Role of Seed Quality in Improving Crop Yields

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Abstract Despite being an important source of food and feed, seeds are essentially an important delivery system of genetic information. Seed quality is a crucial determining factor of yield and quality of crop production. Good quality seed is superior to other standard seed in genetic and physiological purity and is free from seedborne diseases and disorders. The quality of the seeds is determined by the interaction of a number of genetic and environmental factors and climatic changes significantly affect seed characteristics. Production of better quality seeds in an effective and efficient manner is a challenge for increasing food demand. Seed quality is a complex trait and novel research approaches to improve seed quality involve a combination of seed technologies, genetics, and molecular biology. Some of the classical methods of seed improvement include coating, pelleting, priming, and production of artificial seed. Development of hybrid seed varieties that adapt to unfavourable climatic conditions and are resistant to a range of pests and diseases are at the forefront of the seed industry in improving crop yield. Hybrid seed varieties of rice, wheat, corn, barley, soybean, and diverse field crops are commonly used in various regions of the world for enhanced crop yield. Modern gene technology methods are being used to modify (GM) crops/seeds genetically to carry one or more beneficial traits such as herbicide and insect resistance, better resistance to drought/waterlogging, and modified nutritional profiles. Research on genetics of seed development and chemistry of seed reserves is an essential need in developing new technologies for crop improvement. The key challenge ahead is the identification and incorporation of beneficial genes and traits into elite cultivars, and development of new approaches to producing GM crops to minimise regulatory constraints and increase consumer acceptance.

Keywords Seed quality • Climate change • Seed improvement • Hybrid seeds • Genetic modification

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1 Introduction

Seed is a unique and fundamental entity that stores genetic information for the consequent life cycle of a plant. As vital propagating units, seeds play a very important role in crop production and human sustenance. Irrespective of the crop species, agricultural region, and growth season, use of good quality seeds ensures a good yield (Bradford and Bewley 2002). Good quality seed is superior to other standard seed in characteristics such as genetic purity, which include high and even germination rates, uniform growth pattern, physiological purity illustrated by viability and vigour and good health that ensures seeds are free from seedborne diseases and disorders. Other aspects include uniform size, shape, colour, texture, weight, freedom from other crop and weed seeds, insects, and devoid of other undesirable substances (Basra 1995; Seeds (2014) http://www.agriquest.info/; Seed Enhancement (2014) http://www.seedquest.com/keyword/seedenhancement).

In nature, numerous genetic and physical factors are responsible for determining the quality of seeds. Genetic factors that influence quality include genetic makeup and age and nutritional status of the mother plant. Environmental features such as temperature, water status, photoperiod and light quality, soil nutrition at seed setting and development, and physical factors such as injury and damage during planting, establishment, and storage as well as moisture and temperature during storage contribute to a large extent to seed quality. Interaction of genotype and environment ultimately determine the status of the seeds (Bradford and Bewley 2002; Nambara and Nonogaki 2012; Finch-Savage and Leubner-Metzger 2006; Seeds (2014) http://www.agriquest.info; Seed Technology (2014) http://www.seedbiology.de).

There are many advantages to using good quality seeds in agriculture, the utmost advantage being the full exploitation of the genetic potential of the crop providing high return per unit area. The other benefits include the ability of adapting to extreme growth and climatic conditions, higher degree of resistance to pests, diseases, and weeds, uniformity in plant growth, and maturation allowing easy harvesting and postharvest handling and high market value (Bradford and Bewley 2002; Nambara and Nonogaki 2012; Seeds (2014) http://www.agriquest.info; Seed Technology (2014) http://www.seedbiology.de). In brief, good quality seeds are the basic source of a secure food supply.

In many regions, especially in developing countries, famers do not have access to good quality seeds for a number of reasons, including insufficient seed production, the unavailability of quality-checked seeds, inefficient distribution, lack of seed certification methods, and higher seed prices (Seeds (2014) http://www.agriquest.info; Seed Testing International (2014) http://seedtest.org/en/seed-testing-international). The Food and Agriculture Organization (FAO) plays an active role in determining guidelines in seed quality assurance that guarantee the quality of seed from production, harvesting, and postharvest handling until delivery to the farmer (Seeds (2014) www.fao.org/seeds).

With the understanding of seeds as basic and crucial input for increased productivity and profitability, considerable effort has been made to improve seed quality and develop new varieties and hybrids by plant breeding and biotechnology methods.

Over the past years, seed companies contributed to enhancing crop production by utilising seed genetic traits such as insect and pest resistance, water-use efficiency, and higher yields in genetic engineering and breeding programmes.

This chapter encompasses the factors affecting seed quality, methods of seed enhancement, and recent advancements in breeding and biotechnological approaches in improving seed quality for better yield.

2 Impact of Climate Change on Seed Production

Climate change is one of the key problems in agriculture and hence global food security. The major challenges to crop production are global warming, severe and frequent drought and floods, pollution of air and soil, and higher pressure from pathogens. Devastating effects of climate change in agricultural production over a range of crop species have been reported from all over the world (Seeds (2014) http://www.agriquest.info; Seeds (2014) www.fao.org/seeds). Seed quality is significantly affected by climatic changes. Aspects ranging from flower characteristics, pollen viability and pollination, seed setting, length of the seed-filling duration, seed size, dormancy and nutritional profiles, and ultimately the seed quality are considerably influenced by climatic factors. The other climatic change impacts on quality seed production include the changing crop–weed interactions, altered population dynamics of pests, including evolution of new races of pests, changing the status of disease development, diminishing pollinator biodiversity and genetic diversity (Walck et al. 2011; Singh et al. 2013).

The world's food consumption mainly relies upon the seeds of wheat, rice, maize (corn), barley, and sorghum. These grain crops are largely vulnerable to climatic changes, especially global warming and prolonged dry periods. The major impacts on climate change will be on rain-fed farming, especially in Asia and Africa and drought conditions are predicted to affect cereal production dramatically, risking a loss of about 280 million tons of production (Singh et al. 2013).

Warming in terrestrial ecosystems has a pronounced effect on agriculture in every region of the world. In many plant species, increase in temperature results in a decline in the seed number per fruit, reduced seed size, and altered seed physiological conditions (Martínez-Andújarl et al. 2012; Singh et al. 2013). According to the present predictions of rising temperatures, by 2030, rice and maize production in South Asia will have declined up to 10 % and maize production in Southern Africa will have dropped by 30 % (Lobell et al. 2008). Research findings of the International Rice Research Institute (IRRI) indicate that temperatures above 35 °C for more than one hour during flowering cause sterile flowers and consequently produce no grain. According to IRRI forecasts, increased temperature leads to a 20 % reduction in rice yield and a higher night-temperature also causes a decline in production by 10 %. This yield loss has a significant effect on food security in the world, especially in Asia where rice is the staple food (Hybrid rice (2014) www.irri.org/our-work/research/rice-and-the-environment).

Wheat is an essential source of food for a large population of people and it is grown over a wide range of environments. Rise in temperature during the growing season considerably lowers the yields (Asseng et al. 2011). For example, in a study in main wheat-growing regions of Australia, up to 50 % reduction in yield was observed by temperature elevation of ±2 °C during the grain-filling stage. Warmer temperatures prevailing in several regions of the United States during the past few years resulted in faster growth of wheat and corn, reducing the time for the seeds to mature, and subsequently causing reduced yields (Karl et al. 2009). Using a number of crop simulation models, it has been predicted that future climatic projections have a remarkable effect on wheat yield in many agro-ecological zones of the world (Kang et al. 2009).

Maize (corn) species are grown in diverse agro-ecological regions and are a very important staple food in sub-Saharan Africa (SSA) and in many countries in Latin America. Maize production in Africa is badly affected by occasional droughts and increased temperature during flowering and grain-filling time (Maize (2014) http://www.iita.org/maize). Cowpea is an important food crop in many African and Asian countries. Although it is considered as a drought-resistant crop, farmers of SSA face substantial yield losses due to frequent drought conditions (Cowpea (2014) http://www.iita.org/cowpea).

Apart from grain production, much of the other important crop productions are affected by increasing atmospheric temperature, prolonged drought periods and variation in rainfall pattern, and increasing CO_2 concentration (Reddy and Hodges 2000; IPCC 2007). For example, coconut, one of the very important crops in many Asian regions is adversely affected by climatic changes. Long dry spells associated with high temperature result in low nut setting and fruit components. The Coconut Research Institute of Sri Lanka has reported that climatic change is especially sensitive in coconut inflorescence development from primordial initiation to button nut formation (Ranasinghe 2011).

3 Seed Technology and Development of Improved Seeds

Seed technology is described as the methods through which the genetic and physical characteristics of seeds could be improved. It is a multidisciplinary science that includes the processes of variety development, seed production, processing, storage, certification evaluation, and release (Feistritzer 1975). A great deal of attention has been paid to seed improvement by exploring diverse and emerging new technologies ranging from physical seed enhancement, classical and modern breeding, molecular biology, proteomics, metabolomics, and translational biology. Seeds are invaluable carriers of favourable traits from generation to generation and in seed production stringent attention is given to maintain genetic purity and exploit its potentiality in the next generation. Climatic change is a key concern in the seed improvement process and emphasis is paid in integrating stress-adaptive traits by breeding programmes and genetic modifications. Today, seed companies play a leading role in research on producing high-quality seeds of high-yielding varieties. Almost every important crop species in the world today is produced through improved seed varieties.

4 Seed Enhancement

Seed quality enhancement processes comprise the use of physical methods such as seed priming, seed coating, and artificial seed development, classical and modern breeding, and gene technology. These technologies enhance physiology, quality, vigour, and synchronicity of seed establishment and growth under diverse environmental conditions (Halmer 2004; Seed Technology (2014) http://www.seedbiology.de). Environmental parameters as well as plant hormones and growth regulators essentially control seed germination and subsequent growth. In certain seed improvement processes, manipulation of gibberellins, abscisic acid, ethylene, auxin, cytokinins, and brassinosteroids is done.

4.1 Mechanical Seed Enhancement

Rubbing off the seed/fruit coat and polishing followed by sorting of seeds into size classes or densities are some mechanical techniques that improve seed quality. For example, in sugar beet fruits polishing removes projections and hairs that enhance germination (Seed Technology (2014) http://www.seedbiology.de).

4.2 Seed Coating and Pelleting

Seed coating is a method of improvement of seed quality and seedling performance through treatment with plant protection products such as fungicides, pesticides, insecticides, growth stimulants, and nutrients followed by coating with synthetic polymer often with a colour (Ehsanfar and Modarres-Sanavy 2005; Mastouri et al. 2010). This technology offers many benefits including protection from pathogens and pests by precise and even distribution of agrochemicals, and increased shelf life; polymers adhere tightly to the seed and prevent loss of coated material and reduce exposure to dust and other substances, with ease of handling because of increased seed size, higher visibility in the field, and product identification (Ehsanfar and Modarres-Sanavy 2005; Seed Technology (2014) http://www.seedbiology.de). Some film coating techniques are used to modify imbibitions and germination. In seed pelleting, a thick covering is added to seeds to cover irregular seed shapes and to fix plant protection agents/hormones to the pellet matrix. The increased size of the pelleted seeds has the advantage in planting features such as use of machines for sowing seeds, precise placement, and visibility on soil. This method is especially important in small horticultural seeds such as sugar beet and vegetable seeds (Seed Technology (2014) http://www.seedbiology.de; Seed Enhancement (2014) http://www.seedquest.com). Today, a variety of crop seeds improved with the method has been released to the market. A few examples are namaticide-treated corn, cotton, and soybean; systemic insecticide coated wheat and corn seeds; aphid control of vegetable seeds; and controlled release of plant-protecting materials from smart seeds of wheat, corn, and canola (Ehsanfar and Modarres-Sanavy 2005; Seed Testing International (2014) https://www.seedtest.org).

4.3 Seed Priming

Seed priming is a seed quality enhancement method used to increase the rate of germination and uniformity and overcome seed dormancy. It is the most important physiological seed enhancement method by allowing controlled imbibitions and induction of the pregerminative metabolism (Jisha et al. 2013; Seed Technology (2014) http://www.seedbiology.de). Priming solutions can be supplemented with plant hormones or beneficial microorganisms. The standard method is osmopriming in which seeds are incubated in a well-aerated solution of low water potential and subsequently washed, dried, and planted in the regular manner (Seed Technology (2014) http://www.seedbiology.de). Use of primed seeds has a great advantage in adverse conditions in the field such as cold or warm soils and high temperature. There are several examples describing the beneficial effect of seed priming on germination and establishment of a variety of crop species (Jisha et al. 2013). Rice cultivars primed with water and polyethylene glycol (PEG) show significant impact on germination indices, seedling quality, and better tolerance to drought stress (Sun et al. 2010). On-farm seed priming practised for wheat, rice, maize, sorghum, millet, and cowpea in the dry zones of many Asian countries has facilitated fast and vigorous seedling growth subsequently leading to increased crop yields (Harris 2001; Chivasa et al. 2001). For legume crops inoculation of seeds with Rhizobia bacteria is done to increase the process of nitrogen fixation (Seed Enhancement (2014) www.seedquest.com).

4.4 Synthetic Seeds

Synthetic seeds comprise artificially encapsulated somatic embryos, shoot buds, cell aggregates, or any other tissue that has the ability to produce a complete plant (Gray and Purohit 1991; Redenbaugh 1993). Important features of synthetic seeds are large-scale propagation method, genetic uniformity of plants, direct delivery of propagules that eliminate transplanting, and relatively higher multiplication of plants (Seed Technology (2014) http://www.seedbiology.de; Synthetic Seeds (2014) http://www.agriquest.info/index.php/synthetic-seeds). This technique is especially beneficial when seed propagation is not successful, no seeds are formed, or when a certain species produces only a reduced endosperm (Ravi and Anand 2012). There are a number of other advantages such as germplasm conservation, product uniformity, and easy handling during storage, transportation, and planting (Ravi and Anand 2012). However, the exact application of synthetic seeds will vary from species to species. Synthetic seeds are commonly produced in coniferous forest species, cotton, soybean, vegetables including tomato, forage grasses, and in autogamous species such as wheat, barley, and oat in which hybrid seed production is costlier (Ravi and Anand 2012; Synthetic Seeds (2014) http://www.agriquest.info/index.php/synthetic-seeds).

5 Plant Breeding and Hybrid Seed Production

During crop domestication over a long period of time, seed traits have been modified through selection. Most of these selections led to favourable seed traits for agricultural benefits (Martínez-Andújarl et al. 2012). Breeding for improved seeds is a foremost approach in agriculture. Drought, heat tolerance, and pest/pathogen-resistance are the major traits in focus in breeding programmes of crops, vegetables, and fruits. Some of the new methods integrated into breeding programmes include marker-assisted selection methods and quantitative trait loci (QTL) analysis (Birch et al. 2011).

A hybrid is produced by crossing two genetically dissimilar parents. Pollen from the male parent will pollinate, fertilise, and set seeds in the female to produce F1 hybrid seeds. The improved qualities of the F_1 generation are referred to as “hybrid vigour” or “heterosis” and are often superior in yield, disease resistance, and more efficient in use of soil nutrients and weed control. It is of prime importance to ensure that parent lines have high genetic and physical purity to obtain the best quality F_1 seeds. Different methods are being employed in producing hybrid seeds in different crops (Dale 1994; Heffner et al. 2009).

Significant efforts in breeding conventional varieties and hybrids in rice have been made. Today, world rice production mainly relies on hybrid rice. In the past, hybrid rice production was limited because of the self-pollination character of rice. In 1974, a group of Chinese researchers transferred the male sterility gene from wild rice to create the cytoplasmic genetic male-sterile (CMS) line and hybrid combination (FAO 2004). Use of hybrid rice cultivation significantly increased and in China, the area under hybrid rice was 50 % of the total rice area in 1995 (FAO 2004). FAO statistics show that hybrid rice significantly increased yields by 15–20 % more than the improved varieties and also it performed well in unfavourable soil and climatic conditions (FAO 2004). In Egypt, hybrid rice produced higher yields than conventional rice varieties in saline soils (FAO 2004). To date, a large number of hybrids have been released to different countries (Rice and the Environment (2014) www.irri.org). Over the past years, FAO, IRRI, the United Nations Development

Programme (UNDP), and the Asian Development Bank (ADB) have provided strong and consistent support to improving hybrid rice breeding (Rice and the Environment (2014) www.irri.org).

Wheat is a critical crop for much of the world's population and the demand for wheat production increases with population growth. Increasing wheat yields is a major concern to meet the food challenge. World wheat production is also heavily dependent on the hybrids that have heterosis in grain productivity, grain-filling rate, increased plant height, well-developed root system, greater tolerance to a variety of stress conditions, and increased straw mass (Hybrid Wheat (2013) http://www.hybridwheat.net). Yield consistency is a major advantage apart from the yield potential from which farmers of some regions benefit. Some hybrid wheat varieties have 15 % increases in yields compared to conventional wheat even in more stress conditions (Hybrid Wheat (2013) http://www.hybridwheat.net). Hybrid wheat production programmes need a series of tedious technological processes that change floral development and architecture such as male sterility to impose out-crossing (Whitford et al. 2013). To block self-pollination and maintain male-sterile parent by a recessive system is recently being described as an improved method of producing hybrid wheat (Kempe et al. 2014). Several new hybrids were created and a great deal of research into wheat hybridisation was initiated in the 1970s–1990s throughout the world, mainly in the United States, Australia, and Europe. However, at present only a few companies are pioneers in hybrid wheat production (Hybrid Wheat (2013) http://www.hybridwheat.net). Today hybrid wheat is grown on 600,000 acres across Europe, and most commonly grown across whole farms in France (Hybrid Wheat (2014) www.bcwagric.co.uk). Wheat farmers in India profited by the introduction of hybrid wheat varieties that have high adaptability to grow in semi-arid zones of India (Matuschke and Qaim 2006).

Corn is an important crop worldwide next to wheat. In many African and Latin American countries, it is an important food source whereas in other countries most of the corn production is used in livestock and poultry feed. Corn seed is a cross-pollinating variety and pollinated by wind. One of the greatest concerns in hybrid corn seed production is genetic purity. Commonly, hybrid seed production is done by creating male sterility. In general, hybrid corn produces up to 30 % increase in yields per acre compared with conventional varieties. In the United States 95 % of the corn acreage is under hybrid corn, producing 20 % or more corn on 25 % fewer acres than in the 1930s. Some other beneficial aspects of the hybrid strains are consistently larger and better formed ears than those produced by ordinary methods, stronger stalks and roots, allowing the plant better to resist toppling by the wind, and the plants are more adapted to conditions such as drought, dampness, or cold. Most of the hybrid corn types are designed to mitigate yield loss in drought conditions (Corn Seeds (2014) http://www.monsanto.com).

In the world cereal crops, barley was ranked fourth both in terms of quantity produced and area under cultivation (FAOSTAT 2007). Barley is a widely adaptable crop, especially to drought conditions, and has a short growing season. Commercialisation of barley seeds came relatively later than other crop species and today farmers benefit from hybrid barley which has important characteristics such as higher yield combined with yield stability and improved grain quality and adaptation to severe winter conditions (Ullrich 2010). Rye, which is closely related to wheat and barley, is grown extensively as a grain and as a fodder. Hybrid rye is drought tolerant and absorbs soil nutrients more efficiently and therefore has a tremendous value in drought-prone regions and wider range of soil types. Hybrid rye also has good foliar disease resistance and vigorous growth (Forage Rye (2014) http://www.elsoms.com). Cowpea is an important food legume in the tropics. There are several cowpea varieties and a considerable amount of effort has been made on producing hybrid cowpea strains in order to get higher yields from water-limited regions. However, the breeding programme carried out under controlled conditions has proved to be less successful in developed cowpea intraspecific F1 hybrids (Lelou and Van Damme 2006). Sorghum is a grain species used as a food source in some countries especially in Africa, and it is widely grown for animal feed in other countries. Seed industries have developed several sorghum hybrids that are drought tolerant and tailored to localised high yields (Sorghum Hybrids from DuPont Pioneer Can Boost Your Yields (2014) https://www.pioneer.com; Sorghum (2014) http://www.monsanto.com). Soybean is a legume grown as a food or for livestock. Hybrid soybeans have been developed that are able to adapt to various climate conditions and are now grown largely in many states of the United States and in South America (Soybean seeds (2014) http://www.monsanto.com).

Apart from main crop species, hybrid seeds are used widely in potato, canola (rap), sugar beet, and many vegetable and fruit species that have better characteristics mainly in terms of enhanced yields.

6 Genetic Modification

Modern gene technology methods are being used to enhance crops/seeds genetically to carry one or more beneficial genes and traits. The first genetically modified (GM) crop developed through the use of transgenic methods and approved for cultivation was the 'Flavr Savr' tomato in 1994 in the United States(Krieger et al. 2008). The major commercially grown GM crops have the traits of herbicide and insect resistance, better resistance to drought environment, modified nutritional profiles such as improved amino acid composition of maize, improved fatty acid composition of maize and soybean, and modified starch in maize and potato (http://www.worldseed.org).

This technology is developing much faster today and many of the seed companies are producing and marketing GM seeds of a variety of crops, vegetables, fruits, and flower species. In the year 2012 an unprecedented hundredfold increase in biotech crop hectarage from 1.7 million hectares in 1996 to 170 million hectares was observed indicating biotech crops as the fastest adopted crop technology in recent history (ISAAA Brief 44 2012). From 1996 to 2011, biotech crops contributed to food security by increasing crop production valued at US$98.2 billion (ISAAA Brief 44-2012). For GM crops, certain strict scrutiny and biosafety regulations apply before releasing and growing in mass scale to prevent any potential hazardous effects to the consumers and environment.

Genetic engineering has been used successfully mostly to create transgenic rice for better biotic and abiotic stress tolerance and enhance the nutritional quality thereby to overcome the limitations of conventional rice breeding (FAO 2004; FAO Factsheet (2004) http://www.fao.org/rice2004). Advances in genomics and DNA marker-assisted selection processes have been used to improve yields. However, biosafety issues and public perceptions play key roles in further progress of the use of biotechnology in GM rice production. In the past few years IRRI has developed and distributed rice varieties with better tolerance to drought, submergence, cold, and salinity. Several QTLs that give drought tolerance in rice have been identified and introduced into high-yielding varieties (Hybrid rice (2014) http://irri.org/our-work/research/better-rice-varieties). Three QTLs that link to cold tolerance have been identified and introduced into desirable spikelet fertility and early maturity traits that finally resulted in promising cold tolerant lines (Hybrid rice (2014) http://irri.org/our-work/research/better-rice-varieties). These varieties are valuable resources for China and Korea where a considerable yield loss due to low temperature is recorded. A region of rice genome responsible for salt tolerance 'Saltol' has been used to develop salt tolerant varieties during the seedling and reproductive stages of the plant. Submergence tolerance varieties were developed with overexpression of the SUB1 gene which confers resistance to submergence up to 14 days. IRRI has shown that the SUB1 and Saltol can be combined in a high-yielding variety to increase tolerance to salinity and submergence. Development of some improved varieties that tolerate a high concentration of iron in the soil is an achievement in the use of biotechnology and breeding. In addition, considerable research efforts have been made to develop disease, insect, and herbicide resistant rice. Genetic engineering of rice varieties with Bt toxin genes is one of the most commonly known and firstly developed type of insect-resistant rice. Herbicide-resistant rice varieties have been developed by the chemical mutagenesis method. This variety 'Clearfield rice' is resistant to acetolactate synthase-inhibiting herbicides such as imidazolinone. LibertyLink rice has resistance to phosphinic acids such as glufosinate, and Roundup Ready rice, with transgenic resistance to glyphosate (Rong and Snow 2005). Enhancing nutritional quality of rice seed by biotechnological methods is an important theme of ongoing research. Golden Rice, which produces provitamine A (beta carotene), is a good example of a commercially available nutritional quality enhanced variety (Burkhardt et al. 1997; http://irri.org/golden-rice). Golden rice plants were developed by transferring two daffodil genes and one bacterial gene that carried out the four steps required for the production of beta-carotene in rice endosperm. Biofortified crops, such as Golden Rice are an important source of vitamin A in many rice-consuming countries (Burkhardt et al. 1997; Golden Rice (2014) http://irri.org/golden-rice). Transgenic rice has been produced to have increased levels of iron and zinc in the grain by expression of the soybean ferritin gene (Vasconcelos et al. 2003; Borrill et al. 2014).

Genetically modified wheat has been produced mainly for improved drought and salt tolerance, herbicide tolerance, and pest resistance. These innovations are expected to enhance the productivity, sustainability, and profitability of wheat farmers. The first herbicide tolerant wheat 'Roundup Ready™' was produced through introducing a gene from *Agrobacterium tumefaciens* coding for the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) to produce a glyphosate tolerant wheat line (Pocket K No. 38: Biotech Wheat (2014) http://www.isaaa.org; Monsanto and GM Wheat (2014) http://www.monsanto.com). This wheat is still not introduced to the market and is in the phase of field trial evaluation. 'Clearfield wheat' which is tolerant to the imidazolinone herbicide is a product of mutation breeding and not a genetically modified variety. Clearfield® wheat varieties are now grown in many regions across Canada (Monsanto and GM Wheat (2014) www.monsanto.com). Wheat is affected by a number of fungal diseases among which *Fusarium* is the worst, resulting in small and stunted grains or sometimes no grains and producing mycotoxins. Leading seed companies and other research institutions have launched programmes on producing fungal resistant wheat, specifically *Fusarium-resistance* and stem rust resistance varieties (USDA 2010; Pocket K No. 38: Biotech Wheat (2014) http://www.isaaa.org). In addition, a wide range of traits such as resistance to yellow mosaic virus, head scab, powdery mildew, and insects are under investigation (Pocket K No. 38: Biotech Wheat (2014) www.isaaa.org). Producing drought tolerant wheat is also under consideration and the International Maize and Wheat Improvement Center (CIMMYT) used a drought tolerance gene (DREB1A) from *Arabidopsis thaliana* to enhance this trait in wheat (CIMMYT 2004). Promising approaches have been made to increase iron and zinc content in wheat by biotech methods (Borrill et al. 2014). Wheat containing more lysine and with an improved baking quality trait has been developed by identification and genetic modification of candidate genes responsible for β-glucan synthesis in the starchy endosperm (Nemeth et al. 2010).

Certain maize varieties are being genetically modified for agriculturally desirable traits such as drought resistance and pest and herbicide resistance. Glyphosate and imidazoline herbicide resistant varieties have been commercially available since 1996 and farmers of many countries are reported to be benefitted substantially by use of these maize (Genuity DroughtGard Hybrids (2013) http://www.monsanto.com; http://www.bayercropscience). Bt corn is a very popular genetically modified corn variety. One or more proteins from *Bacillus thuringiensis* bacteria are expressed in the corn plant toxic to certain insects and pests such as corn borer, corn ear worms, and root worms. There are different variants of Bt corn depending on the type of Bt gene expressed. These GM corn minimised pest damage and today are grown widely across the world (Bohnenblust et al. 2014; Petzold-Maxwell et al. 2014). To minimise the yield loss from drought stress, GM corn has been developed with improved water-use efficiency. DroughtGard® corn hybrids and other varieties selected for drought-tolerant characteristics are commercially grown (Genuity DroughtGard Hybrids (2013) www.monsanto.com). Allele, ZmDREB2.7 identified in the drought-tolerant maize varieties, was effective in imparting plant tolerance to drought stress (Liu et al. 2013). In a study, overexpression of phytase (*Aspergillus niger phy*A2) in maize seeds led to improved phosphorus availability (Chen et al. 2008).

Genetically modified sorghum has been produced for herbicide resistance (glyphosate and glufosinate), fungal resistance, and improved food and feed quality. All of the GM varieties are still under field trial conditions.

Several different varieties of GM soybean are cultivated in large scale. Transgenic 'Roundup Ready Soybean' is resistant to herbicide Roundup (Soybean seeds (2014) http://www.monsanto.com). Soybean expressing Cry1Ac protein from *Bacillus thuringiensis* and glyphosate resistance is an economically important variety that produces high yield (ISAAA Brief 44-2012: Highlights. Global Status of Commercialized Biotech/GM Crops (2012) http://www.isaaa.org). Importantly, soybean has been genetically modified to improve the quality of oil. The amount of oleic acid and stearic acid has been increased by silencing or knocking out delta 9 and delta 12 desaturases and increased oil stability (Clemente and Cahoon 2009; Sorghum Hybrids from DuPont Pioneer Can Boost Your Yields (2014) www.pioneer.com).

Potato plants resistant to Potato Virus X (PVX) and Potato Virus Y (PVY) have been developed by expressing coat proteins of PVX and RNA silencing, respectively (Huisman et al. 1992; Missiou et al. 2004; http://cipotato.org). Potatoes transformed with a resistance gene for late blight, RB, showed increased resistance to *P. Infestans* (Kuhl et al. 2007; http://cipotato.org). Improvement of amino acid composition of potatoes has been made by expressing *AmA1* from *Amaranthus hypochondriacus* (Chakraborty et al. 2000) and 'Amflora' developed by BASF, produces pure amylopectin starch (www.agro.basf.com). Some of the GM potatoes were grown for a period of time and today none of the GM potatoes are grown commercially.

Research has been done to modify several kinds of fruits and vegetables genetically for characteristics such as pest resistance, herbicide tolerance, improved nutritional quality, flavour, and postharvest storage. GM tomato is the pioneer product available in the market. However, most of these GM products are not released into the market or are being suspended after some time of commercialising. Due to the controversial issues regarding the potential risks of the GM crops to consumers and the environment, introducing them to the market is a question. It is not intended in this chapter to discuss the controversies and issues of GM crop production.

Conclusions and Future Perspective

Seeds are fundamental to agriculture and seed quality has a major impact on crop yield. Seeds as vital propagating entities are greatly affected by the climatic change leading to declining yield and quality. During the last few decades, dramatic advancements in technology led to production of improved seeds as a delivery system leading to increased crop productivity worldwide. Introduction of seed enhancement methods such as seed coating, pelleting, priming, and production of synthetic seeds contributed to enhancement of seed quality. Hybrid seed production at commercial scale using advanced techniques is a significant achievement in the seed industry. Hybrid seeds are developed for features such as increased disease resistance, drought/cold tolerance, and improved nutritional quality. However, hybrid seed development is limited in some crop species due to high cost and the time taken for the process. Research is being continued to overcome these problems and produce hybrid seeds for multiple advantages in the field and evaluate the yield with farmer participatory trials. Farmers in some parts of the world do not have access to improved varieties due to improper distribution, high cost, or lack of knowledge. Efficient distribution of improved seed varieties and knowledge transfer should be considered as a central goal for future food security. Production of transgenic/GMO crop plants in order to better resist certain diseases that cause enormous crop losses, better combat against particular pests, and withstand herbicides, and with increased/modified nutritive values is a major development in agriculture. In brief, seeds are the delivery systems for agricultural biotechnology. However, key issues concerning the GMO on safety of the consumer and the environment should be addressed seriously before they are commercialised. It is of prime importance to develop safer seeds to maximise the yield potential by combining methods of breeding, biotechnology, and agronomy. Ultimately, sustainable agriculture is the answer that attempts to sustain biodiversity through a blending of innovation and traditional local knowledge.

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