Seed Quality: Variety Development to Planting—An Overview

S. Sundareswaran, P. Ray Choudhury, C. Vanitha, and Devendra K. Yadava

Abstract

The importance of availability of quality seed of high-yielding varieties in achieving food security has been recognized globally. The chapter presents an overview of the activities and requirements of seed production system globally, with an emphasis on quality, and highlights the linkages between variety development and seed production programmes. The seed development in angiosperm through the process of fertilization has been briefly touched and understanding the processes underlying pollination, fertilization, seed development, and maturation, which are vital for production of quality seed, has been highlighted. System of variety development and release, maintenance of variety purity during seed multiplication, and their importance have been enumerated to benefit those associated with any seed programme. Seed quality parameters including physical and genetic purity, physiological quality, seed vigour, and health, along with factors determining seed quality, have been presented in a holistic manner. Regulatory mechanism for seed quality assurance including steps in seed certification, seed testing and various field and seed standards has been outlined comparing the Indian system with other major international systems working globally. Procedures for seed health testing and application of advanced molecular marker technologies for varietal identity, genetic purity of seed and detection

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of seed-borne pathogens, which are becoming increasingly relevant in the present seed scenario, have been discussed. Fundamentals of seed processing for quality upgradation, and improvement of seed quality through enhancement technologies, have been explained. The chapter presents an overview of the importance of seed quality, its indicators, regulations, systems of development of varieties and their maintenance and use of modern tools and techniques for assurance and enhancement of seed quality.

Keywords

Seed quality · Variety · Standards · International organizations · Maintenance · Regulation · Enhancement · Seed testing

1 Introduction

Quality seed is the basic and most critical input for sustainable agriculture. The intensive efforts in plant breeding by the breeders in the public research institutions, international organizations (such as the Consultative Group institutions), private seed industry and farmers/farming community resulted in the development of a large number of new and improved crop varieties with high productivity, better resource use efficiency, varying levels of tolerance to biotic and abiotic stresses and specific quality traits which have played a vital role in enhancing the global food production ensuring food and nutritional security. The growth in food grain production and productivity in some of the developing economies, like India, has been remarkable with the adoption of modern plant breeding, development of high-yielding varieties (HYVs), and improved production and protection technologies, bringing its status from food-dependent to food secure in what is termed as 'Green Revolution'. The success of Green Revolution in India to a great extent is credited to linking crop improvement to the seed production system which led to 6.19 times enhancement in production of food grains, 3.30 times in pulses, 7.46 times in oilseeds, 10.31 times in cotton and 7.55 times in sugarcane since 1950. A clear-cut direct correlation between availability of good quality seed and food grain production can be witnessed. With the availability of 350,000 tons of quality seed during 1980–1981, the food grain production was 129.29 million tons, oilseeds production was 9.37 million tons and pulse production was 10.63 million tons whereas, with the availability of 4,836,600 quintals quality seeds, the food grains (310.74 million tons), oilseeds (35.95 million tons) and pulses (25.46 million tons) production have attained all time highest level (Agricultural Statistics at a Glance, DAC & FW, MA & FW, GOI, 2021, www.agricoop.nic.in, http://eands.dacnet.nic.in).

A synchronized development of the crop improvement programmes through All India Coordinated Research Programmes (AICRP) and public seed system, along with enabling policies and regulatory framework, coupled with the contribution of the private sector R&D in breeding and seed production, helped bring such a change. Similar approaches were also adopted successfully in many countries in the SAARC region, African continent and elsewhere. As a result, the demand for quality seeds of improved varieties is growing fast around the world (Tony et al. 2002). However, the production and distribution of seeds is a complex process involving breeders, seed technologists, farmers, growers, government agencies, research institutions, the private seed industry, the farmers' cooperatives and other stakeholders. Mostly the public organizations play a dominant role in the production and distribution of high volume-low value seeds of food security crops such as cereals, pulses and oilseeds, whereas, the private sector seed industry focuses more on high-value segments comprising vegetables, hybrids in field crops and other horticultural crops (Hanchinal 2017). Hence, the production and supply of high-quality seed of improved crop varieties to the growers have become a high priority in agricultural growth and development.

However, the lack of timely availability of quality seed of improved varieties, and also varietal mismatches at times (meaning that despite sufficient availability of seeds of a crop, requirements of the seeds of certain varieties in demands are not fulfilled), particularly in the developing world, is one of the greatest impediments in achieving the potential yields and production targets. Even with ideal conditions of soil, water, and climate, low-quality seeds compromise the proper plant stand, which would directly influence the productivity of the crop. In situations where plant population is drastically below the recommended stand, re-sowing increases the overall cost of production, besides the loss of the best sowing period, problems of herbicide efficiency, and risks of product overlapping (Asif 2016). All these factors contribute to low productivity. Hence, to approach the potentially realizable yield of a cultivar, production and distribution of required quantity of high-quality seed of improved crop varieties are critical. This depends on a thorough understanding of the processes underlying the seed biology from its formation to death; pollination behaviour and its management for production of genetically pure seeds; maintenance of variety purity; a sound system of quality assurance and upgradation, following seed regulations, appropriate quality evaluation procedures and enhancement technologies. This chapter intends to present a brief overview of the aspects that are vital for a sustainable seed system, while these are dealt in more detail in the succeeding chapters.

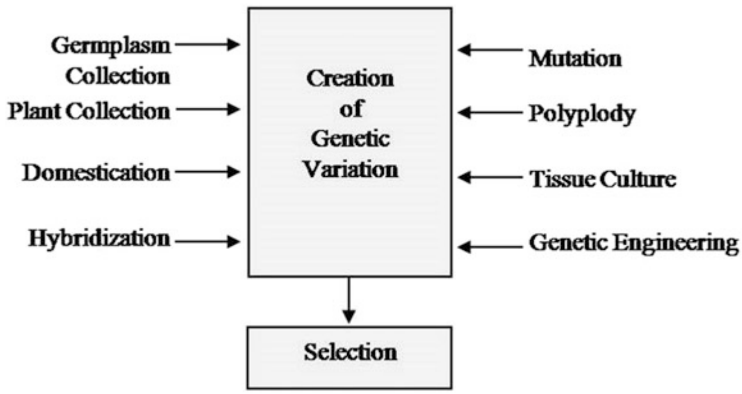
2 Seed Development

Seeds of the angiosperms develop as the result of a unique phenomenon called 'double fertilization' in which after the pollination pollen grains germinate on the stigma and the pollen tube carrying the two male gametes penetrate the embryo sac, wherein one male gamete fuses with the egg cell to produce the diploid embryo (zygote), while the other fuses with the polar nuclei to form the triploid endosperm (Maheshwari 1950; Raghavan 2005). A series of programmed cell divisions after fertilization, and differentiation results in the development of the miniature seed that undergoes several molecular, cellular and metabolic changes to mature into a fully functional and viable seed. The success of seed setting and development of healthy and vigorous seed is influenced by the genetic constitution, physiological status of the mother plant, and its interaction with the environment. Hence, understanding the processes underlying pollination, fertilization, seed development and maturation is vital in the production of quality seed (see chapter "Seed Development and Maturation" for details).

3 System of Variety Development, Release, and Notification

It is well accepted that a continuous flow of improved varieties is vital for the agricultural development of a country. The new improved varieties are bred by the breeders in public institutions, private seed companies, as well as those working independently following four major steps:

1. Selection of breeding lines, making a large number of crosses, and evaluation of the progenies.
2. Identification of promising genotypes.
3. Development of new strains and evaluation of their performance. Various breeding methods can be used for the development of new strains in self and cross-pollinated species as given below:



The value in cultivation and use (VCU) of new strains needs to be evaluated by crop specialists independently at several locations, following a set of performance criteria for a minimum period of 3 years, and simultaneously developing DUS characters, before considering their release for cultivation. Though the system of variety release/registration/notification recommended by the concerned official departments may differ in different countries, the common principles are as follows:

- The new varieties with desired attributes developed by the breeders are expected to be pure, homozygous (except for hybrids) and homogeneous (uniform in its expression), and having clearly distinguishing features.

- Varieties are tested for VCU, indicating its agronomic performance in different agro-climatic regions, including tolerance/resistance against major biotic and abiotic stresses specific to the crop species, and their performances are compared with the existing best checks and qualifying varieties in the test trials.
- Varieties showing improvement and advantage in performance over the existing ones are identified for release at the state (or regional)/national level. The identified varieties are considered for release and notification and also for registration as per extant guidelines of the country.
- In the EU and some other countries, VCU and DUS testing are to be performed simultaneously before release. However, in some countries, like India, the official release is not compulsory for the commercialization of a variety, though registration for VCU in the intended region for 1 or 2 years may be necessary.
- Whether officially registered/released or not, the breeder/breeding organization is responsible for maintaining a small quantity of pure seed stock (breeders' stock/ nucleus seed) for further multiplication.

Thus, the first criterion that determines seed quality is the homogeneity of the genotype (variety) and genetic purity of the source/stock seed (the Indian varietal evaluation and release system is described in chapter "Principles of Quality Seed Production"). The All India Coordinated Research Projects of different field and horticulture crops play a very important role in conducting VCUs at multiple locations in different agro-climatic zones specified for various crops/crop groups. This provides an inbuilt mechanism of early screening of the material for various biotic and abiotic stresses. Considering the diverse agro-ecologies in different parts of the country, plant varieties are released at central or state levels, while both are notified in the Gazette of India (Tandon et al. 2015; Virk 1998). Once a variety is registered or released for commercial use, it is the joint responsibility of the breeder/ breeding organization and the seed-producing agencies to take necessary measures to maintain varietal purity, which conforms to the genetic constitution of the variety, by applying a system of variety maintenance through the generations of seed multiplication. Seed Technology is the link between variety improvement and realization of such improvement by the growers/farmers following scientific methods of seed multiplication, processing and storage, and maintaining a high quality of seed.

4 Seed Production

Profitable production of high-quality and genetically pure seed requires adherence to a set of practices which are not only crop and climate specific, but also the genetic constitution of the variety in use. Thus, knowledge of the flowering and pollination behaviour of the species in question, i.e., self-pollinated, cross-pollinated or often-cross-pollinated; mode of pollination, requirement of supplementary aids to pollination by maintaining bee hives in the seed fields, etc.; and genetic constitution, i.e., whether it is a pure line, hybrid, clonally propagated or genetically modified variety, are vital for the success in seed production. Seed production of vegetable crops is fundamentally different from the field crops in many ways, which must be known well. Similarly, seed production of hybrids takes into account the mode of hybridization, whether based on the male sterility or self-incompatibility systems, or requires manual emasculation and pollination operations; the type of male sterility system operating, i.e., CMS, GMS, CGMS; the mechanism of restoration, etc., all of which are critical for undertaking seed production without compromising the genetic purity of seed (see chapters “Principles of Quality Seed Production”, “Vegetable Seed Production”, and “Principles of Variety Maintenance for Quality Seed Production” for more).

5 Variety Maintenance/Maintenance Breeding

The life of a released/registered crop variety may extend from 10 years (cross-pollinated species) to 20 years (self-pollinated species) or even more. As long as a variety is in active seed multiplication chain, its genetic constitution must be maintained unaltered. Every care is to be taken during maintenance of a variety to ensure that only ‘true-to-type’ plants are selected for seed multiplication and the progenies from such plants/ear heads/pods/panicle are further examined for their trueness before the next step of multiplication. Variety maintenance must be undertaken in its area of adaptation to minimize the influence of environmental stress. Repeated seed multiplication in unfavourable conditions of growth exerts abiotic and biotic pressure resulting in genetic drift causing deviations in the plant type. Sometimes some minute levels of residual heterozygosity may exist in the genotype at the time of release, which remains unexpressed in its phenotype. However, in successive generations, such plant progenies express deviation from the characteristics of the original variety. Similarly, even in self-pollinated species, there are chances of some cross-pollination resulting in genetic variation. Such impurities and off-types must be cleaned by following the procedure of maintenance breeding. Zeven (2002) defined maintenance breeding as ‘all breeding measures taken to conserve the genetic composition of a variety’. In case of varieties that are bred for special quality traits, such as erucic acid content in brassicas or gliadin profile in bread wheat, precise laboratory analysis is followed after table examination of the harvested pods/ears/seed/panicle. Molecular markers can be an effective tool, especially for maintaining the purity of varieties bred with genes for specific trait introgressed. Hence, maintenance breeding followed by the generation system of seed multiplication is the key to ensure varietal purity.

6 Seed Quality

Quality seed plays a vital role in the success of crop production (Singh 2011) as it

- ensures (physical) purity of the seed
- gives desired plant stand and ensures uniform growth and maturity

- enables the crop to withstand adverse conditions and responds well to fertilizer and other inputs
- produces vigorous, fast-growing seedlings that can withstand pest and disease incidence to a certain extent
- establishes well-developed root system that will be more efficient in the uptake of nutrients.

6.1 Physical Quality

The seed with good physical quality should have uniform size, weight and colour, and should be free from undesired materials like stones, debris, dust, leaves, twigs, stems, flowers, other crop seeds, weed seeds and inert material. It also should be devoid of shrivelled, diseased, mottled, moulded, discoloured, damaged and empty seeds (Du and Sun 2004). The quality seed should also be free from seed of other distinguishable varieties (ODVs) of the same crop (see chapters "Seed Processing for Quality Upgradation" and "Testing Seed for Quality" for more). Purity is maintained by field and seed inspections for maintaining standards, and adhering to the processing specifications. Hence, knowledge of seed morphology and identification of weed seeds are important. Purity testing and labelling are therefore, mandatory for quality seed.

6.2 Genetic Purity

Varietal purity is an essential quality requirement, which refers to the true-to-type seed, and is important in obtaining pure plant population of a specific variety. Varietal mixtures can cause uneven maturity, lower yield potential, increased susceptibility to disease and insect pests and poor adaptability to specific environmental conditions (Sendekie 2020). For all quality parameters, specific standards are set by the national and international authorities, which may vary to some extent from one country to the other. This is ensured by complying with the requirements and rules with respect to the source of seed for the specified class, conducting field inspections at specified stages, meeting the field and seed standards at production and processing, post-control plot test and laboratory tests (see chapters "Seed Development and Maturation" and "Role of Seed Certification in Seed Quality Assurance" for more).

6.3 Physiological Quality

Physiological quality determines the actual planting value of seed for cultivation. Physiological quality of seed comprises of two important attributes viz., seed germination and vigour, that determine the potential of the seed to germinate and establish well in the field under a wide range of growing conditions, with optimum population ensuring desired production. The ability of a dry viable seed to remain viable and germinate under favourable conditions is determined by its genetic constitution and modulated by external factors. The highest level of germination and vigour of mature seed undergoes gradual decline subsequently, till it becomes completely non-viable. In oilseeds like groundnut and soybean viability loss is fast if not stored under optimum conditions. Seeds in a lot vary with respect to their physiological status and hence, upon testing some seeds are capable of producing robust and normal seedlings, some produce abnormal or weak seedlings, and others may not produce seedlings at all. In some species, seeds are unable to germinate due to the phenomenon of dormancy. Hence, it is important to evaluate the ability of a seed lot to produce healthy and normal seedlings under favourable conditions by performing germination tests. Germination tests are conducted for a prescribed time period under laboratory conditions that ensure optimum moisture, temperature and light following the ISTA Rules for Seed Testing or as recommended by the other official procedures (see chapters “Seed Dormancy and Regulation of Germination”, “Seed Longevity and Deterioration”, and “Testing Seed for Quality” for more). Germination testing is one of the mandatory requirements for quality assurance in seed.

Since the field conditions at sowing are not always optimum for germination of seeds, assessment of seed vigour is advisable wherever a standard and reliable test procedure is available. Seed vigour not only influences the final plant stand, but also the rate of emergence, uniformity of emergence and post-harvest storability. Seeds low in vigour are more susceptible to biotic and abiotic stresses and would often produce weak seedlings, which have poor chance of survival under sub-optimal or fluctuating growth conditions (Sundareswaran et al. 2021). Vigour testing is applicable only to seed lots meeting the minimum prescribed germination, as all vigorous seeds will be germinable but all germinable seeds need not be vigorous (Finch-Savage and Bassel 2016). Hence, testing seed vigour is important for raising good crop, specially under less favourable or fluctuating conditions of growing, though this is not a mandatory test (see chapter “Seed Vigour and Invigoration” for more). There is need to standardize at least one reliable vigour test for all important food crops and vegetables.

6.4 Seed Health

Health status of seed determines the ability to raise a healthy crop and is determined by the absence of insect pests and pathogens borne on, or transmitted with the seed. The health status of seed also influences its storability and vigour. The causal organisms of designated diseases carried over from one generation to the other affect the growth habit, reproductive efficiency and cause drastic reduction in the seed yield. Hence, it is mandatory to perform appropriate and precise tests for detecting the presence and load of designated pathogens to meet the permissible limits. Several fungi such as *Phomopsis* spp., *Colletotrichum truncatum*, *Cercospora kikuchii*, *Fusarium* spp. and *Aspergillus* spp. are among the most frequently associated with seed quality. Besides detection of seed insect pests and pathogens during seed testing, equally important is to follow appropriate measures of seed health management during production and storage (see chapters "Seed Storage and Packaging" and "Seed Health: Testing and Management" for more).

7 Factors Influencing Seed Quality

The seed quality can be influenced by several factors occurring during the production phase in the field before harvesting, during harvesting, drying, processing, storage, transport and sowing. These factors include extreme temperatures during maturation, fluctuation of moisture conditions including drought and excess rains at maturation, weathering, plant nutrition deficiencies, occurrence of pests and diseases; improper handling, drying and storage (Cavatassi et al. 2010). Seed ageing or deterioration is a natural process over time that results from the interaction of cytological, physiological, biochemical and physical changes in seed causing reduction in vigour, germination and eventually leading to the loss of viability. The extent and rate of seed deterioration depends on species, storage environment, length of storage period and the initial quality of the stored seeds (see chapters "Seed Longevity and Deterioration" and "Seed Storage and Packaging"). Therefore, testing the quality of seeds stored for different lengths of time is important to determine the effect of ageing on seed quality (Finch-Savage and Bassel 2016).

8 Seed Quality Assurance

Quality of the seed can be assured and improved in the following ways:

1. Seed quality regulation
2. Seed quality maintenance
3. Seed quality upgradation and enhancement
4. Genetic improvement

Regulatory mechanism to control seed quality is an important component of the seed programme both for the domestic and international seed trade. Notwithstanding the differences in the seed legislations of different countries, most legislations follow the basic processes of

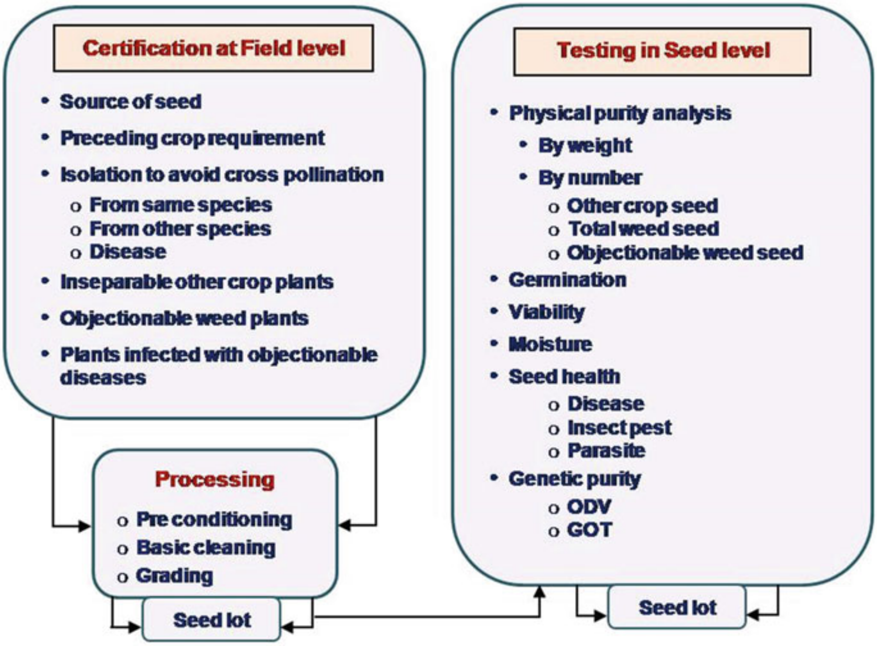
- Registration for multiplication
- Field inspection
- Seed sampling
- Seed testing
- Certification of the seed lot

The primary objective of seed legislation is to make sure that seeds should conform to the minimum prescribed standards of physical and genetic purity, seed health and germination either by compulsory labelling or certification. Further, an

Act provides a system for seed quality control through independent Certification agencies authorized or designated by the government department of agriculture. It also prescribes certain requirements to be complied by the persons/organization carrying out the business of selling seed. Labelling of each class of seed is distinguished by a specific tag/label of a certain colour and dimension. In countries such as India, the USA and many others, where certification is not compulsory, labelling of any notified kind of variety of seed is made compulsory. This category is known as Truthfully labelled/Labelled seed (TL seed), which should maintain the same quality standards as that of CS (see chapter "Role of Seed Certification in Seed Quality Assurance" for more).

9 Seed Certification and Quality Testing

During seed certification, which is the key to seed quality control, the following steps for verification of field standards and laboratory analysis for seed standards are followed in India before the grant of the certificate.



The principles are broadly similar in other countries, though there could be some procedural differences. The Indian Minimum Seed Certification Standards (IMSCS) updated in 2013 cater to the needs of domestic seed certification system and also satisfy many requirements of OECD rules and directions for field inspection to ensure varietal identity and purity. These include both field standards and seed standards (see chapters "Principles of Quality Seed Production" and "Role of Seed Certification in Seed Quality Assurance" for more).

10 Role of International Organizations

The following international organizations are involved in the promotion of quality seed production, testing, certification and trade at the international level (see chapter "Role of Seed Certification in Seed Quality Assurance" for more).

1. International Crop Improvement Association (ICIA): It is an organization of seed certification agencies in the USA and Canada which was changed to the Association of Official Seed Certifying Agencies (AOSCA) in 1969 and is responsible to establish minimum standards for certification in the USA, promote production, identification and distribution of seed and educate seed growers.
2. International Seed Testing Association (ISTA): ISTA is an international network of member laboratories which promotes 'uniformity in seed quality evaluation'. Through the participation of member laboratories and Working Groups under the technical guidance and approval of the Technical Committees, it develops standard procedures for sampling and testing of seed after multi-laboratory testing and validation. The ISTA rules describe the principles and standard procedures for sampling, testing and reporting of results. It also accredits member laboratories after verifying their technical competence and proficiency in conducting various tests. It promotes research, organizes training for capacity building and disseminates knowledge in seed science and technology. This ensures seed quality and facilitates national and international seed trade. ISTA-accredited laboratories are authorized to issue orange and blue international seed analysis certificate which supports global seed trade (Masilamani and Murugesan 2012).
3. Organization for Economic Cooperation and Development (OECD): Develops certification system for international trading acceptable for member countries. Despite the existence of a number of regulatory bodies, whose objective is to harmonize regulations and encourage regional or international seed trade, there are still considerable differences in the seed laws and regulations governing the national and international seed system (Cortes 2009). These differences restrict the seed trade between countries. Hence, there is a need for defining, endorsing and enforcing minimum criteria for the International seed trade. The OECD Seed Schemes prescribe a set of procedures, methods and techniques for certifying the variety identity, purity and quality standards, which are applicable to the varieties from the member countries included in the OECD list under its seven schemes. It provides legal framework for the certification of the movement of seeds in the international trade.

   The schemes ensure the varietal identity and purity of the seed through appropriate requirements and controls through the production, processing and labelling operations. The OECD certification provides for official recognition of "qualityguaranteed" seed, thus facilitating international trade and contributing to the removal of technical trade barriers (Rajendra Prasad et al. 2017). The National Designated Authority (NDA) may issue certificates for each lot of Pre-Basic seed (White label with diagonal violet stripe), Basic seed (White label), Certified seed (C1—Blue label; C2—Red label), Not Finally Certified seed (Grey label) and Standard seed (Dark yellow label) approved under the Scheme.

4. International Plant Protection Convention (IPPC) is a multilateral treaty that promotes effective actions to prevent and control the introduction and spread of pests of plants and plant products. It allows countries to evaluate the risks of their plant resources and promote use of science-based measures for their safety. Implementation of this convention is based on the exchange of technical and official phytosanitary information among member states and adoption of the International Standard for Phytosanitary Measures (ISPM) that is crucial in the international seed movement.

11 Seed Quality Maintenance

Seed quality can be maintained by the following measures:

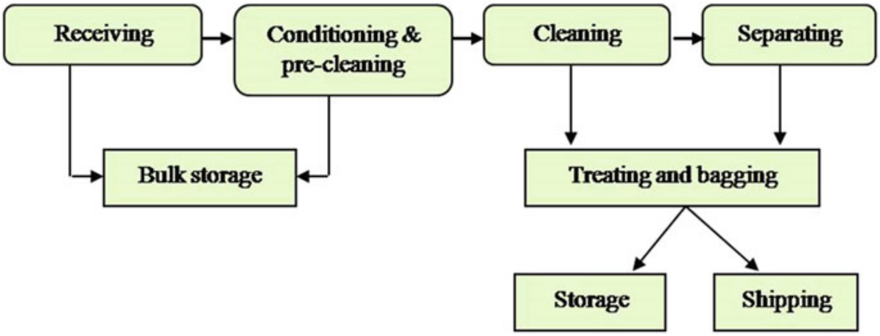
1. Seed production under suitable environment
2. Adoption of proper harvesting and post-harvest management techniques
3. Efficient and effective quality control procedures
4. Use of advanced storage techniques

Among the various environmental factors, moisture and temperature stress have direct influence on reproduction. Early reproductive processes like pollen and stigma viability, anthesis, pollination, fertilization, and early embryo development are all highly prone to moisture stress and/or temperature stress. Failure of any of these processes increases early embryo abortion, leading to lower seed setting, thus limiting the seed yield. Harvesting seed crop at the right stage of maturity, using proper methods of drying and post-harvest handling, and safe storage are important to maintain vigour and viability of seed.

12 Seed Quality Upgradation

A seed lot can be upgraded by the removal of defective and poor-performing seeds to the extent that is practical and economical. In the commercial seed system, good quality seeds are referred as accept fraction, while low-quality seeds are considered as reject fraction of the seed lot. Application of too stringent norms may reduce the economic seed yield, whereas laxity in these will lead to poor quality seed. This makes seed processing a highly specialized activity, which can be effectively performed by taking into consideration parameters which are specific to the seed morphology, structure and composition of the species.

Seed processing narrows down the level of heterogeneity of the harvested seed lot and improves the physical purity of the seed lot by eliminating the undersized, shrivelled, immature, ill-filled seeds using appropriate methods of separation and fine cleaning. The germination and vigour of the seed lot can be improved by grading the seeds based on size, specific gravity, length and density of the seeds (see chapter "Seed Processing for Quality Upgradation" for more). Copeland and McDonald (1995) proposed the following basic steps in seed processing for upgrading the quality of seed lots, which is followed with some modifications as per the specific needs:



13 Genetic Improvement for Seed Quality

Varietal improvement through plant breeding harbours desirable traits by broadening the genetic base through combination of desired genes/alleles, which increases the farm productivity, improve quality, genetic diversity in agro-ecosystems, and thus ensures sustainable food production systems under the climate change scenario. Emphasis is given to breed crops for improvement in yield, quality, adaptability, abiotic and biotic stress resistance, synchronized flowering and maturity, and amenability to mechanical operations. Genetic improvement can also be targeted to increase seed quality traits in many ways by

- Facilitating the maintenance of physiological quality of seeds by increasing their inherent resistance or tolerance to factors which are responsible for seed deterioration, such as seed coat characteristics
- Selecting for inherent physiological or physical properties which contribute to better seedling vigour
- Selecting for longer viability in breeding lines
- Selecting strains performing well under biotic and abiotic stress conditions and exhibiting tolerance to climate change.

14 Seed Quality Enhancement

Seed enhancement is defined as post-harvest treatments that improve germination or seedling growth, or facilitate the delivery of seeds and other materials required at the time of sowing (Taylor et al. 1998). Seed quality enhancement through advanced technologies of coating, pelleting, time and target-oriented seed additives, electron treatment, magnetic treatment, and plasma coating are used for improved performance and better adaptability to biotic and abiotic stresses. Use of third-generation seed quality augmentation strategies viz., nanotechnology for external as well as internal designing of seeds and bio-priming technology, offers enhanced seed performance for eco-friendly and safer agriculture (see chapter "Seed Quality Enhancement" for more).

15 Scope of Molecular Technologies

With the advancement in breeding technologies and expansion of global seed trade, more precise, rapid and reliable diagnostic tools and techniques are needed for variety identification and genetic purity testing, establishing distinctiveness among closely related varieties, seed health testing, assessing the trait purity in GM varieties and detecting adventitious presence of GM seeds, and maintenance of breeding lines. Hence, cost-effective molecular technologies with greater accuracy need to be standardized for assessment of various parameters of seed quality (see chapter "Molecular Techniques for Testing Genetic Purity and Seed Health" for more).

Characterization of released varieties for seed traits like seed viability, longevity and seed dormancy is poorly documented. This information is much required for better seed multiplication, timely harvesting and safe storage. With the advancement of new molecular technologies, different seed quality traits need to be identified to undertake breeding programmes to improve the cultivar performance under variable conditions, uniform maturity; no/low seed shattering; prolonged seed longevity; intermediate or controlled seed dormancy; improved seed coat permeability, etc. Seed quality testing and detection of GM seeds is an area which needs more attention and can be better addressed through molecular tools. Likewise, the genome editing products are also likely to be available for general cultivation in the times to come. Issues of seed quality of gene-edited varieties will be addressed through the existing seed system. The use of molecular tools for genetic purity and implementation of seed traceability will be the two landmark developments during the current decade which will revolutionize the seed systems by ensuring the seed quality.

The role of seed biology on seed production and performance, importance of production and post-production management to achieve highest quality standards, its maintenance through storage and improvement of performance by various seed enhancement technology, testing seed quality using appropriate standard protocols including seed health testing, and application of molecular technologies for precision in quality assessment have been discussed at length in different chapters, along with the regulatory mechanisms for seed quality assurance in different systems.

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