Brief History of Plant Breeding Open Access

Brief History of Plant Breeding (IV): Breeding 2.0, Scientific-Driven Approach of Variation Populations and Phenotype Selection

Jim Fang
Hainan Institute of Tropical Agricultural Resources, Sanya, 572025, China
Corresponding author email: james.xj.fang@qq.com

Tree Genetics and Molecular Breeding, 2023, Vol.13, No.1 doi: 10.5376/tgmb.2023.13.0001
Received: 24 Jul., 2023
Accepted: 07 Aug., 2023
Published: 28 Aug., 2023

Preferred citation for this article:
Fang J., 2023, Brief history of plant breeding (IV): Breeding 2.0, scientific-driven approach of variation populations and phenotype selection, Tree Genetics and Molecular Breeding, 13(1): 1-5 (doi: 10.5376/tgmb.2023.13.0001)

Abstract This paper explores the development of Breeding 2.0, which represents the transition from Breeding 1.0 (primitive selection) to Breeding 2.0 (conventional breeding). Breeding 2.0 is a scientifically driven breeding approach based on Mendel's laws of inheritance and quantitative genetics theory. One of its key features is the creation of variation populations and the application of phenotype selection to improve plant varieties. The emergence of Breeding 2.0 has shifted breeding practices from unconscious selection and empirical methods to a more scientific and conscious selection approach. By creating variation populations and employing phenotype selection, breeders are able to more accurately select and improve plant varieties, enhancing crop yield, quality, and resistance. Breeding 2.0 has had a lasting impact on plant breeding and agricultural development, laying the foundation for future advancements in breeding.

Keywords Variation populations; Phenotype selection; Breeding 2.0; Plant breeding

Plant breeding is an essential field where humans select and improve plant varieties to enhance crop yield, quality, and adaptability. Throughout the course of plant breeding history, from primitive selection (breeding 1.0) to conventional breeding (breeding 2.0), humans have undergone a long evolution and domesticated thousands of species (Wallace et al., 2018). Conventional breeding, as a crucial stage in breeding history, has had a profound impact despite its relatively short span of around a hundred years, playing a vital role in agricultural development and food supply.

Breeding 1.0 originated around 10 000 to 12 000 years ago when humans began exploring and cultivating various edible plants, selectively planting and propagating those with beneficial traits (Fang, 2022). Through extended periods of primitive selection, humans gradually domesticated thousands of plants, including many major crops we cultivate today (Fang, 2023). This phase of breeding was based on non-professional selection by farmers, but due to long-term selection and propagation, significant phenotypic changes occurred in plants.

As time passed, people began to recognize the potential of breeding and engaged in further research and practice, leading to the emergence of breeding 2.0. Breeding 2.0 originated in the late 19th and early 20th centuries when issues of inbreeding depression were realized, and the principles of Mendelian genetics and quantitative genetics were rediscovered, laying essential foundations for the scientific basis of breeding. In contrast to breeding 1.0, breeding 2.0 is characterized by the artificial generation of variation and targeted selection breeding within variation populations (Wallace et al., 2018). During this stage, the methods and techniques of breeding science were further developed and applied, including statistical analysis, experimental design, and hybrid breeding. These advancements allowed for more precise selection and improvement of plant varieties, thereby increasing crop yield, quality, and adaptability.

Through research and practice in breeding 2.0, people not only gained a deeper understanding of plant genetics and principles of phenotype selection but also laid the groundwork for the future development of plant breeding.

1 Breeding 1.0 Recap: Primitive Selection and the Origins of Agriculture

In the brief history of plant breeding, the Breeding 1.0 stage represents the result of mutual dependence between ancient humans and plants. Approximately 10 000 to 12 000 years ago, humans started relying on plants as a source of food and began the practice of primitive selection by choosing plants with beneficial traits for cultivation and reproduction. This stage marked the origins of agriculture and a significant transformation in human society.

The existence of breeding 1.0 is supported by specific archaeological and paleobiological evidence. Archaeologists and paleobiologists, through the study of ancient human habitats and remains, have discovered evidence associated with primitive selection and the origin of agriculture.

In archaeology, researchers have found well-preserved plant fossils and seeds at ancient settlement sites, revealing traces of early human agricultural activities, such as the selection and cultivation of specific plants (Bai et al., 2021).

Paleobiological studies also provide evidence for breeding 1.0. By analyzing ancient plant genetic material, researchers can trace the origin and domestication process of plants. For instance, the study of ancient plant DNA has led to the discovery of genetic differences between early agricultural plants and their wild ancestors, demonstrating the process of human selection and domestication.

This archaeological and paleobiological evidence strongly supports the existence of breeding 1.0, uncovering the historical interaction between humans and plants and validating the presence of plant breeding as a significant cultural innovation.

During breeding 1.0, early human farmers gradually altered the genetic characteristics of plants by selecting those with favorable traits for cultivation and propagation. Through extended periods of primitive selection, humans domesticated numerous plants, making them adapt to different environments and human needs. In this process, humans selected plants with larger seeds, higher yield, weather resistance, and improved taste, which eventually led to the development of many important crops we cultivate today (Leach, 2020).

The agricultural origin during breeding 1.0 had profound effects on human society. With stable and abundant food sources, humans settled and established villages, forming complex social organizational structures and civilizations. Through agricultural development, humans altered their relationship with the natural environment, transitioning from a lifestyle of gathering and hunting to agriculture. The emergence of agriculture not only changed human lifestyles but also promoted the development of handicrafts and industries, such as textiles, dyes, architecture, and medicine.

The significance of breeding 1.0 lies in laying the foundation for plant breeding and providing valuable experience and genetic resources for subsequent breeding phases. The lessons and achievements of this stage serve as inspiration for our modern breeding work. Although the methods and techniques of breeding 1.0 were relatively simple, it marked the beginning of human selection and improvement of plants, laying the groundwork for subsequent breeding 2.0 and breeding 3.0 stages.

As time passed, humans gradually realized the potential of plant breeding and began exploring more scientific and systematic breeding methods. This led to the transition to breeding 2.0, characterized by more precise methods of selecting and improving plant varieties.

2 Breeding 2.0: The Emergence of Scientific-Driven Breeding Methods

The rise of Breeding 2.0 signifies a significant revolution in breeding methods, employing scientific principles and technological tools to achieve more precise and targeted control over the breeding process. In contrast to the unconscious random selection of Breeding 1.0, Breeding 2.0 emphasizes science-based approaches and techniques.

Breeding 2.0 is built upon Mendel's laws of heredity and Morgan's theory of genetics. Scientists rediscovered these essential genetic principles and applied them to the breeding process, allowing for a better understanding of gene transmission and expression, thereby more accurately predicting and selecting desired genotypes (Gayon, 2016; Wolf et al., 2022).

In the creation of variation populations, Breeding 2.0 utilizes traditional hybridization techniques and introduces new methods of mutation induction (Oladosu et al., 2016). Physical mutagenesis techniques, such as radiation-induced mutations, and chemical mutagenesis techniques, such as colchicine-induced mutations and EMS (ethyl methanesulfonate) mutagenesis, are widely applied in Breeding 2.0. Additionally, tissue culture variation has also become a crucial technique in Breeding 2.0.

Regarding selection, Breeding 2.0 transforms from phenotype-based selection to conscious selection. Scientists precisely measure and assess a large number of candidate individuals, selecting the best-performing individuals as breeding materials to achieve the desired genotypes. This phenotype-based conscious selection is based on statistics and quantitative genetics, allowing for more accurate inference and evaluation of genotype performance.

Furthermore, Breeding 2.0 innovates in experimental design. Scientists employ field experimental statistical methods to ensure the reliability and reproducibility of experiments. Through sound experimental design and statistical analysis, they can more accurately evaluate the performance of different genotypes' traits and conduct further selection and improvement based on these results.

In conclusion, the rise of Breeding 2.0 marks the scientification and precision of breeding methods. By applying Mendel's laws of heredity and Morgan's theory of genetics, combining traditional hybridization techniques with new mutation induction methods, as well as statistical and quantitative genetics approaches, Breeding 2.0 makes the breeding process more accurate and targeted.

3 Variation Population and Phenotype Selection

The concept of the variation population is pivotal in Breeding 2.0, referring to a diverse group of individuals generated through variation and phenotypic plasticity. Genetic variation encompasses the diversity of different genotypes and alleles within the population, while phenotypic plasticity refers to the variability of individuals' performance under different environmental conditions. The variation population provides breeders with abundant selection materials, enabling them to choose the most advantageous individuals for breeding improvement through phenotype selection.

Phenotype selection is a critical step in Breeding 2.0, where individuals with desired performances are evaluated and chosen to achieve the goals of breeding improved plant varieties. In contrast to the unconscious random selection of Breeding 1.0, phenotype selection in Breeding 2.0 is conscious and based on precise measurements and evaluations. Breeders select outstanding individuals based on specific breeding objectives, such as yield, quality, resistance, etc., for reproduction and further selection. Through phenotype selection, breeders can quickly screen individuals with desired traits, accelerating the process of variety improvement.

During the era of Breeding 2.0, the creation of variation populations and phenotype selection allows breeders to conduct breeding work more purposefully. By hybridizing and selecting the variation population, breeders can observe and record the genetic traits of different individuals, thus establishing classical genetic maps based on plant genetic traits (Shen et al., 2022). These maps reveal the relationships between different traits, helping breeders better understand the role of genes and the laws of genetic transmission. Based on information from genetic maps, breeders can more accurately select individuals with desired traits for reproduction and selection, enhancing the efficiency and precision of variety improvement (Fang et al., 2001).

The acclaimed Green Revolution with dwarf wheat and China's hybrid rice are successful examples achieved through the creation of variation populations and phenotype selection. The cultivation of dwarf wheat significantly increased crop yields, addressing food shortages; while the breeding of hybrid rice made significant contributions to food security in China and other developing countries (Asano et al., 2011). These instances demonstrate the effectiveness and practical application of variation populations and phenotype selection in Breeding 2.0, bringing significant progress in improving plant varieties.

Through the creation of variation populations and phenotype selection, Breeding 2.0 provides more precise and efficient methods and approaches for breeding work, accelerating the process of variety improvement and making significant contributions to the sustainable development of agriculture and food security.

4 The Value and Cornerstone Role of Breeding 2.0

Breeding 2.0, as a crucial stage of modern genetic breeding, has made indispensable contributions to the development and progress of breeding work and serves as the cornerstone for future Breeding 3.0 and higher-level breeding endeavors.

The emergence of Breeding 2.0 marks a transition from empirical and unconscious selection to scientific and conscious selection in breeding work. By applying Mendel's laws of heredity, Morgan's theory of genetics, and principles of quantitative genetics, Breeding 2.0 enables breeders to predict and select genotypes more accurately, accelerating the accumulation of desirable traits and genetic improvements. Additionally, Breeding 2.0 introduces the application of experimental design, statistical analysis, and modern molecular tools, providing more precise and efficient methods and means for breeding work.

The development of Breeding 2.0 has laid a solid foundation for future Breeding 3.0 and higher-level breeding endeavors. Through establishing genetic maps and applying techniques such as quantitative genetics and molecular markers, Breeding 2.0 offers essential references and insights for the advancement of Breeding 3.0 (Salgotra and Stewart Jr, 2020). The practical experience and scientific principles of Breeding 2.0 underpin the application of genetic improvements and new technologies like gene editing in Breeding 3.0. Moreover, Breeding 2.0 has nurtured a cohort of breeders with rich experience and expertise, contributing to the human resource reserve for future Breeding 3.0.

In the evolving process, Breeding 2.0 faces new challenges and opportunities. With the continuous advancement of science and technology, Breeding 3.0 and higher-level breeding approaches will gradually emerge (Wallace et al., 2018). Breeding 2.0 needs to better integrate with advanced gene editing techniques, tissue culture, genomics, and other fields to drive innovation and breakthroughs in breeding work. Simultaneously, Breeding 2.0 must synergize with sustainable agriculture and environmental protection to make greater contributions to global agricultural sustainability.

In summary, Breeding 2.0, as a crucial stage of modern genetic breeding, has made significant contributions and holds considerable value for modern genetic breeding. It not only brings scientific and modern progress to breeding work but also lays a solid foundation for future Breeding 3.0 and higher-level breeding. The impact of Breeding 2.0 will endure and contribute significantly to food security and sustainable agricultural development in human society.

5 Conclusion

Looking back at the development and application of Breeding 2.0, as well as the significance of variation populations and phenotype selection in Breeding 2.0, its emergence marks a shift from unconscious selection and empiricism in breeding work to a more scientific and conscious selection phase. By creating variation populations and employing phenotype selection, breeders can more precisely choose and improve plant varieties, enhancing crop yield, quality, and resistance. The application of these techniques and methods lays a solid foundation for the progress of breeding work and agricultural development.

Breeding 2.0 will have a lasting impact and development on plant breeding and agriculture. With the continuous advancement of science and technology, Breeding 3.0 and higher-level breeding approaches will gradually emerge. Building on the experience and achievements of Breeding 2.0, we can foresee a future emphasis on the application of cutting-edge technologies such as gene editing, tissue culture, and genomics in breeding. Additionally, Breeding 2.0 needs to synergize with sustainable agriculture and environmental protection to contribute more significantly to achieving sustainable agricultural development.

Clearly, Breeding 2.0 plays a crucial role in plant breeding and agricultural development. Through methods such as variation populations and phenotype selection, Breeding 2.0 provides a foundation for the scientific, precise, and efficient advancement of breeding work. Breeding 2.0 will continue to have a sustained impact on plant breeding, providing direction and challenges for future breeding endeavors. We look forward to more innovations and collaborations, collectively driving progress in plant breeding and making greater contributions to sustainable agriculture and food security.

References

Asano K., Yamasaki M., Takuno S., Miura K., Katagiri S., Ito T., Doi K., Wu J., Ebana K., Matsumoto T., Innan H., Kitano H., Ashikari M., and Matsuoka M., 2011, Artificial selection for a green revolution gene during japonica rice domestication, Proceedings of the National Academy of Sciences of the United States of America, 108(27): 11034-11039.
https://doi.org/10.1073/pnas.1019490108
PMid:21646530 PMCid:PMC3131315

Bai Y., Jiang M., Xie T., Jiang C., Gu M., Zhou X., Yan X., Yuan Y., and Huang L., 2021, Archaeobotanical evidence of the use of medicinal cannabis in a secular context unearthed from south China, Journal of Ethnopharmacology, 275: 114114.
https://doi.org/10.1016/j.jep.2021.114114
PMid:33848611

Fang J., 2022, Brief history of plant breeding (I): from in-situ care to ex-situ planting, Molecular Plant Breeding, 13(25): 1-5.
https://doi.org/10.5376/mpb.2022.13.0025

Fang J., 2023, Brief history of plant breeding (II): From transplantation, division, cutting, grafting to primitive domestication, Molecular Plant Breeding, 14(12): 1-5.
https://doi.org/10.5376/mpb.2023.14.0012

Fang X.J., Wu W.R., and Tang J.L., 2001, Crop DNA marker-assisted breeding, Science Press, PP 1-84.

Gayon J., 2016, From mendel to epigenetics: History of genetics, C. R. Biol., 339(7-8): 225-230.
https://doi.org/10.1016/j.crvi.2016.05.009
PMid:27263362

Leach H.M., 2020, Selection and the unforeseen consequences of domestication, In Where the Wild Things Are Now, Routledge, pp.71-99.
https://doi.org/10.4324/9781003087373-4

Oladosu Y., Rafii M.Y., Abdullah N., Hussin G., Ramli A., Rahim H.A., and Usman M., 2016, Principle and application of plant mutagenesis in crop improvement: a review, Biotechnology & Biotechnological Equipment, 30(1): 1-16.
https://doi.org/10.1080/13102818.2015.1087333

Salgotra R.K., and Stewart Jr C.N., 2020, Functional markers for precision plant breeding, Int. J. Mol. Sci., 21(13): 4792.
https://doi.org/10.3390/ijms21134792
PMid:32640763 PMCid:PMC7370099

Shen Y., Zhou G., Liang C., and Tian Z., 2022, Omics-based interdisciplinarity is accelerating plant breeding, Current Opinion in Plant Biology, 66: 102167.
https://doi.org/10.1016/j.pbi.2021.102167
PMid:35016139

Wallace J.G., Rodgers-Melnick E., and Buckler E.S., 2018, On the road to breeding 4.0: unraveling the good, the bad, and the boring of crop quantitative genomics, Annu. Rev. Genet., 52: 421-444.
https://doi.org/10.1146/annurev-genet-120116-024846
PMid:30285496

Wolf J.B., Ferguson-Smith A.C., and Lorenz A., 2022, Mendel's laws of heredity on his 200th birthday: What have we learned by considering exceptions?, Heredity, 129(1): 1-3.
https://doi.org/10.1038/s41437-022-00552-y
PMid:35778507 PMCid:PMC9273789