the ICIA, which changed its name to the Association of Official Seed Certification Agency (AOSCA) in 1969 (Agarwal, 1996).To guarantee that high requirements are fulfilled globally, it is imperative to harmonize seed certification standards, improve regulatory monitoring, and foster international cooperation in seed quality management. Preserving the suitablecharacteristics of improved cultivars requires addressing genetic drift, outcrossing, seed-borne diseases, environmental stress, and inconsistent regulations. The agricultural community can guarantee that improved crop varieties continue to yield the desired results and maintain their popularity and efficacy in seed multiplication systems by putting strong and creative solutions into place.

Strategies for the Maintenance of Improved Crop Varieties

Effective maintenance of improved crop varieties in seed multiplication systems requires a combination of traditional and modern strategies to preserve genetic purity, health, and performance. These strategies ensure that the desirable traits of improved varieties are retained across successive generations. Key strategies include:

Genetic Purity:

Since it guarantees that the plants that comprise the crop have the intended traits, Kelly (1988) asserts that the genetic purity of the seed is the most crucial component of its quality. the rigorous elimination of unwanted plants from a seed crop based on distinctive morphological traits is known as roguing (Laverack and Turner, 1995). Off-types, diseased plants, undesirable weeds, and other crop plants are all considered rogues. This process improves one or more factors (genetic purity, free from diseases and noxious weeds) of seed quality (Parimala *et al*., 2013).

Rouging must be done correctly and on time to produce seeds. This means that in fields where seeds are produced, undesirable or off-type plants must be regularly removed. Fields used for seed production are physically or chronologically isolated to avoid cross-pollination with other cultivars or wild relatives. Physical isolation can be achieved by keeping a sufficient distance between fields, whereas temporal isolation requires planting at various times to avoid overlapping flowering seasons. Molecular markers ensure the genetic legitimacy of seeds and can be used to detect and eliminate contamination early in the multiplication phase. This method allows for the precise monitoring of genetic purity.

Agarwal (1980) & Hartmann and Kester (1968) recommend the following steps for maintaining the genetic purity of cultivars during seed production:

i Use of only approved seed in seed multiplication

ii Inspection and approval of seed plots prior to planting

iii Growing crops should be inspected and approved in the field at all important growth phases to ensure genetic purity, detect admixtures and weeds, and be free of noxious weeds and seed-borne diseases.

iv Sampling and sealing of cleaned lots.

v Growing samples of potentially authorized stocks to compare with real stocks.

vi Provision of adequate isolation to prevent contamination by natural crossing or mechanical mixture.

vii Routing seed plots before stages of growth when contaminated seed crop occurs.

viii Regular testing of cultivars to ensure their genetic purity

ix Preserving genetic diversity by growing crops only where they are adapted.

x Seed crop certification ensures genetic purity and quality of seed.

xi Adoption of generation system.

Seed Certification:

Strict seed certification procedures ensure that growers only obtain premium, genetically pure seeds. Certification involves multiple stages of quality control, field inspection, and seed testing to maintain standards. According to Douglas (1972), a successful seed certification system should strive for the subsequent three goals:

a A steady increase in superior varieties.

b Identification of fresh varieties and their rapid propagation under appropriate and well-known names.

c . Ensuring regular access to the identical seed material through careful maintenance

India and the other SAARC countries adopt a three-generation seed multiplication approach (Huda and Saiyed, 2011). Only the original breeder or a supported institution produces breeder seed in India. Any of the State seed corporations, National seed corporations, seed cooperatives, public sector initiatives, non-governmental organizations, private seed firms, and farmers' producer groups produce the foundation and certified seed. Only three generations beyond the breeder seed are permitted by the Indian Minimum Seed Certification Standards (IMSCS) (Trivedi and Gunasekaran, 2013).

Following processing, the seed samples are forwarded to the state seed testing lab under ISTA regulations to ensure they meet the requirements for certified seed in vegetable crops.

The seed standards are given below in the table 2.

Seed certification aims to maintain appropriate standards of additional quality parameters, such as freedom from weeds and diseases, seed viability, mechanical purity, and grading, in addition to varietal purity and identification (J.E. Douglas (ed.), 1980). It is essential to regularly test seeds for genetic purity, germination rate, and seed health. To confirm the quality of seeds, advanced techniques like DNA fingerprinting and electrophoresis can be employed.

Breeder and Foundation Seed Maintenance:

Nucleus seed is used to make breeder seed. It needs to have pure genetic makeup. As foundation seed, it is employed. The ICAR's mandate is to produce breeder seed, which is being done with assistance from the State Agricultural University, All India Co-ordinated Research Projects, the ICAR Research Institute, and other organizations. Genetic drift and contamination are reduced when foundation and breeder seeds are kept under carefully monitored conditions. The main source of genetic material for additional proliferation is these seeds. The process for maintaining the nucleus seed of prerelease or recently released varieties of crops was described by Harrington in 1952. Self-fertilized species should have entirely homogenous variations. Nonetheless, in recently released cultivars, a significant degree of variation may still happen throughout the seed production cycle. Therefore, purification of such varieties during the nucleus/breeder's seed care may be required (Agarwal, 1980). At several growth phases, especially flowering and maturity, the breeder seed crop should be examined for genetic purity. The method currently used for producing breeder seeds of pure lines showed a lower genotypic coefficient of variability and more deviation for most traits in progenies derived on a panicle basis from selected bagged plants than in progenies generated on a whole plant basis from selected unbagged plants (Pandey and Seshu, 1998). Breeder seed undergoes inspection and roguing for various traits at various stages (Agrawal and Dadlani, 1987). Maintaining the genetic integrity of the enhanced variety can be achieved by periodically renewing foundation and breeder seeds through backcrossing with the original parent lines. A specific class of seed is produced from a specific class up to a certified seed stage in the generation system of seed multiplication (Agarwal 2008).

Only certified and foundation seeds are subject to the seed certification regulations in India. There exist two distinct categories of standards: field standards and seed standards. The field standards are relevant to standing crops and seed production plots, while the seed standards are specific to seeds. Field requirements include land, isolation, maximum amount of off-type that can be tolerated, inseparable other agricultural plants, pollen shedders (in male sterile line), plants contaminated with illnesses spread by seeds, etc. Standards for seeds include moisture content, germination, other crop seeds, physical and genetic purity, and more. (Tunwar and Singh, 1988)

Protection of Seed-Borne Diseases Using Quarantine Guidelines

A parliamentary measure known as "plant quarantine" restricts plant imports and exports, planting materials, grafts, and seeds, and equipment to prevent plant diseases from spreading to locations where they do not currently exist. This prevents the transmission of pathogens and pests from these sources. Thus, "Rules and Regulations" issued by the government(s) to control the introduction of plants, planting materials, plant products, soil, live organisms, etc. from one area to another can be used to characterize plant quarantine. The purpose of this is to prohibit the establishment and further spread of exotic pests, weeds, and diseases that are detrimental to agriculture and the environment in a country or region, as well as to avoid their unintended introduction without adversely affecting trade (Gupta and Khetarpal 2004).

Therefore, quarantine aims to stop the spread of harmful infections, not to prevent the flow of additional biological material. Timely interventions are made possible by routine monitoring and early disease identification, which help stop the spread of pathogens through seeds.

Hot water treatment was mainly used to sterilize contaminated cereal seeds, but Nega *et al*. (2003) reported that it was effective in controlling seed-borne pathogens, such as *Alternaria* spp. and *Xanthomonas* spp., in carrots, celery, lettuce etc.(Gilbert *et al*., 2005). Koch *et al*. (2010) discovered that hot air treatment of carrot seeds was just as effective as chemical treatment in controlling the seed-borne infection of *Alternaria dauci* and *A. radicina*. Manyhost-pathogen systems have demonstrated the excellent efficacy of aerated steam treatment (Forsberg *et al*., 2002; Tinivella *et al*., 2009; Schaerer, 2012). Additionally, it has proven effective in treating seed-borne illnesses brought on by *F. moniliforme* in sweet corn, *C. michiganensis subsp. michiganensis* in tomatoes, *X. campestris* in cauliflower, and *Septoria apiicola* in celery (Groot *et al*. 2006, 2008). In India, the following 18 crops are approved for use with fungicides that contain benzimidazole: cereals viz. rice, wheat, barley, fibres viz. cotton, jute, fruits viz. mango, apples, grapes, vegetables viz. beans, eggplants, cucurbits, peas, sugar beets, tapioca, flower viz. roses and peanut. For many horticultural and agricultural crops worldwide, systemic fungicide seed treatment is thought to be an economically viable disease management strategy (Bhushan *et al*. 2013; Lamichhane *et al*. 2020). According to Zeun *et al*. 2013, many additional fungicide groups, such as strobilurins, triazoles, phenylpyrroles, and phenylamides, are also used to treat seeds for some diseases that are transmitted by seeds. Both seeds and seedlings are protected against pathogens when treated with microbial antagonists. Eighty-four percent of microbial antagonists are bacteria., followed by fungi (16%). In recent decades, numerous bacterial biocontrol agents have been identified and used to treat diseases propagated via seeds. Many bacteria have been thoroughly studied and successfully marketed as biological control agents, such as *Burkholderia cepacia*, *B. subtilis*, *S. marcescens*, *P. fluorescens*, and *Streptomyces griseoviridis* (Singh, 2014; Bisen *et al*., 2015; Keswani *et al*., 2016; Gouda *et al*., 2018).

To control a variety of phytopathogens, including seed-borne diseases, the most often employed bacterial biocontrol agents are species of *Pseudomonas* and *Bacillus* (Abhilash *et al*., 2016; Bhat *et al*., 2019; Khan *et al*., 2020). Likewise, the potential of a variety of fungi to act as biocontrol agents against seed-borne diseases has also been investigated. The species of *Phomosis*, *Ectomycorrhizae*, *Trichoderma*, *Cladosporium*, *Gliocladium*, and other fungi are significant fungal biocontrol agents. *Trichoderma spp.* is a well-researched and extensively utilized biopesticide worldwide, among other fungal biocontrol agents (Singh 2006; Keswani *et al*., 2013; Bisen *et al*., 2016; Singh *et al*., 2016). *Trichoderma spp*. have been shown to have antagonistic action against a variety of soil- and seed-borne fungi, making them suitable plant symbionts. The market share of trichoderma formulation in the global biopesticide industry is greater than 60% (Keswani *et al*., 2013).

Community-Based Seed Production:

The goal of community-based seed production is to enable farmers to produce better, high-yielding seed that is desired locally by their fellow community farmers. The primary goals of community-based seed production are to supply farmers and other seed purchasers with high-quality seed, develop local seed markets, and create opportunities for individuals to establish seed-trading businesses in their communities (Engels *et al*., 2008). Worldwide, the term "community seed bank," "farmer seed house," "seed hut," "seed center," "seed savers group," "seed producer group," and "seed library" are among the several names for the CBSP concept (Vernooy *et al*., 2013). With assistance from USC Canada-Nepal, the first CBSB in Nepal was founded in 1994 at Dalchoki, Lalitpur, to manage conventional crops such as cereals, grains, legumes, and vegetables (Joshi, 2013; Bhandari *et al*., 2017). Improving the sustainability and acceptability of enhanced varieties can be achieved through involving local communities in seed production and management. By closing the divide between the formal and unofficial sectors, the CBSS is a crucial tool to boost farmers' access to varied crop types in rural areas, especially for resource-poor farmers (Maharjan & Khanal, 2015).Farmers are frequently trained in the best procedures for seed production and preservation as part of community-based programs. Incorporating farmers within the breeding and selecting process guarantees that the enhanced cultivars align with regional tastes and circumstances, so augmenting their acceptance and durability.

Policy Support and Regulation:

The following factors have limited the farmers' access to these improved seeds: i) Insufficient funds to buy seeds and related inputs (like fertilizer and pesticides); ii) Limited market availability of seeds; iii) Uncertainty regarding the benefits of new germplasm compared to local varieties; iv) Insufficient knowledge to develop high-quality seeds; v) Uncertainty regarding yields and fluctuating product prices; vi) Inability to comply with phytosanitary regulations; and vii) Lack of recognition and support for the seeds produced by small farmers' seed systems. The practice of farmers conserving and exchanging seeds has, however, evolved because of technological advancements that have kept pace with environmental changes. Traditional seed systems, which were under farmer control, have gradually shifted to the government sector, plant breeders, and private seed businesses due to the rapid advancement of agricultural technology. Technology advancements like hybridization and genetic improvement linked to the green revolution were the key causes of this change (Shrestha & Thapa, 2019).

Policymakers, practitioners, and researchers all agree that seed provisioning is crucial for agrobiodiversity and germplasm conservation, food security and nutrition, rural livelihoods, and agricultural development (Coomes *et al*., 2015). Although there has been a greater advancement in seed system technology, it is still a constant process that must adhere to several internal and external elements, with plant breeders and biotechnologists playing a crucial role. October 18–19, 2014, in Kathmandu, Nepal, POD "Cooperation among Bangladesh, India, Nepal, and IRRI in seed sector Protocol of Discussion" was made by the SAARC Member States, specifically Bangladesh, India, Nepal, and IRRI, to achieve the goals of the SAARC Seed Bank (SAARC, 2014). The POD was expected to directly help the farmers of all three areas by circulating the rice varieties that are released in one region for use by farmers in other countries.

The following laws, policies, and rules for advancing the Farmers' Right have been approved by the SAARC Member States:

Afghanistan: National Seed Policy 2005; Seed Act 2009.

Bangladesh: Plant Varieties Act of Bangladesh 1998; Biodiversity and Community Knowledge Protection Act of Bangladesh; Seed Act 2018;

Seed Rules 1998; National Seed Policy 1993; and Hybrid Rice Variety Evaluation and Registration Procedures, 2016.

Bhutan: Biodiversity Act 2003 with provisions for breeders and farmers' rights; Seed Act 2000; Seed Rules and Regulation 2006, 2017 (revised).

India: Protection of Plant Varieties and Farmers' Rights Act 2001 (PVA); Biodiversity Bill 2002; Seed Development, 1988; National Seed Policy 2002; National Seed Plan 2005-06 and Seed Act 1966/Seed Rules.

Nepal: The Seed Act 1988 (with amendment in 2008); Protection of Plant Varieties and Farmers' Right draft Bill (2005); Agrobiodiversity Policy 2006 (revised in 2014); Agriculture Development Strategy (ADS) 2014; Inclusion of seed/food sovereignty in Constitution 2015 (Seeds Act 1988 amendment in 2008 and Seeds Rules 2013; National Seed Policy, 1999 and Seed vision 2013-2025).

Pakistan: Plant Breeders' Rights Ordinance 2000; Seed (Amendment) Act 2015; National Seed Policy 2016; Seed (Truth-in-Labeling) Rules 1991; Plant Breeder Act 2016

Sri Lanka: Protection of New Plant Varieties (Breeders Rights) 2001; National Seed Policy 1996; Seed Law 2003.

Sustaining improved varieties requires government policies that encourage research, seed certification, and farmer education. Fair trade principles and easier access to premium seeds should also be priorities for policymakers. Maintaining the genetic integrity and health of enhanced varieties is aided by harmonizing seed laws and regulations to guarantee uniform quality requirements across geographical areas.

Technological Innovations:

Biotechnology achievements like CRISPR and other gene-editing methods can be utilized to generate more resilient and easier-to-maintain variations while also enhancing desired features. Only a few species have been researched thus far using this strategy (Zhou *et al*., 2020). The speed at which agricultural enhancement transitions has accelerated because to the precise and targeted genetic alteration of crops made feasible by recent developments in CRISPR/Cas9 technologies (Chen *et al*., 2019).

Since 2013, the application of CRISPR/Cas9 and its variations has taken center stage. A DNA fragment known as CRISPR is made up of tiny, non-contiguous DNA repeats separated apart by spacers or variable sequence pieces. Accordingly, this research suggested that prokaryotes' elicitation of adaptive immunity may be caused by CRISPR/Cas9 (Bolotin *et al*., 2005; Pourcel *et al*., 2005). According to Leibowitz *et al*. (2021), ISPR/Cas9 could treat diseases, and its application significantly influences plant biology (Zhan *et al*., 2021). In an experiment conducted in 2007, researchers thought the bacterial phenotypic was phage-resistant and that the bacterial phenotype could be changed by adding or removing particular spacers. This was the first documented application of CRISPR/Cas9. (Barrangou *et al*., 2007). Genetically modifying plants to improve agriculture will be simple in the future (Sharma *et al*., 2021). Cas9, a protein referred to as "biological scissors," is being used to modify genomes in a way that redefines standards and opens new possibilities for agricultural crop enhancement (Sharma *et al*., 2021). Cas9 has been used to address several abiotic stressors in important crops, including rice, wheat, maize, cotton, and potatoes. By creating crops that are resistant to abiotic stressors or climate change, plant breeding has updated plant breeding. Any sequence can be changed, and any character can be introduced into crops using CRISPR/Cas9. Numerous genes linked to abiotic stress tolerance were found by molecular breeders, who then incorporated them into crops (Razzaq *et al*., 2021). Mutants of the slmapk3 protein gene produced by CRISPR/Cas9 enhanced tomatoes' defense response to drought stress (Wang *et al*., 2017). Two genes, TaDREB3 and TaDREB2, linked to abiotic stress resistance in wheat protoplasts, have been studied using Cas9. Using the T7 endonuclease test, mutant gene expression was found in about 70% of the transfected wheat protoplasts.In contrast to plants of the wild type, all mutant plants demonstrated drought tolerance (Kim *et al*., 2018). A thorough analysis on how to use Cas9 to improve plants' resistance to drought stress (Joshi *et al*., 2020). The function of the rice OsAnn3 gene, which was altered to withstand cold stress, was investigated in plants with altered genomes (Shen *et al*., 2017). To investigate the stress mechanism in rice, the gene SAPK2 was modified. This gene improved rice's resistance to salinity and drought, according to a prior study (Lou *et al*., 2017). Targeting the ARGOS8 gene to produce novel variations has led to the development of drought tolerance, and this is incredibly significant for maize (Shi *et al*., 2017). Liao *et al*. (2019) reported that the Cas9-induced mutation of Leaf1,2 in rice resulted in drought resistance by modifying the pattern of protein production and scavenging of reactive oxygen species. In 2019, Zhang *et al*. increased rice's resistance to salt by targeted mutation of the OsRR22 gene.

In view of Digital Agriculture, leveraging digital tools for monitoring and managing seed production can enhance precision and reduce human error. Technologies like drones, remote sensing, and data analytics can provide valuable insights into field conditions and crop health.

Table 1: India's minimum isolation standards for certified seed of some vegetable crops

Name of Vegetable crops	Scientific name	Open Pollinated seeds	Hybrid seeds
Bottle gourd	*Lagenaria siceraria*	500	1000
Snake gourd,	*Trichosanthes cucumerina*	500	1000
Sponge gourd	*Luffa aegyptiaca*.	500	1000
Bitter gourd	*Momordica charantia*	500	1000
Muskmelon	*Cucumis melo*	500	1000
Cucumber	*Cucumis sativus*	500	1000
Tomato	*Lycopersicon esculentum* (Mill.)	25	100
Carrot	*Daucus carota*	800	800
Onion	*Allium cepa*	500	600
Bringal	*Solanum melongena*	100	200
Amaranth	*Amaranthus* spp.	200	-
Spinach	*Spinach oleracea*	1000	-
Radish	*Raphanus sativus*	1000	
Beetroot	*Beta vulgaris.*	1000	
Cowpea	*Vigna unguiculata*	25	-
Garden pea	*Pisum sativum*	5	-
Capsicum	*Capsicum frutescens*	200	-
Chilli	*Capsicum annuum*	200	
Okra	*Abelmoschus esculentus*	200	
Cabbage	*Brassica oleracea* var. capitata	1000	-
Cauliflower	*Brassica oleracea* var. botrytis	1000	-

Source: IMSCS, 2013

Table 2: Minimum seed standard of vegetable crops

Name of vegetable crops	Percentage of Germination (%)	Percentage of inert matter (%)	Percentage of Purity (%)
Cole crops	70	2	98
Gourds	60	2	98
Chilli, radish	60	2	98
Tomato	80	2	98
Brinjal	70	2	98
Bhindi/Okra	65	1	99
Amaranth	70	5	95
Celery	70	3	97
Lettuce	70	2	98
Fenugreek	70	2	98
Asparagus	70	4	96

Source: IMSCS,2013

Table 3: Some Important agri-horti seed crops in India have specified diseases that can be spread by seeds as well as acceptable limits for certified seed :

Name of crop	Name of Disease	Causal organisms	Seedstandard (%)
Sorghum	Ergot, Sclerotia	*Claviceps sorghi*	0.04
Common wheat	Karnal bunt	*Tilletia tritici*	0.25
Triticale	Karnal bunt	*T. indica /Tilletia tritici*	0.25
Sweet potato	Scurf	*Monilochaetes infuscans*	1.0
Common wheat	Loose smut	*Ustilago tritici*	0.50
Barley	Loose smut	*Ustilago nuda / Ustilago segetum var. nuda*	0.50
Green gram	Halo blight	*Pseudomonas phaseoli = P. savastanoi pv. phaseolicola*	0.20
Sesame	Leaf spot	*Cercospora sesami*	1.0
Chilli	Leaf blight	*Alternaria solani*	0.50
	Anthracnose	*Colletotrichum capsica*	0.50

Source: IMSCS 2013

CONCLUSION

The yield and otheryield-attributing characters of improved varieties may be changed or loosened byimproper management practices during seed multiplication systems. The designated characteristics of improved varieties must be maintained through several kinds of strategies, including strict seed certification, community involvement, legislative support, genetic purity maintenance, and technological developments. Farmers can obtain improved varieties of crops that are still in demand and productive by successfully implementing all of these tactics, which will raise the yields of crops and ensure food security.

ACKNOWLEDGMENTS

The author is grateful to the staff of P.N. Bhaduri Crop Research and Seed Multiplication Farm, University of Burdwan, for providing internet facilities includinga computer, and laptop for necessary searching information.

CONFLICTS OF INTEREST

The authors declare that they have no potential conflicts of interest.

REFERENCES

Abansi C L, Duff B, LanticanF A and Juliano BO. (1992). Consumer demand for rice grain quality in selected rural and urban markets in the Philippines. *Consumer Demand for Rice Grain Quality: Terminal Report of IDRC Projects National Grain Quality (Asia) and International Grain Quality Economics (Asia)*, 37-57.

Agarwal PK andDadlani M. (1987). Techniques of Seed Science and Technology, South Asian Publishers, New Delhi. P. 1-5.

Agarwal RL. (1980). Seed Technology. Oxford & IBH Publishing Co. Pvt. Ltd. New Delhi. P. 43-51 and 66-79.

Agarwal RL. (1996). Seed Technology. Oxford and IBH Publication Co., New Delhi

Agarwal RL. (2008).Seedtechnology.Oxford & IBH Publishing Co. Pvt. Ltd, NewDelhi

Aguilar R, Ashworth L, Galetto L and Aizen MA. (2006). Plant reproductive susceptibility to habitat fragmentation: review and synthesis through a meta-analysis. *Ecol Letters*, 9: 968-980.

Alhashim R, Deepa R and Anandhi A. (2021). Environmental impact assessment of agricultural production using LCA: A review. *Climate*, 9(11), 164.

BarrangouR, Fremaux C, Deveau H, Richards M, Boyaval P, Moineau, S and Horvath P. (2007). CRISPR provides acquired resistance against viruses in prokaryotes. *Science*, 315(5819), 1709-1712.

Bhandari B, Joshi B K, Shrestha P, Sthapit S, Chaudhary P, Acharya AK and MoAD SD. 2017. Custodian farmers, agrobiodiversity rich areas and agrobiodiversity conservation initiatives at grass root levels in Nepal. In *Conservation and Utilization of Agricultural Plant Genetic Resources in Nepal (BK Joshi, HB KC and AK Acharya, eds). Proceedings of 2nd National Workshop* (pp. 22-23).

BhatM A, Rasool R and Ramzan S. (2019). Plant growth promoting rhizobacteria (PGPR) for sustainable and eco-friendly agriculture. *Acta Sci. Agric*, 3(1), 23-25.

Bhushan C, BhardwajA and Misra SS. (2013). State of pesticide regulations in India. Centre for Science and Environment, New Delhi, 1-72.

Bisen K, Keswani C, Patel JS, SarmaBK and Singh H B. (2016). Trichoderma spp.: efficient inducers of systemic resistance in plants. *Microbial-mediated induced systemic resistance in plants*, 185-195.

Bjerknes, A.L., Totland, O., Hegland, S.J. & Nielsen, A. (2007). Do alien plant invasions really affect pollination success in native plant species? *Biol Cons*, 138, 1-12.

Bolotin, A., Quinquis, B., Sorokin, A., & Ehrlich, S. D. (2005). Clustered regularly interspaced short palindrome repeats (CRISPRs) have spacers of extrachromosomal origin. *Microbiology*, 151(8), 2551-2561.

Borlaug, N. E., & Dowswell, C. R. (2003, May). Feeding a world of ten billion people: a 21st century challenge. In *Proceedings of the international congress in the wake of the double helix: From the green revolution to the gene revolution* (pp. 27-31). Ames, IA: Iowa State Press.

Callaway, E. (2018). CRISPR plants now subject to tough GM laws in European Union. *Nature*, 560(7716), 16-17.

Chen, K., Wang, Y., Zhang, R., Zhang, H., & Gao, C. (2019). CRISPR/Cas genome editing and precision plant breeding in agriculture. *Annual review of plant biology*, 70(1), 667-697.

Chen, L., Xie, H., Wang, G., Qian, X., Wang, W., Xu, Y., ... & Yang, J. (2021). Reducing environmental risk by improving crop management practices at high crop yield levels. *Field Crops Research*, 265, 108123.

Chen, X., Cui, Z., Fan, M., Vitousek, P., Zhao, M., Ma, W., ... & Zhang, F. (2014). Producing more grain with lower environmental costs. *Nature*, 514(7523), 486-489.

CIAT, CRS, World Vision, Care, AGRITEX & CIMMYT., (2009). Seed System Security Assessment, Zimbabwe. A study funded by the United States Agency for International Development. Office of Foreign Disaster Assistance. Rome, July 2009.

Codex Alimentarius Commission. Codex Standard for Rice. (1995).

Coomes, O. T., McGuire, S. J., Garine, E., Caillon, S., McKey, D., Demeulenaere, E., ... & Wencélius, J. (2015). Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. *Food Policy*, 56, 41-50.

Cruz, N. D., & Khush, G. S. (2000). Rice grain quality evaluation procedures. *Aromatic rices*, 3, 15-28.

Darzi-Naftchali, A., Bagherian-Jelodar, M., Mashhadi-Kholerdi, F., & Abdi-Moftikolaei, M. (2020). Assessing socio-environmental sustainability at the level of irrigation and drainage network. *Science of the Total Environment*, 731, 138927.

Douglass (ed.), J.E. (1980). Successful Seed Programme : A planning and Management Guide, Westview Press, Boulder, CO, 1980.

Douglass, J.E. (1972). Opening opportunities for seed technologists, *Seed Technol. News* 2(4):2.

Dubin, H. J., & Brennan, J. P. (2009). Fighting a 'Shifty Enemy', the international collaboration to contain wheat rusts. Millions Fed. Proven Successes in Agricultural Development. DJ Spielman and R. Pandya-Lorch (eds.). International Food Policy Research Institute. Washington, DC pp, 19-24.

Engels, J. M., Polreich, S., & Dulloo, M. E. (2008). Role of community gene/seedbanks in the conservation and use of crop genetic resources in Ethiopia (pp. 149-159). *Farmers' seeds and varieties: Supporting informal seed supply in Ethiopia*. Wageningen: Wageningen International.

Evans, L. T. (1998). Feeding the Ten Billion: Plants and Population Growth. Cambridge: Cambridge University Press

Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A., ... & Huang, J. (2017). Crop production under drought and heat stress: plant responses and management options. *Frontiers in plant science*, 8, 1147.

Fitzgerald MA, Resurreccion AP. (2009) Maintaining the yield of edible rice in a warming world. *Functional Plant Biology*. 36, 1037

Forsberg, G., Andersson, S., & Johnsson, L. (2002). Evaluation of hot, humid air seed treatment in thin layers and fluidized beds for seed pathogen sanitation. *Journal of Plant Diseases and Protection* , 357-370.

Garnett, T. (2014). Three perspectives on sustainable food security: efficiency, demand restraint, food system transformation. What role for life cycle assessment. *Journal of Cleaner Production*, 73, 10-18.

Gereziher, T., Seid, E., Diriba, L., & Bisrat, G. (2017). Adaptation Study of Mung Bean (Vigna Radiate) Varieties in Raya Valley, Northern Ethiopia. *Current Research in Agricultural Sciences*, 4(4), 91-95.

Gilbert, J., Woods, S. M., Turkington, T. K., & Tekauz, A. (2005). Effect of heat treatment to control Fusarium graminearum in wheat seed. *Canadian Journal of Plant Pathology*, 27(3), 448-452.

Graham, R. (2002). A proposal for IRRI to establish a grain quality and nutrition research center. *IRRI Discussion Paper Series No*. *44*. Los Baños (Philippines): International Rice Research Institute. 15 p

Groot, S. P. C., Birnbaum, Y., Kromphardt, C., Forsberg, G., Rop, N., & Werner, S. (2008). Effect of the activation of germination processes on the sensitivity of seeds towards physical sanitation treatments. *Seed Science and Technology*, 36(3), 609-620.

Groot, S. P. C., Birnbaum, Y., Rop, N., Jalink, H., Forsberg, G., Kromphardt, C., ... & Koch, E. (2006). Effect of seed maturity on sensitivity of seeds towards physical sanitation treatments. *Seed Science and Technology*, 34(2), 403-413.

Guinée, J. B., & Heijungs, R. (2011). Life cycle sustainability analysis. *Journal of Industrial Ecology*, 15(5), 656-658.

Gupta, K., & Khetarpal, R. K. (2005). Concept of regulated pests, their risk analysis and the Indian scenario. *Annual Review of Plant Pathology* 3(3), 409-441.

Hammer, K., & Teklu, Y. (2008). Plant genetic resources: selected issues from genetic erosion to genetic engineering. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, 109(1), 15-50.

Hartmann, H.T. & Kester. D.E (1968). Plant Propagation : Principles and Practises, Prentice Hall, New Delhi, 1968.

Heijungs, R., Huppes, G., & Guinee, J. (2009). A scientific framework for LCA. Deliverable (D15) of CALCAS Project. Institute of Environmental Sciences, Leiden University,(CML).

Hodgkin, T., Rana, R., Tuxill, J., Balma, D., Subedi, A., Mar, I., ... & Jarvis, D. I. (2007). Seed systems and crop genetic diversity in agroecosystems. In Managing biodiversity in agricultural ecosystems (pp. 77-116). Columbia University Press.

Ikehashi, H., & Khush, G. S. (1979). Methodology of assessing appearance of the rice grain, including chalkiness and whiteness. In Workshop on Chemical Aspects of Rice Grain Quality. Los Baños, Philippines: International Rice Research Institute (pp. 223-230).

IMSCS (2013). (INDIAN MINIMUM SEED CERTIFICATION STANDARDS. 2013).

JOSHI, B. K. (2012). A Brief Overview of Community Seed Bank Initiatives in Nepal31. *Community Seed Banks in Nepal: Past, Present, Future*, 41.

Joshi, R. K., Bharat, S. S., & Mishra, R. (2020). Engineering drought tolerance in plants through CRISPR/Cas genome editing. *3 Biotech*, 10(9), 400.

Kansiime, M. K., & Mastenbroek, A. (2016). Enhancing resilience of farmer seed system to climate-induced stresses: Insights from a case study in West Nile region, Uganda. *Journal of rural studies*, 47, 220-230.

Kelly, A. F. (1988). Seed production of Agricultural Crops, Longman Scientific & Technical, New York

Keswani, C., Singh, S. P., & Singh, H. B. (2013). A superstar in biocontrol enterprise: Trichoderma spp. *Biotech Today*, 3(2), 27-30.

Khan, N., Bano, A., Ali, S., & Babar, M. A. (2020). Crosstalk amongst phytohormones from planta and PGPR under biotic and abiotic stresses. *Plant Growth Regulation*, 90, 189-203.

Kim, D., Alptekin, B., & Budak, H. (2018). CRISPR/Cas9 genome editing in wheat. *Functional & integrative genomics*, 18, 31-41.

Koch, E., Schmitt, A., Stephan, D., Kromphardt, C., Jahn, M., Krauthausen, H. J., ... & Groot, S. P. (2010). Evaluation of non-chemical seed treatment methods for the control of Alternaria dauci and A. radicina on carrot seeds. *European journal of plant pathology*, 127, 99-112.

Kremen, C., Williams, N.M. & Thorp, R.W. (2002). Crop pollination from native bees at risk from agricultural intensification. *Proc Natl Acad Sci U S A*, 99, 16812-16816.

Laborte, A. G., Paguirigan, N. C., Moya, P. F., Nelson, A., Sparks, A. H., & Gregorio, G. B. (2015). Farmers' preference for rice traits: insights from farm surveys in Central Luzon, Philippines, 1966-2012. *PLoS One*, 10(8), e0136562.

Lamichhane, J. R., You, M. P., Laudinot, V., Barbetti, M. J., & Aubertot, J. N. (2020). Revisiting sustainability of fungicide seed treatments for field crops. Plant Disease, 104(3), 610-623.

Laverack, G. K., & Turner, M. R. (1995). Roguing seed crops for genetic purity: a review. *Plant Varieties & Seeds*, 8(1), 29-45

Leibowitz, M.L.; Papathanasiou, S.; Doerfler, P.A.; Blaine, L.J.; Sun, L.; Yao, Y.; Zhang, C.-Z.; Weiss, M.J.; Pellman, D. (2021), Chromothripsis as an on-target consequence of CRISPR–Cas9 genome editing. *Nat. Genet*. 53, 889–905.

Leipzig Declaration. International Technical Conference on Plant Genetic Resources, Leipzig. (1996). Available online: **https://link.springer.com/chapter/10.1007/978-3-662-05212-9_2** (accessed on 7 June 2022).

Liao, S., Qin, X., Luo, L., Han, Y., Wang, X., Usman, B., ... & Li, R. (2019). CRISPR/Cas9-induced mutagenesis of semi-rolled leaf1, 2 confers curled leaf phenotype and drought tolerance by influencing protein expression patterns and ROS scavenging in rice (Oryza sativa L.). *Agronomy*, 9(11), 728.

Lou, D., Wang, H., Liang, G., & Yu, D. (2017). OsSAPK2 confers abscisic acid sensitivity and tolerance to drought stress in rice. *Frontiers in plant science*, 8, 993.

Maharjan, K.L. & Khanal, N.P. (2015). A Framework for Understanding Sustainability of Community-Based Seed Production System. Eds. Ojiewo CO, Kugbei S, Bishaw, Z. & Rubyogo J.C. *Community Seed Production. Workshop Proceedings, 9-11 December 2013*. FAO, Rome & ICRISAT, Addis Ababa. 176 pp.

Memmott, J. & Waser, N.M. (2002). Integration of alien plants into a native flowerpollinator visitation web. P*roc R Soc Lond [Biol]*, 269, 2395-2399.

Mesfin, T., Tesfahunegn, G. B., Wortmann, C. S., Nikus, O., & Mamo, M. (2009). Tied-ridging and fertilizer use for sorghum production in semi-arid Ethiopia. *Nutrient cycling in agroecosystems*, 85, 87-94.

Mustajarvi, K., Siikamaki, P., Rytkonen, S. & Lammi, A. (2001). Consequences of plant population size and density for plant-pollinator interactions and plant performance. *J Ecol*, 89, 80-87.

Nagel, R., Durka, W., Bossdorf, O., & Bucharova, A. (2019). Rapid evolution in native plants cultivated for ecological restoration: not a general pattern. *Plant Biology*, 21(3), 551-558.

Nalley, L., Tsiboe, F., Durand-Morat, A., Shew, A., & Thoma, G. (2016). Economic and environmental impact of rice blast pathogen (Magnaporthe oryzae) alleviation in the United States. *PloS one*, 11(12), e0167295.

Nega, E., Ulrich, R., Werner, S., & Jahn, M. (2003). Hot water treatment of vegetable seed—An alternative seed treatment method to control seed-borne pathogens in organic farming / Heißwasserbehandlung von Gemüsesaatgut—Eine alternative Saatgutbehandlungsmethode zur Bekämpfung samenbürtiger Pathogene im ökologischen Landbau. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz / Journal of Plant Diseases and Protection*, 220-234.

Pandey, M. P., & Seshu, D. V. (1998). Selection criterion for basic seed production of rice cultivars. *ORYZA*, 35, 202-207.

Parimala, K., Subramanian, K., Mahalinga Kannan, S., & Vijayalakshmi, K. (2013). A manual on seed production and Certification. December 2013.

Pourcel, C., Salvignol, G., & Vergnaud, G. (2005). CRISPR elements in Yersinia pestis acquire new repeats by preferential uptake of bacteriophage DNA, and provide additional tools for evolutionary studies. *Microbiology*, 151(3), 653-663.

Ratna, M., Begum, S., Husna, A., Dey, S. R., & Hossain, M. S. (2015). Correlation and path coefficients analyses in basmati rice. *Bangladesh Journal of Agricultural Research*, 40(1), 153-161.

Razzaq, M. K., Aleem, M., Mansoor, S., Khan, M. A., Rauf, S., Iqbal, S., & Siddique, K. H. (2021). Omics and CRISPR-Cas9 approaches for molecular insight, functional gene analysis, and stress tolerance development in crops. *International journal of molecular sciences*, 22(3), 1292.

Ricketts, T.H., Regetz, J., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Bogdanski, A., Gemmill-Herren, B., Greenleaf, S.S., Klein, A.M., Mayfield, M.M., Morandin, L.A., Ochieng, A. & Viana, B.F. 2008. Landscape effects on crop pollination services: are there general patterns?. *Ecol Letters*. 11: 1121-1121.

Roberts, D. P., & Mattoo, A. K. (2018). Sustainable agriculture—Enhancing environmental benefits, food nutritional quality and building crop resilience to abiotic and biotic stresses. *Agriculture*, 8(1), 8.

Rubyogo, J. C., Sperling, L., Nasirumbi, L., & Kasambala, S. (2007, December). Developing seed systems with and for the marginalized: case of common beans (Phaseolus vulgaris L.) in East, Central and Southern Africa. In *Proceedings of Farmer First Revisited Conference, Sussex, UK* (Vol. 1214).

SAARC. (2014). Cooperation among Bangladesh, India and Nepal in Seed Sector Protocol of Discussion. SAARC Secretariat, Kathmandu, Nepal.

SAARC. (2017). Siem Reap Protocol of Discussion: Cooperation between Bangladesh, Cambodia, India, Nepal, and Sri Lanka in Seed Sector. SAARC Secretariat, Kathmandu, Nepal.

Sabiha, N. E., Salim, R., & Rahman, S. (2017). Eco-efficiency of high-yielding variety rice cultivation after accounting for on-farm environmental damage as an undesirable output: An empirical analysis from Bangladesh. *Australian Journal of Agricultural and Resource Economics*, 61(2), 247-264.

Saiyed, I. M., & Huda, M. N. (2011). Quality seed in SAARC countries. In Regional Workshop on Quality Seed in SAARC Countries: Production, Processing, Legal and Quality Control, and Marketing System (2009: New Delhi, India). SAARC Agriculture Centre.

Schaerer, H. (2012, October). Seed treatments for healthy vegetable seedlings. In *Cost action FA1105 meeting–organic greenhouse horticulture, state of the art and future trends* (pp. 15-17).

Schweiger, O., Biesmeijer, J.C., Bommarco, R., Hickler, T., Hulme, P., Klotz, S., Kühn, I., Moora, M., Nielsen, A., Ohlemuller, R., Petanidou, T., Potts, S.G., Pysek, P., Stout, J. C., Sykes, M., Tscheulin, T., Vilà, M.,Wather, G.R. & Westphal, C. (2010). Multiple stressors on biotic interactions: how climate change and alien species interact to affect pollination. *Biol Rev*, 85, 777-795.

Sharma, A., Badola, P. K., & Trivedi, P. K. (2021). CRISPR-Cas9 System for Agriculture Crop Improvement. *Genome engineering for crop improvement*, 97-111.

Sharma, S., & Vakhlu, J. (2021). Evolution and biology of CRISPR system: a new era tool for genome editing in plants. *The Botanical Review*, 1-22.

Shen, C., Que, Z., Xia, Y., Tang, N., Li, D., He, R., & Cao, M. (2017). Knock out of the annexin gene OsAnn3 via CRISPR/Cas9-mediated genome editing decreased cold tolerance in rice. *Journal of Plant Biology*, 60, 539-547.

Shi, J., Gao, H., Wang, H., Lafitte, H. R., Archibald, R. L., Yang, M., ... & Habben, J. E. (2017). ARGOS 8 variants generated by CRISPR-Cas9 improve maize grain yield under field drought stress conditions. *Plant Biotechnology Journal,* 15(2), 207-216.

Shrestha, R. B., & Thapa, Y. B. (2019). Policy and Program Priorities for Agricultural Research and Development in South Asia (P 1-29). SAARC Agriculture Center, Dhaka, Bangladesh, and Asia-Pacific Association of Agricultural Research Institutions (APAARI), Bangkok, Thailand, 376.

Singh, H. B. (2006). Trichoderma: A boon for biopesticides industry. *J Mycol Plant Pathol*, 36, 373-384.

Singh, H. B. (2014). Management of plant pathogens with microorganisms. *Proc. Indian Natl. Sci. Acad* 80(2), 443-454.

Singh, V., Upadhyay, R. S., Sarma, B. K., & Singh, H. B. (2016). Seed bio-priming with Trichoderma asperellum effectively modulate plant growth promotion in pea. International Journal of Agriculture, *Environment and Biotechnology*, 9(3), 361-365.

Teixeira, J. C., & Huber, C. D. (2021). The inflated significance of neutral genetic diversity in conservation genetics. *Proceedings of the National Academy of Sciences*, 118(10), e2015096118.

Tinivella, F., Hirata, L. M., Celan, M. A., Wright, S. A., Amein, T., Schmitt, A., ... & Gullino, M. L. (2009). Control of seed-borne pathogens on legumes by microbial and other alternative seed treatments. *European journal of plant pathology*, 123, 139-151.

Tomlins, K., Manful, J., Gayin, J., Kudjawu, B., & Tamakloe, I. (2007). Study of sensory evaluation, consumer acceptability, affordability and market price of rice. *Journal of the Science of Food and Agriculture*, 87(8), 1564-1575.

Trivedi, R. K., & Gunasekaran, M. (2013). Indian minimum seed certification standards. The Central Seed Certification Board, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi, 2013, 401-402.

Unnevehr, L. J. (1986). Consumer demand for rice grain quality and returns to research for quality improvement in Southeast Asia. American Journal of Agricultural Economics, 68(3), 634-641.

Varaprasad, K. S., & Sivaraj, N. (2010). Plant genetic resources conservation and use in light of recent policy developments. *Electronic Journal of Plant Breeding*, 1(4): 1276-1293

Vernooy, R. O. N. N. I. E. (2012). In the hands of many: a review of community gene/seed banks around the world. *Community Seed Banks in Nepal: Past, Present, Future*, 3-15.

Wang, L., Chen, L., Li, R., Zhao, R., Yang, M., Sheng, J., & Shen, L. (2017). Reduced drought tolerance by CRISPR/Cas9-mediated SlMAPK3 mutagenesis in tomato plants. *Journal of agricultural and food chemistry*, 65(39), 8674-8682.

Yamano, T., Arouna, A., Labarta, R. A., Huelgas, Z. M., & Mohanty, S. (2016). Adoption and impacts of international rice research technologies. *Global Food Security*, 8, 1-8.

Yuan, S., Linquist, B. A., Wilson, L. T., Cassman, K. G., Stuart, A. M., Pede, V., ... & Grassini, P. (2021). Sustainable intensification for a larger global rice bowl. *Nature communications*, 12(1), 7163.

Yuan, S., Stuart, A. M., Laborte, A. G., Rattalino Edreira, J. I., Dobermann, A., Kien, L. V. N., ... & Grassini, P. (2022). Southeast Asia must narrow down the yield gap to continue to be a major rice bowl. *Nature Food*, 3(3), 217-226.

Zeun, R., Scalliet, G., & Oostendorp, M. (2013). Biological activity of sedaxane–a novel broad-spectrum fungicide for seed treatment. *Pest management science*, 69(4), 527-534.

Zhan, X., Lu, Y., Zhu, J. K., & Botella, J. R. (2021). Genome editing for plant research and crop improvement. *Journal of Integrative Plant Biology*, 63(1), 3-33.

Zhang, A., Liu, Y., Wang, F., Li, T., Chen, Z., Kong, D., ... & Luo, L. (2019). Enhanced rice salinity tolerance via CRISPR/Cas9-targeted mutagenesis of the OsRR22 gene. *Molecular breeding*, 39, 1-10.

Zhou, J., Li, D., Wang, G., Wang, F., Kunjal, M., Joldersma, D., & Liu, Z. (2020). Application and future perspective of CRISPR/Cas9 genome editing in fruit crops. *Journal of integrative plant biology*, 62(3), 269-286.