Polyploidy: Perspectives and practical applications for genetic improvement

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ABSTRACT
This work explores polyploidy and its significant implications for plant genetic improvement. Polyploidy, which is characterized by the presence of multiple sets of chromosomes, is an essential evolutionary force that impacts the evolution of plant species. This phenomenon is associated with several advantages, such as greater genetic diversity, vigor and resistance to abiotic and biotic stresses, making it crucial for the development of more productive cultivars adapted to adverse conditions. The study reviews methods of polyploidy induction, including physical, chemical, and biotechnological techniques, and discusses their practical applications, such as in the production of seedless fruits and in increasing biomass. In addition, it addresses the challenges and future prospects, highlighting the need for more research to fully understand its genomic and phenotypic consequences. It is concluded that the exploitation of polyploidy is vital to meet the growing demand for food and face climate change, providing new opportunities in the improvement of several species, including ornamental and medicinal, expanding their economic and ecological potential.

Keywords: Polyploids, Antimitotics, Autopolyploids, Allopolyploid, Genetic variation.

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INTRODUCTION

Polyploidy, characterized by the presence of multiple sets of chromosomes in a cell, is a significant evolutionary force that has played a crucial role in the evolution of plants (Mezzasalma *et al.,* 2023; Van de Peer *et al.,* 2020). This phenomenon, common in many plant species, has profound implications for genetic improvement, as it is associated with several structural, physiological and biochemical changes that can directly influence the agronomic characteristics of plants (Van de Peer; Mizrachi; Marchal, 2017; Madani *et al*., 2021).

The study of polyploidy has become increasingly relevant, especially in the context of plant breeding. Polyploid plants generally have greater genetic diversity, vigor and resistance to abiotic and biotic stresses, characteristics that are of great interest for the development of new cultivars that are more productive and adapted to adverse conditions (Sattler; Oak; Clarindo, 2016; Zhang *et al.,* 2018). In addition, polyploidy has been explored as a tool for seedless fruit production, biomass increase, and improvement of plant nutritional quality (Zhang *et al.,* 2018). These advantages allow polyploid plants to play a crucial role in food security, as they make it possible to create more resilient and efficient cultivars, especially in the face of climate change and increased demand for food (Van de Peer *et al.,* 2020). The exploitation of polyploidy also opens up new opportunities in programs for the improvement of ornamental and medicinal species, expanding the economic and ecological potential of vegetable crops (Madani *et al*., 2021).

Therefore, this work aims to investigate the role of polyploidy in plant species, focusing on its implications for genetic improvement. The main methods of polyploidy induction, their practical applications in the development of new cultivars, as well as the challenges and future perspectives in this field of study were explored. The research seeks to answer the following question: what are the effects of polyploidy on the agronomic characteristics of plant species and how can this phenomenon be used for genetic improvement?

METHODOLOGY

For the conception of this study, a narrative literature review was carried out, literature reviews play a crucial role in the foundation of any type of research and are essential for the advancement of knowledge. When done properly, they can also generate new ideas and direct the development of a specific field. For Greenhalgh, Thorne and Malterud (2018) a narrative review is an academic summary associated with interpretation and criticism. Sukhera (2022) points out that properly performed narrative reviews provide a readable, thoughtful, and practical synthesis on a subject, allowing authors to address other ideas while describing and interpreting what is known in the literature on the topic of interest of the research. They make it possible to conduct a subjective and critical examination while providing *insights* into the advancement of the field of study, new theories, or current evidence seen from different or unusual perspectives to build a scientific knowledge base.

RESEARCH PROCEDURES

The bibliographic research was conducted using scientific articles and relevant documents found in databases such as Google Scholar, Scielo, Science Direct, ResearchGate, Lilacs, PubMed, Thesis Bank and Capes Journals, and with textbooks. The keywords used for the search included the terms "polyploidy", "plant species", "genetic improvement", "genetic variability" and "agronomic traits", in Portuguese, and "polyploidy", "plant species", "genetic improvement", "genetic variability" and "agronomic characteristics", in English, in different combinations. The time window used to guide and restrict this search was the last 10 years, so relevant articles from the period 2014 to 2024 were filtered.

STAGES OF THE REVIEW

The literature review was carried out in three main stages:

- Initial search: the first stage consisted of bibliographic research in the aforementioned databases and textbooks, using the defined keywords;
- Selection of texts: in the second stage, the selected texts were screened, based on the reading of the abstracts and the relevance of the studies to the central theme of the work, meeting the proposed objective;
- Detailed analysis: in the third stage, complete and analytical readings of the selected texts were carried out, extracting relevant data that allowed the analysis and elaboration of the present work.

LITERATURE REVIEW

POLIPLOIDIA

Polyploidy is a powerful evolutionary force that played a key role in the early genomic evolution of plants (Mezzasalma *et al.*, 2023)element. It is a common phenomenon among plant species, in which there is an increase in the number of chromosomes, generating organisms or cells with more than two complete sets of chromosomes. It is associated with a wide variety of changes, including structural, physiological, biochemical, and plant development, which offers new opportunities for breeders in the selection of plants with the ideal characteristics for various purposes, such as medicinal, ornamental functions, and increased resistance (Madani *et al*., 2021; Ghasemi *et al.,* 2021; Passos *et al.,* 2023; Salma; Kundu; Mandal, 2017).

Polyploidization is the name for the process of formation of polyploid organisms, and is widespread and particularly common in angiosperms. The resulting genetic redundancy has a very important impact on species formation and diversity, phenotypic variation, environmental tolerance, and interactions between species (Van de Peer; Mizrachi; Marchal, 2017).

Polyploids are not restricted only to crops of agronomic interest such as wheat, corn, potatoes, and brassicas, but also occur frequently in wild species and in natural habitats (Guerra, 2020; Heslop-Harrison; Schwarzacher; Liu, 2023).

Polyploidy in plants can arise naturally or be induced under laboratory conditions by physical, chemical, or biotechnological methods (Islam *et al*., 2022), and has been used as a tool in plant genetic improvement for several decades.

As for origin, how the size of the genome is increased, popliploids are classified as autopolyploids, resulting from the duplication of only one genome, and allopolyploids, which are the combination of two or more different genomes, resulting from the crossing of different species (Griffiths *et al*., 2022; Ramalho *et al*., 2022). Polyploid organisms also arise spontaneously by the fusion of unreduced gametes, and can give rise to bilateral polyploids (by the union of two unreduced gametes) or unilateral polyploids (formed from the fusion of a reduced gamete with another unreduced gamete) (Sattler; Oak; Clarindo, 2016). Darmasaputra, Rijnberk, and Galli (2024) cite that polyploid cells can form as a result of failures in the cell division process, DNA damage, or tissue injury.

According to Ravandi, Rezanejad and Dehghan (2014), polyploidy can cause alterations in gene regulation and biosynthesis of plant growth regulators, enabling significant changes in the way genes are expressed and in the way plants produce chemicals essential for their growth and development.

Regarding the purpose of somatic polyploidy, what seems to be the most accepted in the scientific community is that it would be a strategy for the production of larger cells, since fewer cells of larger sizes would have functional advantages over a similar total mass of a larger number of smaller cells, implying an increase in gene expression and metabolism (Frawley; Orr-Weaver, 2015).

Polyploid plants have greater genomic and genetic diversity compared to other plants. Early ripening varieties, seedless fruits, sterile lines, highly productive crops, resistance to adversity, and plants with therapeutic properties are obtained through the use of polyploidy (Guerra, 2020; Yali, 2022).

Soltis *et al*. (2016) gathered data, in tables, on the most studied polyploid systems regarding genome size, structural and/or karyotypic evolution, gene expression, tissue-specific gene expression, methylation patterns, transposable elements, alternative splicing, ecogeography, population genetics, reproductive ecology and physiology, reporting that the genomic/genetic systems *Gossypium, Brassica, Nicotiana, Glycine, Arabidopsis, Senecio, Spartina, Aegilops-Triticum* and *Tragopogon* are the ones with multiple temporal polyploidy samplings.

Fox *et al*. (2020) point out that polyploidy is a resource to be better explored in many fields. These authors propose a broad interdisciplinary challenge, 'polyploidy 2030', a collective study involving researchers from across the whole tree of life and in diverse fields, including evolutionary biology, ecology, agriculture, and medicine, working in an integrated manner to provide a meaningful synthesis of the role of polyploidy in biological systems and subsystems.

IMPORTANCE OF POLYPLOIDY FOR PLANT BREEDING

Polyploidy has been used for the development of new cultivars, including large crops such as wheat, cotton, potatoes and sugarcane, for example. Its genetic implications can lead to significant increases in yield, disease resistance, and grain quality, making it an area of great interest for researchers and plant breeders. Understanding and manipulating polyploidy can therefore contribute significantly to meeting the growing demand for sustainable food and agricultural resources (Zhang *et al*., 2018).

It can have several important genetic implications, such as increasing genetic variability, which can be beneficial for plant adaptation and evolution. Polyploidy has been shown to be a crucial mechanism for adaptation and speciation in plants, with great relevance to agriculture, as many important agricultural species are polyploid. Its consequences on natural populations aroused the interest of breeders for its application in crop breeding, and the "giga" effect, which increases the size of commercial organs, is especially valued. In addition, genome "buffering", heterozygosity, and heterosis (hybrid vigor) are phenomena that can confer greater vigor to polyploids compared to their diploid relatives, making them a focus in breeding programs (Guerra, 2020; Renny-Byfield; Wendel, 2014; Sattler; Oak; Clarindo, 2016).

Regarding the effects on phenotype, Madani *et al*. (2021) highlight that the change in chromosome groups and the number of genes in a cell trigger consequences that can be desirable or undesirable, and that polyploidy occurs in more than 80% of plant species, accounting for 2-4% of speciation in flowering plants.

Another factor that makes polyploidy an object of study of great interest for plant breeding is the growing accumulation of evidence that biotic interactions, such as those with pathogens or mutualists, affect polyploids differently compared to non-polyploids, and depending on the context, this difference can be exploited to develop resistance mechanisms in agricultural crops, for example (Van de Peer *et al*., 2020).

Due to its impacts on plant growth and development, chromosomal duplication has been applied in plant breeding to increase the levels of specific compounds and enhance morphological characteristics (Madani *et al*., 2021).

With Stevia *rebaudiana plants,* Zhang *et al*. (2018) observed significantly improved morphological and physiological characteristics of tetraploid plants compared to diploid plants. They found a notable increase in the density of glandular trichomes, which was approximately two to four times higher, potentiating the secretion of steviol glycosides. In addition, this study also showed that the chlorophyll content in tetraploid plants was significantly high, indicating a superior photosynthetic capacity. The plants also showed vigorous growth, with larger and thicker leaves, more robust stems and shorter internodes, resulting in a higher biomass in the aerial part. In terms of glycoside production, the levels of stevioside and rebaudioside A in tetraploid plants were, respectively, 2.5 and 1.5 times higher than in diploid plants. With these results, the authors highlighted that polyploidy induction can be an effective strategy to improve the production and quality of desirable compounds in *Stevia rebaudiana.*

A study by Ravandi, Rezanejad and Dehghan (2014) points to a disadvantage of polyploidy in relation to diploidy. In an experiment with plants in vitro, the authors concluded that polyploidy exerted a significant impact on the regeneration capacity, specifically in the plant species *Cichorium intybus* L. One of the main observations was the loss of organogenic potential in calluses of tetraploid origin, which demonstrated a lower regeneration capacity compared to calluses of diploid origin. This suggests that polyploidy may be associated with a decrease in the ability of plants to regenerate in controlled environments.

Another aspect to be highlighted is that polyploidy expands the potential base of variability, increasing the number of genes that can be mutated. It contributes to increasing genetic diversity in the plant kingdom, allowing deleterious recessive mutations to be masked by its dominant alleles in the polyploid condition (Yali, 2022).

In addition to improving yield by the "giga" effect of autopolyploidy, polyploids are essential for gene transfer between species where direct breeding is unfeasible and for restoring the fertility of sterile hybrids, caused by meiotic errors. Thus, the application of polyploidy has been crucial in the development of more productive, adapted cultivars that add economic value (Sattler; Oak; Clarindo, 2016).

It is important to note that a polyploid organism, after being originated, goes through several critical stages during growth until it generates a plant that is capable of maintaining itself for several generations. One of the difficulties to overcome is to perform regular meiotic division, to make a balanced distribution of homologous chromosomes in anaphase I to produce viable gametic cells, thus avoiding the formation of cells with an unbalanced number of chromosomes, and/or to resort to asexual reproduction (Guerra, 2020).

In the context of abiotic and biotic stress management, the identification of the implied mechanisms represents the most significant line of research in polyploidy. Genetic improvement based on polyploidy combines the advantages of heterosis and apomixis, and may be a promising option for crop improvement in the future (Islam *et al.*, 2022)element.

Within the forestry sector, polyploidy has been an alternative biotechnological strategy with great potential for the generation of more robust plants within breeding programs. Silva (2016), considering the absence of natural eucalyptus polyploids, developed protocols for the induction of in vitro polyploidization in *Eucalyptus grandis* seedlings, aiming to obtain tetraploid plants. The methodology established in the research presented promising results to be used in the acquisition of synthetic polyploids on a large scale in experimental fields and in breeding programs of this species.

Still on eucalyptus, Muniz *et al*. (2023) compared tetraploid with diploid materials, in relation to the quality of wood for the production of pulp and paper, this work was carried out through the analysis of physical and anatomical properties of wood. The results of the study indicated that the diploid clone had an average basic density of 552 kg/m^3, 7% higher than the average of tetraploid clones, which ranged between 502 and 524 kg/m^3. Regarding the lignin content between the clones, there were no significant differences. However, in relation to fibers, tetraploid clones had fibers with length and width about 16% and 20% larger than diploids. The fiber quality indices were similar between the polyploids and the control clone. The tetraploid clones stood out in volume after five years of cultivation. These results support the premise of the benefits of polyploidy in plant breeding, suggesting that polyploidy is a promising strategy for the genetic improvement of eucalyptus, with benefits for pulp and paper production.

METHODS OF POLYPLOIDY INDUCTION

Artificial polyploidy induction is a technique that can be used to support plant breeding and aims to double the number of chromosomes to generate plants with greater genetic variability. This leads to a broader recombination of enhanced traits (Barichello *et al*., 2019). This is done through the use of antimitotic agents that bind to the tubulin protein, blocking the formation of microtubules and inhibiting the formation of the achromatic spindle. During the cell division process, chromatids are unable to separate and migrate to the cell poles, preventing the formation of a new membrane around the duplicated DNA (Souza *et al*., 2019).

Polyploidy induction can be performed by more than one method, using chemical, physical and biological agents, and by several antimitotic substances, with colchicine, oryzalin, 8-

hydroxyquinoline and trifluralin being the most used. However, the polyploidization process does not depend only on the method or inducing agent used, but also on other variables (Madani *et al*., 2021).

Several protocols have been developed to induce polyploidy in a wide variety of cultivated species. Since the discovery of colchicine, in vitro polyploidization with this antimitotic agent has become one of the main techniques to induce artificial polyploidy. Although only a few induced autopolyploids have achieved commercial relevance, polyploidy has become a highly valuable tool in breeding programs (Sattler; Oak; Clarindo, 2016; Souza *et al*., 2019).

Colchicine works by stopping the formation of the mitotic spindle during cell division, which prevents the separation of duplicated chromosomes and results in cells with twice the number of chromosomes. This method is widely used due to its effectiveness, although it requires specific care regarding dosage and exposure time to avoid toxic effects and irreversible damage to plants. In a study carried out by Abou and El-Shereif (2014), with citrus seeds, it was found that the survival of these structures decreased with the increase in colchicine concentration and exposure time. The control, without colchicine, had the highest survival (92.3%), while treatment with 0.2% colchicine for 48 hours resulted in the lowest percentage (37%). This shows that higher concentrations and times increase toxicity, negatively affecting seed survival.

Melloni *et al.* (2015) mentioned that treatments with the herbicides trifuraline, oryzalin and 8-hydroxyquinoline had increased use due to their low toxicity content and for having a greater affinity with the β-tubulin protein, even at low concentrations.

In the research by Bonn, Karsburg and Gallo (2016), trifluralin was used as an antimitotic aiming at the induction and identification of polyploidy in jatoba root meristematic cells through morphological and cytological characteristics. The preliminary results indicated that the concentration of 3 μM of trifluralin for 96 hours at 4ºC was effective in inducing polyploidy, causing the duplication of the genome of *Hymenaea courbaril* L. var. stilbocarpacom (2n = 4x = 48) and the increase in the mean size of the stomata (0.215 mm), statistically higher than the other three treatments.

When studying ploidy stability in cassava (*Manihot esculenta* Crantz) plants treated with orizalin, Souza *et al*. (2019) carried out experiments that identified tetraploid samples with no significant difference in the level of chromosomal duplication between 0.5 cm and 1 cm explants. After six cycles of subcultures, it was found that 92% of the individuals maintained the stability of the ploidy level, with peak values ranging from 2.98 to 3.28, while only 8% presented mild chromosomal variation, with peaks between 2.90 and 2.93. These results analyzed by flow cytometry indicate that the technique of polyploidy induction with oryzalin was effective in the generation of cassava tetraploid plants, and that most of these plants maintained chromosomal stability after multiple subcultures, with the exception of some individuals that required new subcultures to confirm the chromosomal content.

On the other hand, Carvalho *et al.* (2016) after conducting the research with the same species and also aiming to develop a methodology for in vitro induction of polyploidy with oryzain and colchicine, concluded that the concentrations of oryzain (3 and 15 μM) and the time of exposure affected the development of cassava plants, producing only a few tetraploid individuals, while the concentrations of colchicine (1.25 to 6.25 mM) caused phytotoxic effect and, death of the explants.

Chromosomal duplication can also occur naturally, but it is a much slower process compared to artificially induced techniques (Souza *et al*., 2019).

IMPACT OF POLYPLOIDY ON PLANT SPECIES CHARACTERISTICS AND PRACTICAL APPLICATIONS

Polyploidy, by introducing multiple sets of chromosomes into the cells of a plant, can have profound and varied effects on its agronomic and physiological characteristics. Studies have shown that polyploidy exerts significant effects on several aspects of plants, such as genome structure, gene expression, metabolism, among others, which ends up promoting changes in the phenotype. These changes can occur soon after polyploidization and be retained or lost later. Therefore, plant breeders should be aware of and be aware of the stability of these modifications when analyzing their experiments (Yu *et al*., 2021).

Polyploid plants generally demonstrate greater hardiness and vigor, with a significant increase in tissues compared to the same diploid genotype, resulting in thicker and larger leaves, stems, and roots (Souza *et al*., 2019).

Another impact of polyploidy on plant species is on the production of secondary metabolites, which are compounds that are not essential for growth, but that have important functions, such as defense against pests, for example. Polyploidy can modify its production since it alters the enzymatic activity of plants, impacting biosynthetic pathways and, consequently, the production patterns of secondary metabolites (Madani *et al*., 2021).

Polyploidy can have a profound impact on the agronomic and physiological characteristics of plants, often resulting in reduced fertility due to meiotic irregularities. This condition is associated with the production of seedless fruits (Sattler; Oak; Clarindo, 2016), being advantageous to add value to the final product.

Heslop-Harrison; Schwarzacher and Liu (2023) highlight it as an important driver of evolution. Thus, the influence of polyploidy on the evolution of the genome and chromosomes has been the subject of numerous investigations. This genetic mechanism, which can trigger a series of phenotypic changes, offers numerous opportunities for practical applications in breeding (Segraves;

Anneberg, 2016). These applications can be targeted at developing varieties with desirable traits, including increased yields, improved disease resistance, and increased tolerance to environmental stresses. For example, polyploid cassava plants resulting from induction by oryzalin exhibited significant morphological changes, including larger leaf blade, larger diameter stems, and greater robustness compared to diploid genotypes (Souza *et al*., 2019).

Vilcherrez-Atoche, Iiyama and Cardoso (2022) highlight that orchids represent the largest flower market in the world and that for this reason the objectives of breeding programs are aimed at obtaining flowers with greater size, durability, intense colors and resistance to pathogens, being the genera *Cymbidium*, *Dendrobium* and *Phalaenopsis* those with the largest number of studies and published reports on obtaining polyploid plants.

To verify whether polyploidy plays a significant role in expanding the environmental tolerance of species with polyploid cytotypes, Silveira (2014) analyzed the chromosome numbers of 14 *Eugenia* L. species (26 populations) with conventional cytogenetic techniques. His initial hypothesis was confirmed after submitting the results to statistical tests. The polyploid and diploid populations showed different spatial distribution patterns and environmental conditions. The polyploid individuals were collected in places where the environmental conditions were considered more adverse. These findings reinforce the importance of polyploidy in the diversity and survival of plant species in different environmental conditions.

However, while polyploid lineages have a greater capacity to face challenging environments, they are often equally or even more susceptible to extinction than their diploid predecessors. It is necessary to consider that polyploidization comes with several costs to new polyploid individuals, such as genomic instability, mitotic and meiotic abnormalities, reduced fitness, and exclusion of minority cytotype. Duplication of the entire genome can have important effects not only on genetics, but also on the ecology and life history of populations. Therefore, in order to understand the behavior of polyploids and the consequences of polyploidization on the adaptive potential of populations, different areas of research need to be linked, as many aspects remain understudied (Clo, 2022).

CHALLENGES AND FUTURE PERSPECTIVES OF POLYPLOIDY.

In recent decades, significant progress has been made in the study of polyploidy, with the discovery of several mechanisms related to its causes and consequences. However, many questions remain unanswered, highlighting the need for more research to clarify the effects of autopolyploidy and allopolyploidy on plant genomes. An in-depth understanding of the connection between genomic changes and the expression of new phenotypes after polyploidy holds promise for crop breeding, allowing breeders to manipulate polyploid genomes with greater precision and achieve better results (Sattler; Oak; Clarindo, 2016).

Despite the advantages, the possible negative effects of generating new polyploid organisms should be considered, regardless of the specific purposes. This is because, although polyploidy is a powerful tool, its use must be carefully planned to avoid unintended consequences (Madani *et al*., 2021).

The genomic complexity of polyploidy is one of the main obstacles, due to the multiple sets of chromosomes, so understanding their genetic interactions requires advanced genomics and bioinformatics approaches. Interpreting phenotypes associated with polyploidy is challenging, which means that a deeper understanding has great potential for crop breeding, by enabling a more precise association between genotype and phenotype, and by filling gaps in the genetic transmission of desirable agronomic traits between cultivated species and their wild relatives (Bharadwaj, 2015).

In addition, understanding how polyploidy affects gene regulation and gene expression is not yet fully understood. To begin to try to solve this question, modern integrative approaches, which combine molecular, cytogenetic, and bioinformatics techniques, can provide clarification on the still poorly understood genetic and developmental mechanisms related to the formation, reproduction, and sex determination of neopolyploids (Mezzasalma *et al*., 2023).

Polyploidy can be a valuable source of genetic variability for plant breeding and functional studies are essential to understand the molecular mechanisms underlying polyploidy, including the identification of key genes and affected metabolic pathways. Although it is now widely recognized that polyploid cells tend to be larger and produce nutrients or signaling molecules to the surrounding environment, there is a lack of experimental studies examining how polyploidization specifically affects cell growth rates, mRNA transcription, protein synthesis, and nutrient secretion (Darmasaputra; Rijnberk; Galli, 2024).

Interdisciplinary collaboration between molecular biology, genetics, and agronomy is crucial to address the challenges of polyploidy in a comprehensive way, given that despite the advances achieved, a complete understanding of the polyploidization process is still not possessed (Islam *et al*., 2022).

All in all, while research on plant polyploidy faces significant challenges, it offers exciting opportunities to improve crop yields and sustainability.

FINAL CONSIDERATIONS

Polyploidy is a biological phenomenon of great relevance for the evolution and genetic improvement of plants. By introducing multiple sets of chromosomes into plant cells, this process offers a range of advantages that include increased genetic variability, contributing significantly to the adaptation of species to adverse environmental conditions and to obtaining more productive and resistant cultivars.

The study of polyploidy, both natural and induced, has shown profound impacts on the agronomic characteristics of plants, such as hybrid vigor, seedless fruit production, increased biomass and greater resistance to biotic and abiotic stresses. These changes are extremely important for the development of new cultivars, especially in a global agricultural scenario that requires sustainable and efficient food production.

However, the complexity involved in the manipulation of polyploids, especially with regard to genomic stability and fertility, still poses a challenge for plant breeders. The need for additional research to better understand the genetic and physiological mechanisms underlying polyploidization is evident. Integrative approaches that combine genetics, biotechnology, and bioinformatics are essential to overcome these obstacles and optimize the use of polyploidy in crop breeding.

It is concluded that polyploidy is a promising and strategic tool for plant genetic improvement, with the potential to boost agricultural innovation and ensure the production of more robust, resilient and productive cultivars. However, it is necessary to continue advancing in technical and scientific knowledge to fully explore the possibilities offered by this phenomenon, seeking solutions to the challenges that still exist.

This review process allowed for a critical and reflective approach, providing an understanding of the role of polyploidy in plant species and some of its implications for genetic improvement.

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