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Agriculture Development: Utilization of Genetic Gain as an Indicator for Agricultural R&D and Data-Intensive Plant Breeding

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Abstract

Building on the availability of new data technologies and bridging the biological interest in crop improvement with the economic interest in increasing the cost efficiency of breeding programs, accelerating the rate of genetic gain has emerged as a key objective in plant breeding for the Global South in recent years. The changing knowledge-control regimes of plant breeding, the social and political repercussions for smallholder farmers, and climate-adaptive agriculture are all the focus of this paper, which explains the concept of genetic gain, the conditions that led to its emerging status as an indicator of agricultural development, and the broader implications of this move. When choosing agricultural policies, we look at how the relationship between development goals and practice is affected by prioritizing the variables used to derive the indicator. In the absence of information on other key areas (such as agrobiodiversity, seed systems, and the differential impact of climate change on soil, crops, and communities) and tools to evaluate the advantages and disadvantages of the acceleration in seed selection, management, and evaluation fostered by the adoption of genetic gain as a key indicator, we conclude that genetic gain should not be considered as a primary indicator of agricultural development.

Keywords: Indicators; Genetics in numbers; Cloning of plants; Agriculture; Climate change

Introduction

On a practical, social, epistemic, and technological level, the organization of biological research and the production of biotechnologies has changed significantly as a result of the genomics revolution in biosciences. The development of transgenic technologies and genome editing techniques like CRISPR for food and agriculture have received a lot of attention, and plant science and its applied fields are no exception [1]. These technologies are frequently referred to as "new breeding techniques," and their novelty, disruptive potential, and risk are frequently examined. Plant scientist Caixia Gao, on the other hand, pointed out that CRISPR and similar technologies' ability to produce "identical results to conventional [breeding] methods in a much more predictable, faster, and even cheaper manner" is a significant advantage that goes beyond the headlines. In point of fact, major debates continue to focus on the question of whether gene editing produces outcomes that are distinct from those produced by conventional breeding methods like chemically induced mutagenesis, as well as what this might mean for regulation. Speed and efficiency in the identification and production of valuable varieties are increasingly prioritized as both practical and policy goals at a time when the role of genomics in plant breeding is still being defined. The use of gene editing technologies for this purpose is just the tip of the iceberg; in point of fact, this strategy is fraught with difficulties [2]. Limited resources make it difficult to scale up cutting-edge technologies like CRISPR for international agricultural research and breeding networks that focus on the Global South; Areas of the Global North that cannot replicate the conditions required of intensively managed crops or are remote from large-scale processing infrastructure face similar concerns. Agricultural research networks are being reorganized in ways that combine older statistical and more recent data-intensive breeding techniques, which has a wide impact on scientific research, breeding practice, and agricultural systems. This change is less obvious but has a larger impact.

The Bill and Melinda Gates Foundation (BMGF), which is currently a major funder of the CGIAR and of international research focused on development more generally, is spearheading this commitment in plant breeding for the public domain and the Global South [3]. The CGIAR is arguably the most influential and extensive research network for agricultural research in the world. Advanced commercial plant breeding programs also have well-established objectives that are comparable. In order to focus on the specific changes to public plant breeding in the international arena, where resources are limited and the structure of objectives is explicitly oriented towards a wider range of development goals beyond commercial growth, we, on the other hand, leave the latter aside in this paper.

We identify a set of proposals for the use of genetic gain as a performance indicator by analyzing relevant scientific literature and international initiatives that promote data-intensive agriculture. These proposals prioritize the achievement of greater genetic gain in seed systems and agriculture as a necessary step toward food security and sustainable agricultural development. We draw attention to the difficulties that climate-adaptive agriculture and sustainable seed system management face as a result of this set of proposals. In conclusion, we make the observation that genetic gain, despite its value as one of the primary indicators of agronomic performance, is insufficient to evaluate the rate of plant breeding progress toward agricultural development objectives [4]. Instead, breeding programs need to make sure that breeding outputs are adaptable to a variety of agroecological systems and that breeding programs recognize the multiple benefits of agricultural biodiversity. This should be done in addition to the tendency to prioritize and reward the speed of breeding.

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The following structure of the paper serves this purpose: The paper's second section provides an overview of genetic gain and its status as an indicator. In section, we discuss the context in which the value of genetic gain has been placed and the reasons why it has gained prominence in modern plant breeding. In the third section, we discuss the changing context in which genetic gain is used in international plant breeding. We focus on a number of modernizations that aim to make plant breeding more data-driven and a related set of changes in the knowledge-control regimes that structure international breeding networks. The fourth section returns to the idea of genetic gain and demonstrates how the elements that were used as variables in the calculation of the indicator are prioritized as investment targets. This has an effect on whether or not greater genetic gain contributes to major goals like the creation of climate-adaptive agriculture and how it does so [5]. The implications of accelerating genetic gain for seed systems are the subject of the fifth section, which focuses on how these commitments to greater speed are directly linked to visions of greater agricultural commercialization in the Global South. In conclusion, we expand our focus to the place that agronomic indicators play in the broader knowledge-control regimes of agricultural development and consider the questions that the aforementioned analysis raises for this particular field. We suggest ways to use indicators for agricultural development in a way that is understandable, responsive to stakeholders, and takes into account a wider range of agroecological diversity and sustainability goals and values.

Methods and Materials

Plant breeding is the science and practice of improving plants through controlled mating and selection. It involves various methods and materials to achieve desired traits and develop improved plant varieties. Here are some commonly used methods and materials in plant breeding:

Phenotypic evaluation

Phenotypic evaluation is the assessment of observable traits or characteristics of plants, such as plant height, flowering time, disease resistance, yield, and quality attributes [6]. This evaluation is often done visually or through measurements and is an essential initial step in identifying desirable traits for breeding. Selection is the process of choosing individual plants or breeding lines with desired traits for further propagation. It can be based on phenotypic evaluations, where plants displaying the desired traits are selected, or on pedigree information, where plants with known superior genetics are chosen. Hybridization involves controlled mating between two parent plants with complementary traits to produce offspring with a combination of desirable characteristics. The parents may be different varieties, cultivars, or even species. Hybridization is commonly used to introduce traits like disease resistance, improved yield, or specific quality attributes into breeding programs.

Cross-pollination is the transfer of pollen from the male reproductive organs (anthers) of one plant to the female reproductive organs (stigma) of another plant. It is a common method used in plant breeding to achieve genetic recombination and introduce genetic diversity into the offspring.

Self-pollination

Self-pollination occurs when pollen from the anthers of a flower is transferred to the stigma of the same flower or another flower on the same plant. Self-pollination is advantageous for maintaining desirable traits in a plant population and for producing true-breeding lines [7]. It is commonly used in self-pollinated crops like wheat, rice, and soybeans. Inbreeding is the process of mating plants that are closely related, such as siblings or self-pollinated individuals, to produce offspring with a higher degree of genetic uniformity. Inbreeding helps to fix desired traits and create homozygous lines, which are important for developing pure breeding lines or parental lines for hybridization. Crossbreeding involves the deliberate crossing of two different plant varieties or populations to create hybrid offspring. The goal is to combine desirable traits from the parents and produce plants with improved characteristics. Crossbreeding is commonly used to develop hybrid varieties that exhibit hybrid vigor or heterosis, resulting in increased yield and other desirable traits. Mutation breeding involves inducing genetic mutations in plants to generate new and novel traits. This can be achieved through exposure to radiation (e.g., gamma rays) or chemicals that induce mutations in the DNA. The mutated plants are then screened for desired traits and selected for further breeding.

Biotechnology

Biotechnological tools, such as genetic engineering and genome editing techniques, are increasingly being used in plant breeding. Genetic engineering involves the introduction of specific genes or genetic material from one organism into another to confer desired traits, such as pest resistance or herbicide tolerance [8]. Genome editing techniques, like CRISPR-Cas9, enable precise modifications of specific genes within a plant's genome to create targeted improvements. Germplasm refers to the collection of plant genetic resources, including seeds, tissues, or living plants, that can be used for breeding purposes. Germplasm banks, gene banks, and seed banks preserve and provide access to diverse plant genetic materials for breeders to use in their breeding programs.

These methods and materials are widely employed in plant breeding to develop improved plant varieties with enhanced traits, such as higher yield, disease resistance, improved quality, and adaptation to environmental conditions.

Result and Discussion

Plant breeding has yielded significant results and has sparked numerous discussions in the field of agriculture and plant science. Here are some key results and topics of discussion associated with plant breeding. Plant breeding has played a crucial role in increasing crop yield and productivity. Through the selection and development of high-yielding varieties, breeders have contributed to the global food supply and addressed food security challenges. Improved yield potential has been achieved through traits such as increased photosynthetic efficiency, disease resistance, and tolerance to abiotic stresses. Plant breeding has successfully introduced genetic resistance to various diseases and pests. Breeders have identified and incorporated genes from resistant plant sources into cultivated varieties, reducing crop losses and the reliance on chemical pesticides [9]. Discussions revolve around the development and deployment of resistant varieties to combat emerging diseases and pests.

Plant breeding has focused on developing crops with enhanced tolerance to abiotic stresses such as drought, heat, salinity, and cold. Through genetic selection and hybridization, breeders have introduced traits that enable plants to thrive under adverse environmental conditions. The development of stress-tolerant varieties contributes to climate change resilience and sustainable agriculture. Plant breeding has been instrumental in improving the nutritional quality of crops. Breeders have developed varieties with increased levels of essential nutrients, such as vitamins, minerals, and antioxidants. This has the potential to address malnutrition and improve human health. Discussions center around biofortification, the process of breeding crops with enhanced nutritional content. Plant breeding plays a vital role in developing crops that can adapt to changing environmental conditions. With climate change impacts, breeders aim to develop varieties that can tolerate temperature fluctuations, erratic rainfall, and shifting pest and disease patterns. Discussions focus on breeding for resilience, ensuring crop productivity and food security in a changing climate.

Plant breeding takes into account consumer preferences and market demands. Breeders work to develop crop varieties that meet consumer expectations for taste, appearance, texture, and other quality attributes. Discussions involve understanding and aligning breeding objectives with consumer preferences, promoting sustainable food systems, and addressing market demands. Plant breeding efforts also contribute to the conservation of genetic diversity in cultivated crops. By utilizing diverse germplasm resources and wild relatives, breeders preserve and harness genetic variation to develop improved varieties. Discussions revolve around the importance of maintaining genetic diversity for future breeding programs and mitigating the risks of genetic erosion.

Plant breeding, especially biotechnological approaches like genetic engineering, raises ethical and social concerns [10]. Discussions revolve around the safety, environmental impacts, and public acceptance of genetically modified crops. Balancing the potential benefits of new breeding technologies with ethical and social considerations is an ongoing topic of discussion. Intellectual Property Rights and Access to Genetic Resources surrounding intellectual property rights and access to genetic resources play a significant role in plant breeding. Breeders face challenges related to patenting, seed ownership, and fair benefit-sharing arrangements. Discussions focus on balancing intellectual property protection with the need for equitable access to genetic resources and the fair distribution of benefits.

Plant breeding has achieved remarkable results in improving crop traits, increasing yield, and addressing various agricultural challenges. Ongoing discussions encompass the development of sustainable and climate-resilient crop varieties, addressing emerging diseases and pests, ensuring equitable access to genetic resources, and navigating the ethical and social implications of new breeding technologies [11]. The continuous advancement and collaboration in plant breeding are essential for sustainable agriculture and global food security.

Conclusion

In conclusion, plant breeding is a dynamic and essential field of agriculture and plant science. Through the application of various methods and the use of diverse materials, plant breeders have achieved significant results in improving crop traits, increasing yield, enhancing nutritional quality, and developing crops with resistance to diseases, pests, and environmental stresses. The outcomes of plant breeding have contributed to global food security, sustainable agriculture, and the adaptation of crops to changing environmental conditions. Improved varieties have provided higher yields, reduced crop losses, and increased resilience to biotic and abiotic stresses. Additionally, plant breeding has addressed nutritional deficiencies, enhanced consumer preferences, and promoted the conservation of genetic diversity.

However, discussions surrounding plant breeding continue to evolve. Ethical considerations, regulatory frameworks, intellectual property rights, and public acceptance of genetically modified crops remain important topics. Balancing scientific advancements with societal concerns is crucial for responsible and equitable implementation of plant breeding technologies. Looking ahead, plant breeding will continue to play a vital role in addressing emerging challenges in agriculture, such as climate change, evolving pests and diseases, and the need for sustainable and nutritious food systems. The integration of advanced technologies, such as genetic engineering, genome editing, and high-throughput phenotyping, will further enhance the efficiency and precision of plant breeding efforts.

Ultimately, plant breeding will be crucial for ensuring global food security, promoting sustainable agriculture practices, and meeting the diverse needs of an ever-growing population. Continuous collaboration, innovation, and dialogue within the field will contribute to the development of improved crop varieties and the advancement of agriculture as a whole.

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Conflict of Interest

None

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