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Review Article

Increasing or Limiting Genetic Diversity of Crops through Plant Biotechnology: A Review

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ABSTRACT

In various debates in society plant breeding is looked upon as a major threat to biodiversity. Producing uniform varieties by fewer and fewer companies would lead to reduced biodiversity in farmers' fields. The diversity of crops has gone through domestication, dispersal and modernization bottlenecks of diversity. Plant breeding may contribute to diversity in farmers' fields or significantly reduce it. History has numerous examples of both. Biotechnology has proven to support diversity, notably Marker Assisted Selection. Gene editing may also contribute to the same goal. However, both biotechnology and biodiversity policies could reverse the trend. We warn for a fourth, a policy bottleneck to the diversity of crops.

Keywords: Genetic resources; Diversity bottleneck; Plant breeding; Genetic diversity; Plant biotechnology

INTRODUCTION

Plant breeding collects, induces and rearranges genetic diversity followed by selection. The balance between diversity enhancing forces and selection, reducing diversity determines the outcome in terms of gain or loss of diversity by plant breeding. Plant breeding may contribute to diversity in farmers' fields or significantly reduce it. History has numerous examples of both. Biotechnology has proven to support diversity, notably Marker Assisted Selection.

HISTORY OF BREEDING IN RELATION TO DIVERSITY

Genetic diversity of crops has gone through various bottlenecks in history, followed by gradual increases. First, only a small fraction of natural diversity was used by the first farmers to create crops. This created the domestication bottleneck [1]. However, when exposed to farming conditions, new traits emerged through mutation and introgression farmers' and natural selection in these new growing conditions where competitiveness with weeds was less important and so was dispersal of seeds [2]. The result was that shattering was reduced and seed size of cereals increased dramatically.

The second bottleneck was created when a small fraction was taken from the original areas of domestication to other continents, notably in the era of European expansion. This is dubbed the dispersal bottleneck [3]. Potato from the Andes in Europe but also cocoa trees from Brazil to West Africa, Oil palm from West Africa to Asia, and sugar cane from the pacific Islands to the Caribbean. Sometimes this went well, when care was taken not to carry the most important pests such as with cocoa, but with potato, the lack of diversity was one of the causes of the Irish Famine in the 19th century. Some crops gained a lot of diversity in their new environments, such as common beans in Africa, creating so called secondary centers of diversity [4].

The third bottleneck came along with modern breeding, combining as many 'positive traits' in one variety, following the with the 'invention' of line selection and pedigree selection in Svalöf, Sweden [5]. And the rediscovery of the laws of heredity formulated by Mendel in [6]. These uniform varieties replaced many genetically more diverse farmers' varieties. Large scale reduction of diversity came along with the international breeding programmes of the Green Revolution, popularizing single varieties across continents [7,8]. Alarm bells started to ring when it became clear, that modern breeding threatened its own future, by destroying the very diversity that it relies upon. The establishment of genebanks, following the example of Nicolai Vavilov was the first response [9]. Followed by on-fam and *ex situ* strategies to manage the diversity of important crops.

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REVERSING THE TREND

Diversity within varieties: multiline breeding various ideas has emerged to reverse the trend of diversity losses, initially especially focusing at the agronomic value of diversity in the field. Resistance tends to be broken by crop diseases, leading to a race between the breeder and the pathogen. The Bremia fungus and the lettuce crop is a well-known example, where new alleles have to be found and introduced into new varieties continually to safeguard the crop from being wiped out. Creating diversity in the crop might in some cases slow down epidemics and reduce the selective forces on the disease agent. An interesting breeding strategy to cope with this was the development of variety "Tumult" (Dutch for havoc) in wheat, where different resistance genes to yellow rust were introduced in near isogenic lines of wheat. These were then mixed in order to create a multiline variety that is sufficiently uniform for mechanized cultivation, but sufficiently diverse to beat the rust disease [10]. ''Tumult'' reached the market in 1980 and created havoc with the variety registration authorities (the variety was not sufficiently uniform for the applicable standards. It did not become a commercial success though because the creation of the isogenic lies had taken additional years that other breeders had used to select for higher yield levels. It did prove however that carefully chosen diversity can be functional in a farmers' field.

At the same time, increasing diversity through interspecific crosses became increasingly popular [11]. Such programmes were quite cumbersome as the 'wild characters' had to be removed through subsequent backcrossing relying on mainly visual observations.

INCREASING DIVERSITY AMONG VARIETIES DUE TO BREEDING

Some decades later it is becoming increasingly clear that modern breeding contributes to diversity. An increasing body of literature is emerging illustrating that breeding is increasing genetic diversity among varieties, i.e. the diversity that farmers can choose from, in regions where modern agricultural practices are dominant. However, van de [12,13]. Present a broad literature review for a wide number of crops that prove this. Various economic, technological and market forces are responsible for this trends supporting diversity in modern breeding.

A major economic force is held responsible for this by Van de [14]. They attribute it to the stimulating effect of the protection of breeder's rights which supported investments in breeding in Europe from the 1970s onwards. Breeders can recoup their investments in plant breeding through these rights; competition among breeders led to increased numbers of varieties being brought to market and provide an incentive to come up with markedly different 'products' to beat competition. This apparently outweighs the trend starting in the 1970s that the number of lettuce breeding companies declined. They argue that the larger breeding programmes were able to use a wider diversity of parent materials in their breeding.

The second is a technological development: [15]. Highlights the relevance of marker assisted breeding technologies in increasing diversity in crops. Interspecific crosses can be better tracked [16]. and backcross programmes can be made much more efficient using the molecular tools [17,18]. This has contributed to the observed increases in diversity, since a much wider gene pool could effectively be used in breeding following the introduction of Marker Assisted Selection technologies. Transgenesis obviously also introduces additional genetic diversity into a crop. However, this technology has been applied on a few crops and for a very limited number of traits only, so the importance of that trends should not be over-estimated. It may even have operated in the opposite direction since the same traits have been used in a relatively small number of varieties, used in large tracts in various agro-ecologies. An important reason for this is the compound effect of the complexities of and cost involved in the technology and the enormous deregulation costs of a new GMO-trait, reducing the application of the technology to relatively few events, and the patents granted to such traits reducing their use in a diversity of crops.

Finally, there are market forces that may stimulate diversity [19]. Report that the observed increased genetic diversity among tomato varieties in Europe is likely to stem from, additionally to the economic and technological developments, also due to market trends. They claim that it was the tomato consumers that demanded different types of produce in the 1990s compared to the standard type in the market. The different sizes, tastes, colours and uses that breeders created obviously also increased genetic diversity. The importance of market forces in the creation of diversity was well known in ornamental breeding, but that the authors also could prove it for food crops was new.

LOOKING AHEAD

Biotechnology has advanced enormously during recent years. It is too early to assess what the outcome will be of these technological developments in terms of diversity among varieties available to farmers. The example of marker assisted selection positive and transgenics (limited or negative) illustrate the important of policies in this respect. Technically, the use of gene editing techniques in breeding has been facilitated enormously with the development of CRISPR Cas technologies, compared with the earlier TALEN and ODM. Potentially, anyone with sufficient knowledge about genetics and a basic laboratory can experiment with gene editing now. It has the potential to create new diversity within the basic genomes efficiently and effectively through deletions leading to silencing (SDN-1) and small edits (SDN-2). It might facilitate the creation of near isogenic lines in a multiline breeding programme, reducing the limitations experienced some 50 years ago and providing interesting options for resistance management. It may even make the transfer of functional genes more acceptable, especially in the case of location specific cis-genesis. Whether these promises will become realities depend both on the patenting strategies applied and the regulations that the products of gene editing may be faced with.

A prerequisite is that the products of gene editing are not over-regulated. The case of transgenics shows that the costs of deregulating traits (events) have contributed tremendously to reducing the number of transgenes developed. Currently (2020) a very a very diverse set of policies and regulations have emerged in different parts of the world with Argentina having a facilitated acceptance system, while the European Union considers the products of gene editing regulated GMO.

Furthermore, the patent situation may have a significant effect on the accessibility of the technology by potential users. FRAND licensing of technology patents [20]. And limitation of product patenting will likely increase the diversity of users of the technologies.

Louwaars in their study [21]. Highlights the importance of genetic resource policies. Breeders can produce diverse materials especially when they have access to genetic diversity, which is regulated by international agreements such as the Convention on Biological Diversity (CBD, 1993) and the International treaty for plant Genetic Resources for Food and Agriculture (FAO, 2001). Specifically, with respect to biotechnology, current debates are relevant that intend to include Digital Sequence Information in the definition of "genetic resource" making access to such information subject to a wide range of rules. If this will have the effect that such data are used less by breeders, then the outcome is likely that the diversity among varieties is restricted. This would undermine the very objectives of both the Convention and the Treaty, but it is still possible that additional rules may apply.

CONCLUSION

Genetic diversity in crops has gone through three major bottlenecks: the domestication, dispersal and modernization bottleneck. After these bottlenecks, diversity has picked up through natural processes, and after the modernization bottleneck through scientific breeding. Biotechnologies, such as marker assisted selection, have proven to support genetic diversity of a number of crops. Modern biotechnologies such as gene editing promise to significantly increase genetic diversity of crops, but various policies may come in the way. There is thus a chance that we will face a fourth, a policy bottleneck for the diversity of crops. It would be very unfortunate for food security at a time of climate change when robust crops are more needed than ever.

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