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Approaches in cereal breeding

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A B S T R A C T

The main goal of plant breeding is to improve quality traits, yield and resistance to abiotic and biotic stress factors. A thousand years ago, people selected the best plants, seeds or fruits to produce seed for new crops and food for human and animal nutrition. Modern plant breeding is based on genetic principles and contributes to increases in yield and quality components (contents of protein, amino acids, fat, sucrose, mineral elements etc.). Breeders in conventional breeding programs in the last six decades have made changes to plant phenotypes, significantly improved resistance to diseases, earliness, and frost and drought resistance, and improved scientific farming practices, baking and milling technologies, and beverage production technology. Through bioinformatics and improved technology, breeders have developed ways to improve and accelerate the breeding process to combine desired traits in new genotypes as well to operate at the level of individual cells and their chromosomes. Nowadays, modern biotechnology is used to improve human nutrition, and develop genotypes with significantly higher yields and quality compared with genotypes created by conventional breeding. By genetic modification it is possible to add, modify or delete a trait without interfering between two complete genomes. However, genetically modified crops can be used after their assessment in terms of human health, food safety and the environment.

Keywords: breeding, genotype, biotechnology, yield, quality.

И З В О Д

Основни циљ оплемењивања биљака је побољшање особина квалитета, приноса и отпорности на стресне абиотичке и биотичке факторе. Пре хиљаде година људи су бирали најбоље биљке, семе или плод за производњу семена за нове усеве и храну за исхрану људи и животиња. Савремено оплемењивање биљака засновано на генетичким принципима је допринело међусобном повећању приноса и побољшању компонентни квалитета (садржај протеина, аминокиселина, масти, сахарозе, минералних елемената итд.). Оплемењивачи у програмима конвенционалног оплемењивања у последњих шест деценија су остварили промене фенотипова биљака, значајно побољшање отпорности на болести, раностасност, отпорност на мраз и сушу. Такође је остварено побољшање технологије гајења и унапређење примене мера неге и заштите и жетве биљака, побољшање технологије млевења и печења, као и технологије производње пића. Коришћењем биоинформатике и побољшане технологије, оплемењивачи су развили начине за побољшање и убрзавање процеса хибридизације, комбинујући особине које су пожељне да имају новостворени генотипови, као и спровођење инжењеринга на нивоу појединачних ћелија и њихових хромозома. Данас се модерна биотехнологија користи за побољшање исхране људи и за развој генотипова са знатно већим приносом и квалитетом у поређењу са генотиповима створеним у конвенционалном оплемењивању. Генетичком модификацијом могуће је додати, изменити или избрисати (елиминисати) особину без нарушавања два комплетна генома. Међутим, генетички модификовани усеви могу се користити након процене њихове безбедности за здравље људи, оцене безбедности хране и животне средине.

Кључне речи: оплемењивање, генотип, биотехнологија, принос, квалитет.

1. Introduction

Plant breeding is very important for improving biological and economic traits of genotypes. It involves the creation of varieties with higher genetic potential for yield and quality and possibilities for their utilization for food and feed. High genetic variability has been a favorable basis for the implementation of breeding programs and development of high quality varieties in order to improve the nutritional value of food (Menkovska et al., 2017; Knezevic et al., 2011; 2016). Varieties and hybrids created by plant breeding are characterized by enhanced features of both phenotype and genotype and greater adaptive capacity based on genes responsible for adaptability in certain environments (Knežević et al., 2006; Torbica et al., 2007; Knezevic et al., 2017).

For their survival under different climatic conditions, plants require favorable adaptations of their life cycles to the prevailing conditions. Numerous breeding approaches to modifying the life cycle through the manipulation of genes responsible for the control of complex traits, such as flowering time, the efficiency of photosynthetic systems, assimilates acceptor and the adoption of energy efficiency, have been developed. Another breeding approach refers to the adjustment of the life cycle of plants that makes them grow and mature at the time of year when they are least sensitive to stress conditions (Dodig et al., 2008; Marijanović et al., 2010). The characteristics of the plant phenotype are determined by genetic factors that are inherited from parental crops. Maintaining genetic diversity is an important aim of plant breeding. Breeders have successfully implemented this goal through selection and hybridization.

To create high-yielding genotypes adaptable to different environmental conditions, it is necessary to use sources of genes from natural populations (Zečević et al., 2009). Increasing the yield of plants is an important contribution to scientific knowledge and methods in the fields of physiology, mineral nutrition and plant genetics (Paunović et al., 2006; Knežević et al., 2016; Grčak et al., 2020). The protection and improvement of biodiversity are possible through preservation of plants in natural conditions and transformation of the plant genome by using many genetic techniques such as selection or genetic engineering (Karp et al., 1997; Reed et al. 2011). More recently, new sophisticated techniques have been used to develop crops artificially in culture from plant parts to produce whole plants (Engelmann, 2011). The contribution of genetics to increasing crop yields is enormous. Great possibilities are offered by the recombinant DNA technology, which allows the analysis of the molecular basis of yield, and the manner of achieving increased productivity of crops (Bajaj, 2001) Thanks to biotechnology, it is now possible to achieve greater progress in the provision of varieties and creation of hybrids. In fact, it is possible that microorganisms within plant cells are biological factories for the production of proteins, amino acids, vitamins and other compounds. Using these methods it is possible to transfer genes that control the synthesis of an organic compound (Ye et al., 2000; Chen et al, 2003; Engelmann, 2012). The application of marker technology is of great importance in understanding the genetic basis of plant crops and the commercial behavior of the breeder (This et al. 2001). It is also used by physiologists and biochemists to understand the genetic basis of metabolic processes (Cahoon et al, 2003; Kumar et al., 2018).

Man creates continuous models which provide optimal conditions for the manifestation of the biological potential for yield, which is specific to each species (Mićanović et al., 1997). Due to pronounced differences in environmental conditions that are linked to different latitudes, longitudes, altitudes, relief and soil, it is difficult to create optimum conditions. For all agricultural crops, progress has been achieved by increasing yields, although the constantly changing limit has not been reached (Mićanović et al., 1997; Knežević et al., 2015; Madić et al., 2019).

2. Characterization of prehistoric plant selection

For millennia, human beings have participated in the spread of agriculture across the Earth and at the same time started the selection of plants. Traces of surviving ancient plants and artifacts have been used for the study of ancient genetic material (DNA) and for the reconstruction of the period of archaic cultivation of particular species (Zeder et al., 2006). When people started sowing a portion of seed of harvested plants, they started domesticating plants and intentionally selecting plants for numerous desired traits in species cultivated for grains, roots, tubers, fruits, vegetables or fodder. There are a lot of literature sources which reported the “place” and “time” of domestication and theories and conclusions about the origins of agriculture and centers of origin of major plants (Sauer, 1993; Harris and Hillman, 1989). In different places across the world people selected, domesticated and transformed different plants. Especially important is the question how long they carried out the domestication of plants and whether they selected certain traits as criteria for plant selection intentionally or accidentally. The question is how ancient selection influenced farmers, plant breeders, the genetic structure of plant populations, and the genetic diversity of today’s cultivated plants. The answer is available through theoretical knowledge and experience regarding today’s major crops (cereals, grain legumes) and their most prominent characteristics.

For domestication, in prehistory, plants with edible reproductive biomass attracted greater interest. They were mainly annual plant species, because herbaceous perennials generally produced less grain in a season than annuals, which was the reason for the increased cultivation of annual seed producing plants at the end of the Pleistocene (Cox *et al*., 2002). However, ancient people used seeds of perennial species for food, as confirmed in the investigation of 3 perennial and 12 annual charred seeds of small grained grasses, which people consumed in the place of today’s Israel 23000 years ago (Weiss et al., 2004). This indicates that perennials grain species were rarely domesticated because of low competition with weed species. In the Neolithic period, people kept populations of plants through the sexual cycle. The selection of non-shattering plants was spread at the time when people began tilling new land year after year to sow plant seed. Occasional hybridization or somatic mutation as well as rare sexual recombination led to a low degree of domestication (Scarcelli et al., 2006; Zohary, 2004).

Plant cultivation is very important as a food resource, a resource of important nutritional compounds and chemicals, as well as a source of nonfood products (drugs, oil, pigments etc) (Djukic et al., 2011; Menkovska et al., 2017; Laze et al., 2018; 2019). Therefore, breeders are constantly trying to improve the yield and quality of their products by using more effective techniques (Knežević et al 2006; Menkovska et al. 2000; 2002).

3. Initial selection within plant species

The process of domestication and cultivation of plant species was not simple. People noticed differences between plants through practice. In shattering plant species, farmers estimated disadvantages because of a short period between full maturity and loss of seed through shattering. Non-shattering plants were characterized by increasing fertility of formerly sterile florets and a longer period from ripening to harvesting depending on plants and the environment. Under natural conditions, the frequency of mutation alleles for non-shattering is low (once every 5 to 20 years) Hillman and Davies (1990). Under those conditions, gatherers sometimes unconsciously selected plants with desirable genes. People have an incentive and consciously strongly favor genes for non-shattering through long term harvesting and sowing self-pollinated plant species. With conscious selection, in the case of mutant frequency, less than 5% people can accelerate the increase in mutant frequency by half the length of time required for domestication. It was calculated that it took approximately 300 to 1000 years to fix the domestication gene *tb1* that telescopes the lateral branches in maize (Wang *et al.,* 1999). Other studies found that modern mutant alleles of the genes *tb1*, *pbf* (prolamin box binding factor) and *su1* (starch debranching, which affects tortilla quality) were common approximately 4400 years ago (Jaenicke-Despres et al., 2003). But that was almost 2000 years after the date of the oldest known archaeological evidence of maize domestication. Based on archaeological evidence from northern Syrian Arab Republic and southeastern Turkey, we can argue that "wild cereals could have been cultivated for over 10000 years before the emergence of domestic varieties", partly because Neolithic cultivators may have taken care to harvest grain before any of it began shattering (Tanno and Willcox, 2006). That would have reduced the selection pressure on alleles for non-shattering. During the domestication of rice, einkorn and barley, selection for grain size proceeded faster than selection for non-shattering, while selection for grain size was slower in pearl millet and leguminous crops (Fuller, 2007). Also, the author concluded that shattering was not fully eliminated for 1000 to 2000 years.

Physical remains often indicate that domestication took much longer than would be predicted by genetic models. The models based on a few genes can estimate only the minimum duration of the domestication process, whereas archaeological data provide a 'reality check' (Gepts, 2002)

To improve the yield of wild perennial relatives of wheat in the process of domestication from 600 kg to 2300 kg ha^{-1}, and if they could exponentially increase yields by 10% per generation or 110 kg ha^{-1} per generation, it would take 16 generations or 48 years, at the fastest possible rate of increase of 3 years per generation, to achieve a yield of 2300 kg ha^{-1}.

4. Conventional plant breeding

A thousand years ago, man began the process of plant improvement. Pre-agricultural man learned how to put seeds into the soil and at what time of the year to produce similar seed-producing plants (Lawrence, 1968). This was the beginning of domestication of plants and led to the production of the first crops. Later, within the same plant species, man discovered differences in growth, taste etc., which became the starting point of selection breeding. In the 19th century, Charles Darwin in his theory of 'Natural Selection' described the "survival of the fittest". This theory shows how natural selection influences plants to grow in specific parts of the world. This knowledge was useful for farmers to develop the process of plant selection, and farmers were able to choose plants, which grew well, and had high yields and good quality (Kuckuck et al., 1991; Šekularac et al., 2018).

Significant results in wheat breeding were achieved by Strampelli in 1900, who performed 105 crosses between wheat and studied the mode of expression of 27 characteristics in wheat (spike properties, resistance to rust...). The first cross was Noe/Rieti 1900. According to the developed concept of breeding, the cultivars with earliness were used for the crosses (Akakomughi). In 1914, Strampelli released one of his first wheat varieties, named Carlotta. The results of the genetic experiments by Jasenko on the hybridization of wheat and rye were published in 1911.

For success in plant breeding, the breeder must have a large population of seeds, which should contain several different genetic types that are well adapted to environmental conditions and seasonal climate change (Dodig et al. 2008; Zečević et al., 2009; Carter et al., 2019; Djukić et al. 2019; Iqbal, et al., 2020). These basic populations are called ***landraces*** and are generally found in regions where older plants have been growing for a long time. Natural selection has already occurred leaving only those crops that have been able to adapt to their environment (Kuckuck et al., 1991). Landraces are generally found in areas where cross-breeding results in a lot of new genetically divergent genotypes which are constantly being introduced into the environment. In such populations, through selection, some plants are selected for next sowing, and plants with undesired traits are removed. This process leads to the survival of plants with most desired traits and the creation of new lines or cultivars of crops selected for their specific traits (Knežević et al., 2006).

Another efficient method of plant selection is when two different pure lines are crossed giving an offspring, which is called a ***hybrid***. In this way, the obtained plants have the genetic basis for many desirable traits exhibited by each of the parents. For some crop species (maize), the seed supplied to growers is that produced from the first cross between selected parents. The resulting genotypes, known as F_1 hybrids, offer potential advantages in crop performance, which are unique in expressing 'hybrid vigor' in the growing crops for a single year.

In wheat, new cultivars are created using conventional plant breeding, which involves crossing carefully chosen parent plants, then selecting the best plants from the resulting offspring to be grown on for further selection. For cereals, hundreds of individual crosses are carried out by hand to create seed for the first filial (or F_1) generation. The resulting F_1 plants are uniform, but in the following generation several hundred thousand different plants are produced. The offspring in F_2 and later generations show an enormous diversity of different gene combinations (heterozygosity). Within each generation breeders cultivate and select individual plants with desirable traits (Yueming et al., 1996). As promising new lines emerge, tests are conducted on each plot to assess factors such as yield, disease resistance and end-use quality (Madić et al., 2009).

The aim of breeders is to generate completely homozygous plants species, ensuring that the cultivar is uniform across the population. This is achieved in self-pollinated species (wheat, barley), characterized by selfing as the mode of reproduction. In wheat, barley and other self-pollinated plants, the pollen of the same parent plant fertilizes an ovule. After fertilization, the ovule develops into a seed in the ovary. Eliminating heterozygous alleles is a long-term process, which can be realized through many generations. However, technological developments have accelerated the process by stimulating a phenomenon known as ***double haploid***.

The dramatic gains in agricultural productivity seen in the second half of the last century are often linked to increased mechanization and the application of fertilizers and agrochemicals. Great progress has been made in agronomy through the permanent use of fertilizers and their precise rates in the absence of competition from weeds, pests and diseases (Zečević et al., 2005; 2010; Paunović et al., 2006; Dolijanović et al., 2019). The yield of crops was higher by 50% under proper care and fertilization treatments, depending on genotype, as well as on soil fertility and other environmental factors (Kovačević et al., 2006). In addition, a major challenge in breeding for increased nitrogen use efficiency and capacity, which is extensively studied, is the presence of microorganisms in the rhizosphere of roots and their associative contribution to the uptake of free nitrogen by non-leguminous plants (Mićanović et al., 1997; 2005; Roljević Nikolić et al., 2018).

This “Green Revolution” would not have been possible without the huge genetic improvements made to the crops. On average, plant breeding has contributed around half of the three fold increase in wheat yields recorded in the last 5 decades of the 20th century. Plant breeding can directly improve the performance of crops in different ways:

– Developing crop varieties with high efficiency of converting their biomass into *productive yield* is the single biggest contribution to improved crop output. The introduction of shorter-strawed cereals contributed to developing genotypes with more effective translation of synthesized matter into grain. On this basis, in wheat, harvest index increased up to 60% without changing the total above ground biomass, which is a profit of about 25% (Austin, 1980).

– Changing a crop’s *physical characteristics* (structure) can also contribute to increased yields. For example, the introduction of shorter-strawed cereals in the development of semi-dwarf plants contributed to developing genotypes with more effective translation of synthesized matter into grain. It was found that the genes *Rht-B1b, Rht-B1c* lead to a reduction in stem height by 25%, grain mass – by 10%, fertility by up to 20% and grain yield by 8% (Worland et al., 1998; Friedli et al., 2019). A cross between Japanese dwarf cultivar Norin 10 and Brevor, which are adaptable to temperature and photoperiod conditions in the region, disease resistant and susceptible to lodging, resulted in semi-dwarf varieties Penjamo 61 and Pitic 62, which exhibited a high yield.

– Genetic *resistance to disease* enables crops to realize their yield potential – it can also mean reduced use of pesticides (Gošić Dondo et al., 2020). Plant breeding has significantly improved the genetic resistance of crops against the threat of viral and fungal infection (the key example is resistance to barley yellow mosaic virus in cereals). The challenge of breeding resistant varieties is constant because new strains of disease develop naturally.

– Improvements in the uniformity of crop *maturity time* to be ready for harvest, which have not only reduced potential crop losses at harvest, but have also improved growers’ ability to mechanize harvesting operations.

Other agronomic factors which contribute to progress in agricultural productivity are genetic resistance to pests, shorter crop life-cycle (to expand a crop’s geographical growing areas), and stress tolerance, such as frost resistance, drought tolerance etc. (Brentrup et al., 2004; Korshaet et al., 2012; Memon et al., 2014; Sallam et al., 2019; Buffagni et al., 2020).

Through improved productivity, developments in plant breeding have also contributed to a significant improvement in crop quality (Zečević et al., 2007; Knezevic, et al., 2012).

Growers must compete with the best in the world on quality and cost of production. Consumer expectations about food are also more exacting (Đurović et al., 2020). This is reflected in tighter quality specifications along the food chain (Menkovska. 2003; 2017; Knežević et al., 2009) as well as in the use of specific traditional foods of different national cultures and their approach in estimating food quality on the basis of knowledge, profitability and legislation (Tomašević et al., 2020a: 2020b). Plant breeders have responded with a continuous stream of new varieties, tailored to the needs of specific end-markets (Knežević et al., 2007; Zečević et al., 2013).

In the past 50 years of breeding, an average increase in wheat grain yield has been 1% per year, with increases in European countries ranging from 2000 kg ha^{-1} to 6000 kg ha^{-1}. This increase was achieved on the basis of the genetic potential of the newly created varieties of wheat and on the basis of the development of optimal cultivation technology. In addition, a similar increase in yield was achieved in the USA. Then in Mexico the yield of wheat increased from 750 kg ha^{-1} to 3200 kg ha^{-1} due to the use of improved varieties and appropriate agricultural practices for their cultivation.

5. Plant genetics and biotechnology

Gregor Mendel, in the mid-19th century, first provided a scientific explanation of genetic inheritance, which was accepted in early 20th century as the basis of modern scientific plant breeding. With a basic understanding of how genetics plays a role in determining phenotype, as well as growth responses of a plant, geneticists have been able to apply new techniques for growing plants. Also, geneticists have improved knowledge as well as the ability to modify the genetics of certain plants artificially, using an asexual technique to grow these plants.

The breeding process mainly takes a long time, approximately 10–12 years, from hybridization to approval of new cultivars. Within each generation, selection is conducted until only those with the best traits remain and undesirable features cease to emerge. Conventional breeding has also been used to shorten the life cycle of wheat, allowing it to be grown at higher latitudes with shorter growing seasons. New knowledge and improved technology have enabled breeders to improve the selection process to be faster and more accurate. There are several ways to reduce the lengthy interval between the first cross of selected parents and establishing true breeding lines of promising new varieties. Some breeders run parallel breeding programs in the northern and southern hemispheres, so that in a year they benefit from two growing seasons. Plants cultivated for breeding processes are grown under strictly controlled conditions that optimize their growing environment.

Recent scientific and technological developments have allowed a greater rate of improvement. New techniques involve growing whole plants from single cells artificially in cultures that contain all the required nutrients and factors involved in cell growth (Chawla, 2000). This technique is referred to as plant *cell culture*. Breeders can produce cultivars in the laboratory through:

– *protoplast fusion*, which involves the following: Individual plant cells with their outer walls removed are fused, and the fused cells are then induced to divide and grow in a culture medium. This process can regenerate plants containing new combinations of genes from the two parents.

– *Embryo rescue and assisted pollination* allow breeders to expand variability of traits by making crosses between species which would not produce viable offspring outside the laboratory.

– *Double haploid breeding* enables breeders to produce genetically uniform lines within one generation. This effectively by-passes the lengthy process of self-pollination and selection normally required to produce true breeding plants. A doubled haploid plant has cells containing 2 gene sets which are exactly identical**.** Haploid production by wide crossing was reported in barley (Kasha and Kao, 1970).

Genomics – enables breeders, by the genetic mapping of a genome, to identify the position and function of particular genes. Genome mapping has revealed striking similarities in the genomes of different crop species, such as rice, wheat, barley and rye, which is very important for improving the precision and efficiency of plant breeding.

Marker assisted breeding – allows breeders at an early stage of the breeding process to determine whether desired traits are present in a new variety.

Proteomics – allows breeders to estimate how genes behave in different organs of the plant and under different growing conditions.

Genetic modification – Furthermore, scientists have been able to clone specific genes from one species and insert them into evolutionary distant plants to introduce new characters that may benefit the plant species (Bajaj, 2001). This procedure is known as transgenic and used for the creation of genetically modified crops. Furthermore, selection was put into operation to find crops that could withstand certain pests and environmental conditions, such as drought or low temperatures. This procedure can result in crops that are resistant to harmful microorganisms or certain conditions. This also allows farmers to reduce the amount of pesticides required in protecting their crops

Genetically modified crops were planted on approximately 90 million ha of land in 2005, while in 2009 GM crops were planted on 134 million ha. Among cereals, GM maize is the most widely planted crop. GM maize was grown on 21 million ha in 2005, and on 42 million ha in 2009. The field area planted with GM maize hybrids increased from 7% in 1996 to 80% in 2009. The share of insect-resistant *Bt* hybrids in the total sown area decreased from 21 to 17%,and herbicide tolerant hybrids were less sold. The proportion of hybrids with combined insect resistance and herbicide tolerance (*stacked genes*) increased from 28 to 40 percent of the maize land.

In 2002, approved an herbicide resistant, genetically modified wheat cultivar, which shows superiority in competition with weeds (Blackshaw and Harker, 2003). Also modified wheat had a higher yield for 5-15% of the wheat to be treated with conventional herbicides. GM wheat is not very different from standard wheat to the constituent components that are important in human and animal nutrition (Obert et al., 2004) and not contains more allergic, toxic and antinutritional factors in comparison with standard cultivars of wheat (Goodman et al. , 2003). By modification of gene expression were 19Kda zein were obtained of maize genotypes with increased content of esential amino acids (Huang et al., 2004).

Providing mineral elements (iron, calcium, selenium, iodine) and vitamins (vitamin A, E, B_6) in human nutrition is important for maintaining good health, as they have a role in reducing the risk of various diseases. About 1.8 million people worldwide suffer from lack of vitamin A and even more from lack of iron, which is recorded in the population of people who consume mainly rice. Rice does not contain any β-carotene, a precursor of vitamin A. Thanks to biotechnology, the rice genome was incorporated with four genes from daffodils and the bacterium *Erwinia uredovora* which encode enzymes involved in the biosynthesis of vitamin A i.e. beta-carotene (Ye et al., 2000).

Another significant achievement is the transfer of genes responsible for the efficient uptake of iron into the rice genome. Crossing these two genotypes resulted in "golden rice", which was modified for both these properties. The transfer of genes for ferritin (iron storage protein) into rice was successfully performed by several researchers, resulting in a threefold increase in iron content in modified rice than in ordinary rice (Datta et al., 2003, Vasconcelos et al., 2003). Chen et al. (2003) have made the transfer of genes controlling the synthesis of the enzyme dehydroascorbate reductase from wheat to corn, where vitamin C content increased more than 100 times. By modifying the genes involved in the control of the biosynthesis of vitamin E, isolated from barley, rice and wheat, six times higher content of vitamins was obtained in transgenic maize (Cahoon et al., 2003).

6. Conclusions

In recent decades, plant breeders have developed a lot of different genotypes with improved characters to satisfy the requirements of growers, consumers and the processing industry. Newly created varieties have contributed to the change in gene frequency in their crops in favorable directions.

Since the start of breeding in prehistoric times, vast experience and knowledge have accumulated regarding the use of methods to domesticate crops and improve their genetic, phenotypic, technological and nutritional characteristics, and adaptive and economic values. Modern breeders' methodologies are often very different, but they are rooted firmly in the past. They use the first plant breeders' unwritten knowledge, which survives in the genetic code of the plants. Plant characteristics are determined by genes – units of hereditary material that are transferred from one generation to the next. Since each plant contains many thousand genes, and the breeder is seeking to combine a range of traits in one plant, such as high yield, quality and resistance to disease, developing a successful variety is an extremely lengthy process – up to 12 years in the case of cereals. The recent developments in genetic science have greatly contributed to enhance the breeding process.

This enables plant scientists to select for the traits that were most suitable for the crops they are growing without having to go through the long and tedious procedures of growing the crops and selecting for the traits that are within that population. Genetic modification offers precise manipulation of characteristics by changing or deleting genes or inserting new genes from other organisms, without reshuffling two complete genomes. This enables specific genes to be expressed in a crop plant without the introduction of unwanted characteristics, resulting in the creation of cultivars with drastically increased yield, quality and resistance to biotic and abiotic stress factors.

In addition, the cultivars produced using genetic modification must also pass through a separate process of regulatory scrutiny. European law and expert advisory committees specify that no GM crops can be marketed until they have been assessed and approved in terms of human health, food safety and the environment, and their uses regulated at a global level under the internationally agreed Biosafety Protocol.

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