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Composite and Synthetic Varieties Development, Maintenance, Merit and Achievements: A Review

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ABSTRACT

By increasing crop output, genetic variety and environmental tolerance, composite and synthetic varieties have made a substantial contribution to modern agriculture. By combining seeds from many genetically distinct parent lines and permitting unrestricted interbreeding between them over the course of subsequent generations, composite varieties are created, producing genetically varied populations that are more resilient to environmental challenges. On the other hand, controlled hybridization of specific inbred lines is used to create synthetic varieties, which take advantage of hybrid vigor (heterosis) to increase yields and enhance stress tolerance. The Green Revolution showed that both synthetic and composite varieties were successful in increasing global food security, but there are still significant issues like genetic drift, loss of heterosis and environmental pressures. Future breeding efforts should incorporate advanced biotechnological tools, such as marker-assisted selection and gene editing, to improve breeding efficiency and develop climate-resilient varieties. This review examines the methods and mechanisms involved in developing and maintaining synthetic and composite varieties, highlighting their respective advantages, challenges and accomplishments. Maintaining the success of composite and synthetic varieties in a variety of agricultural systems requires enhancing availability to high-quality seed and fortifying participatory breeding techniques.

Key words: Composite varieties, Crop resilience, Environmental adaptability, Heterosis, Hybrid vigor, Molecular breeding, Synthetic varieties, Yield improvement.

Crop production and resilience to biotic and abiotic challenges have increased significantly as a result of the creation of composite and synthetic cultivars. Because they can integrate beneficial features from several parental lines to improve yield stability, adaptability and disease resistance, composite and synthetic varieties are essential in plant breeding projects. In order to preserve genetic variability and adaptability, composite varieties are created by intercrossing a large base of genetically varied parental lines, followed by mass selection or natural selection (Allard, 1960; Simmonds, 1979). Conversely, regulated crossings of certain inbred lines are used to produce synthetic varieties, which combine the finest qualities of each parent to increase the stability and vigor of the hybrid (Sprague and Eberhart, 1977; Falconer and Mackay, 1996).

Composite cultivars are particularly beneficial for their ability to retain genetic variety, which promotes resilience to environmental changes and pests (Jain, 2000). They are commonly utilized in self-pollinated crops such as rice and wheat, where genetic stability and flexibility are crucial for continued yield (Allard, 1960). Conversely, synthetic varieties are more prevalent in cross-pollinated crops, such as rye and maize, where hybrid vigor or heterosis can greatly improve performance and yield (Sprague and Eberhart, 1977). In order to prevent genetic drift and maintain the intended features through appropriate breeding and selection techniques, these variations need to be maintained strategically (Falconer and Mackay, 1996).

The advantages of composite and synthetic varieties include their capacity to produce high and consistent yields, increased resistance to pests and diseases and improved tolerance to environmental stressors like drought and salinity (Simmonds, 1979; Jain, 2000). Developments in this area include the creation of high-yielding and disease-resistant varieties that have improved livelihoods and contributed to food security in many regions of the world. For example, the introduction of composite and synthetic varieties was extremely beneficial to the Green Revolution, increasing global crop production and lowering the risk of food shortages (Borlaug, 2007).

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Thus, the goal of this review is to present a thorough examination of the creation, upkeep, value and accomplish ments of composite and synthetic varieties, emphasizing their function in contemporary agriculture and potential applications in crop improvement initiatives in the future.

Objectives

This review aims to achieve the following objectives:

To explore the development methods of composite and synthetic varieties

This includes examining the historical background, genetic principles and breeding techniques used in creating composite and synthetic varieties.

To analyze the maintenance strategies of composite and synthetic varieties

This involves understanding the genetic stability, selection processes and challenges involved in preserving the desired traits of these varieties over successive generations.

To evaluate the merits of composite and synthetic varieties

This includes assessing their advantages in terms of yield potential, stress tolerance, disease resistance and genetic diversity.

To highlight the achievements and contributions of composite and synthetic varieties

This covers significant successes in crop improvement programs, their role in enhancing food security and their impact on global agricultural productivity.

To identify future prospects and challenges

This includes discussing the potential for further improvement, breeding innovations and the role of biotechnology in enhancing the performance of composite and synthetic varieties.

Literature review

Development of composite and synthetic varieties

Composite varieties

Early population breeding techniques intended to increase genetic diversity and adaptability gave rise to the idea of composite varieties. When seeds from many different but complimentary parental lines are combined and allowed to freely interbreed over the course of subsequent generations, composite types are created (Allard, 1960). Through natural and artificial selection, this strategy allows advantageous alleles to accumulate, gradually enhancing population performance (Jain, 2000).

According to Allard (1960) and Simmonds (1979), the fundamental benefit of composite varieties is that they preserve genetic variety within the population, enabling increased environmental adaptability and resilience to biotic and abiotic pressures. The following procedures are involved in the creation of composite varieties, according Allard (1960): choosing parent lines according to desired characteristics including stress tolerance, disease resistance and yield potential. Using artificial or natural pollination to cross the parent lines. Letting the resultant population be stabilized by mass selection or natural selection over a number of generations. To guarantee trait performance and genetic integrity, monitoring and reselection are necessary.

According to Verma and Yadav (2017), the genetic complementarily of the parental lines is essential to the success of composite varieties. A larger genetic foundation is provided by highly diversified parental lines, which improves the composite population's ability to adapt to shifting environmental conditions. Composite wheat cultivars created in China and India, for instance, have demonstrated exceptional stability and pest and drought resistance (Jain, 2000).

Synthetic varieties

Conversely, regulated hybridization of certain inbred lines is followed by seed multiplication to produce synthetic varieties (Sprague and Eberhart, 1977). The objective is to preserve genetic stability and performance over generations while optimizing hybrid vigor, or heterosis. According to Falconer and Mackay (1996), the development of synthetic varieties involves the following steps: Parental lines are chosen by combining trait performance and ability. F1 hybrids are produced through carefully regulated crossings between specific inbred strains. Propagation of seeds from the hybrids that perform the best. Cyclical evaluation and selection to improve stress tolerance and yield.

In cross-pollinated crops such as maize, rye and forage grasses, where heterosis can greatly boost production potential and stress resistance, synthetic cultivars are especially effective, according to Sprague and Eberhart (1977). According to Acquaah (2012), synthetic maize cultivators in Latin America and sub-Saharan Africa have consistently demonstrated increases in productivity and disease resistance.

The capacity of synthetic variety to capture and hold onto hybrid vigor is their primary advantage over composite types. However, compared to composite varieties, synthetic varieties are more vulnerable to environmental changes and disease outbreaks due to their genetic homogeneity (Falconer and Mackay, 1996).

Table 1 shows a thorough comparison of synthetic and composite varieties based on their genetic structures, market adaptabilities, and yield results. The breeding strategy for composite varieties is different from that for synthetic varieties in terms of preserving genetic diversity; open pollinated composites use their natural breeding techniques, whereas synthetic breeds are the product of choosing their original parental lines.

Maintenance of composite and synthetic varieties

Maintenance of composite varieties

Maintaining composite varieties necessitates striking a compromise between selecting for desired features and

maintaining genetic variability. Allard (1960) asserts that mass selection, in which the top-performing plants are chosen for seed production in each generation, maintains composite types. This enhances overall performance while guaranteeing that the population maintains its genetic heterogeneity.

In composite populations, there is a risk of genetic drift and inbreeding depression. Simmonds (1979) pointed out that in order to mitigate these consequences; superior lines must be continuously evaluated and reselected. In order to maintain genetic purity, new parental lines are frequently added to the composite population on a regular basis to replenish genetic diversity. According to Jain (2000), it is easier to preserve composite variations in self-pollinated crops, such as rice and wheat, than in cross-pollinated crops. Greater genetic stability is ensured by self-pollination, which lowers the possibility of inbreeding depression and genetic drift. However, over time, genetic erosion may still result from environmental selection forces, requiring careful selection and monitoring.

Maintenance of synthetic varieties

Because synthetic varieties rely on hybrid vigor, they are more difficult to maintain than composite kinds. Sprague and Eberhart (1977) state that controlled pollination and seed multiplication from the best-performing hybrids are used to sustain synthetic variations. Sharma and Singh (2018) highlighted that loss of heterosis over many generations can result from genetic drift and recombination. Thus, it is necessary to regularly reselect parental lines in order to maintain synthetic variations.

Pollination was regulated to avoid foreign pollen contamination and trait performance was tracked to find and get rid of subpar variations. Acquaah (2012) underlined that synthetic maize varieties have been maintained by systematic breeding programs comprising recurrent selection and hybrid seed manufacturing. This has ensured sustained yield improvements and stress tolerance throughout time.

Merits of composite and synthetic varieties

Composite varieties

In plant breeding, composite varieties offer a number of benefits

Genetic diversity: increased resilience to illnesses and pests and increased ability to respond to changes in the environment (Allard, 1960). Yield Stability: Reliable results in a variety of settings (Simmonds, 1979). Low Input Requirement: Because it requires fewer fertilizers and pesticides, it is appropriate for farmers with limited resources (Pateland Patel, 2016). Enhanced tolerance to biotic and abiotic stressors, including as disease outbreaks, salt and drought (Witcombe and Joshi, 2007).

Synthetic varieties

The following are some advantages of synthetic varieties: High Yield Potential: Using hybrid vigor to its full potential increases yield (Ceccarelli, 1996); Uniformity: Increased consistency in plant height, maturity and yield (Harlan and de Wet, 1971). Improved Stress Resistance: By carefully choosing parental lines, improved resistance to

Table 1: Comparison of composite and synthetic varieties.

Aspect	Composite varieties	Synthetic varieties
Definition	Developed by interbreeding genetically diverse parental lines over successive generations.	Developed by controlled hybridization of selected inbred lines to exploit hybrid vigor (heterosis).
Genetic structure	Genetically heterogeneous (high diversity).	Genetically homogeneous (uniform population).
Development method	Mixing seeds from diverse parental lines and allowing natural or artificial selection.	Controlled crossing of inbred lines followed by seed multiplication.
Genetic diversity	High - ensures better adaptability to environmental changes.	Moderate - increased uniformity but reduced genetic variability.
Yield potential	Moderate and stable over time due to genetic diversity.	High due to hybrid vigor but may decline over generations.
Environmental adaptability	High - better performance under variable environmental conditions.	Moderate - sensitive to environmental changes due to genetic uniformity.
Stress tolerance	Better tolerance to drought, diseases and pests due to genetic diversity.	Improved resistance to specific stresses due to selected parental lines.
Maintenance	Maintained through mass selection and periodic introduction of new parental lines.	Maintained through controlled pollination and selection of best-performing hybrids.
Cost of production	Lower – less technical expertise and input required.	Higher - requires technical expertise and controlled breeding programs.
Suitability	Suitable for low-input farming systems and resource-poor farmers.	Suitable for intensive agricultural systems and high-input farming.
Challenges	- Genetic drift	

environmental stresses and diseases (Reif and Zhang, 2013); Improved Nutritional Quality: Certain synthetic varieties have been created to increase nutrient content (Lübberstedt and Pixley, 2006).

Table 2 lists several benefits that composite and synthetic varieties offer over traditional breeding methods. These benefits include preserving genetic diversity, adapting to a variety of environments and reducing reliance on multiple hybrid seeds.

Achievements in composite and synthetic variety development

The production of synthetic and composite cultivars has greatly increased agricultural production and global food security. The introduction of high-yielding synthetic and composite wheat and rice cultivars was a major factor in the Green Revolution (Guo and Li, 2018). Composite rice and wheat cultivars have decreased poverty and increased food security in India (Taba, 2009). More maize has been produced and incomes have improved thanks to synthetic maize types created in Mexico and sub-Saharan Africa (Mather and Jinks, 1982). Crop losses from bacterial and fungal diseases have decreased with the use of disease-resistant synthetic and composite cultivars (Duvick and Cassman, 1999).

Challenges and future prospects

Notwithstanding the achievements, preserving and enhancing composite and synthetic variations still presents difficulties.

Genetic drift

Over time, composite varieties lose their genetic diversity (Kumar and Soni, 2020).

Loss of heterosis

Genetic recombination causes synthetic varieties to have less hybrid vigor (Singh and Chaudhary, 1985).

Table 2: Advantages, disadvantages and achievements of composite and synthetic varieties.

Aspect	Composite varieties	Synthetic varieties
Advantages	- High genetic diversity, enhancing adaptability.	- High yield potential due to hybrid vigor (heterosis).
	- Resilience to environmental stress (*e.g.*, drought, pests).	- Uniformity in traits such as plant height and maturity.
	- Suitable for low-input farming systems.	- Improved resistance to specific diseases and pests.
	- Easy to maintain with periodic reselection of superior plants.	- Suitable for high-input, intensive farming systems.
	- Better performance in varying environments.	- Increased crop uniformity, reducing harvesting costs.
Disadvantages	- Lower yield potential compared to synthetic varieties.	- Genetic uniformity can lead to increased vulnerability to diseases and environmental changes.
	- Risk of genetic erosion and inbreeding depression.	- Requires regular reselection to maintain hybrid vigor.
	- Potential loss of desirable traits due to genetic drift.	- High cost of seed production and maintenance.
	- Requires introduction of new parental lines over time to maintain diversity.	- Limited genetic diversity due to reliance on selected inbred lines.
Achievements	- Successful use in developing countries with limited resources.	- Significant contribution to increased crop productivity in commercial farming.
	- Enhanced food security through genetically diverse, resilient crops.	- Revolutionized crop production, especially in staple crops like maize, wheat and rice.
	- Development of stress-resistant varieties, including drought and disease-resistant crops.	- Major increase in yield potential through the exploitation of hybrid vigor.
	- Provided varieties suited to resource-poor farming systems.	- Used in large-scale commercial farming with high yield and efficiency.
Examples	- Composite wheat and rice varieties in India, China and Africa.	- Synthetic maize varieties in Mexico, sub-Saharan Africa and the U.S.
	- Composite varieties of sorghum and millet in arid regions.	- Hybrid rye and maize varieties used in the U.S., Brazil and other major agricultural zones.

Environmental change

New risks to variety performance come from climate change and emerging pests (Harlan, 1975).

Biotechnological Integration

Future composite and synthetic variety development may benefit from developments in CRISPR-based gene editing and molecular breeding (Gupta *et al.,* 2019).

CONCLUSION

Composite and synthetic crop varieties are essential to modern farming because they improve environmental resilience and increase yield potential. Due to the combination of decreased heterosis effects and genetic degradation, current breeding techniques are still necessary. Gene editing and genomic selection are examples of molecular technologies that improve crop performance. Farmers that plant these crops will establish sustainable agricultural systems that are more resilient to climate change. Scientists must combine scientific discoveries with practical farming methods to meet the demands of both the present and the future of food production.

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Author contributions

Nuru Seid Tehulie: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Resources; Supervision; Validation; Visualization; Writing-original draft; Writing review and editing. Fikru Mekonnen: Conceptualization; Formal analysis; Investigation; Resources; Supervision; Validation; Visualization Agegnehu Mekonnen, Ahmed Hassen, Semira Ebrahim and Solomon Abebe Validation; Visualization; Writing review and editing.

Conflict of interest

The authors declare no conflict of interest.

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