**Polyploidy: An evolutionary plant breeding approach**

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**ABSTRACT**

Plants have a favourable impact on human life and supply food, medicine, and fuel. To address the issue of the need to diversify crop plants, modern breeding techniques are developed. These techniques significantly reduce the length of the breeding period and also have an impact on the breeding of some plants whose improvement is not possible using conventional techniques. The new sources of germplasm that can be exploited to create new cultivars or in breeding programmes are haploid, double haploid, and polyploid plants. Artificial polyploidy induction is one of the breeding techniques used to enhance the desirable traits of plants. Improvements in varieties, the creation of sterile lines, the recovery of hybrid fertility, growth and increased vigour, an increase in allelic diversity, and heterozygosity etc. All of these aspects must be taken into account in a genome-wide context to maximize marker-assisted selection and crop plant improvement. Plants that have all of their chromosomes duplicated (instead of only some of them) have more distinguishing characteristics, such as altered phytochemical properties, a higher concentration of therapeutic compounds, and unique plant shapes, colours, sizes, scents, and flowering times. The genotype of the plant and the type of sample must be taken into account in order to create an effective protocol for chromosomal duplication. Principal aspects that must be taken into account include the kind, quantity and length of mitotic inhibitors.

**Keywords:**Diversity, Germplasm, Heterozygosity and Polyploidy.

**I. INTRODUCTION**

The term "polyploidy" refers to the presence of more than two basic sets of chromosomes in an organism (Acquaah 2007; Chen 2010; Comai 2005; Ramsey and Schemske 1998). Polyploidy breeding refers to the genetic enhancement of crop plants through chromosome number manipulation. Widespread in nature, polyploidy allows for adaptability and the emergence of new species. Many crop plants have undergone polyploidy during their evolutionary process, according to Chen *et al.* (2007). According to Comai (2005), angiosperms create polyploid plants much more frequently than other plant types, with one plant becoming polyploid for every 100,000 plants, as it is estimated.

Numerous studies have been conducted to better understand the nature of polyploidy, and the current chapter aims to shed light on the uses and consequences of polyploidy in plant breeding and other commercial endeavors. A few fundamental concepts must be defined in order to comprehend polyploidy. "x" stands for the entire basic set of chromosomes, while "2n" stands for the total number of chromosomes in a somatic cell. While gametes only have a haploid pair of chromosomes, somatic cells have twice as many (Acquaah 2007; Otto and Whitton 2000). Stebbins in 1947 has described three different types of polyploids in the plants *viz.* autopolyploidy, allopolyploidy, and segmented allopolyploidy. In first, every genome is similar and develops as a result of genome duplication within a single species. (Stebbins 1947; Lewis 1980). Allopolyploids can result from the hybridization of two different species and can have two or more different genomes (Stebbins 1947; Grant 1975). Segmental allopolyploids, the third type, contain more than two incompletely different genomes, which can create both bivalents and multivalent following chromosome pairing (Stebbins 1947; Levin 2002). Early in the 20th century, the occurrence of polyploidy became much more significant. One of the earliest examples of natural polyploidy was Hugo De Vries' initial work on mutation of *Oenothera lamarckiana*, where he described his work in ‘Theory of Mutation’ in 1990 later, Digby (1912) discovered that a fertile-type *Primula kewensis* could arise from a sterile interspecific hybrid through chromosome doubling, but the author was unaware of the significance of this in the context of polyploidy. Numerous agricultural crops, including wheat, maize, sugarcane, coffee, cotton, and tobacco, are polyploid either as a result of deliberate hybridization and selective breeding (such as some blueberry varieties) or an ancient polyploidization event (such as maize) (Ramsey and Schemske 2002). Polyploidy appears to be extremely advantageous in long-lived perennials with a variety of vegetative methods of propagation (such as *Fragaria*, *Rubus*, *Artemisia* and *Potamogeton*, etc.) and those with frequent occurrences of natural interspecific hybridizations (Hilu 1993).

**II. CHANGES IN CHROMOSOME NUMBER**

Aneuploidy results from alterations in one or more chromosomes. These chromosome number variations are calculated in proportion to the somatic chromosome number (2n) of the species. Nullisomic aneuploid creatures are those that are missing one pair of chromosomes (2n-2). While monosomic aneuploids (2n-1) are those that have just one chromosome. Two chromosomes from two separate chromosome pairs (2n-1-1) are absent in double monosomic individuals. Trisomy (2n+1) refers to the presence of one additional chromosome in an aneuploid person, and double trisomy (2n+1+1) refers to the presence of two extra chromosomes from two separate chromosomal pairs. A tetrasomic individual possesses an additional pair of chromosomes (2n+2). Euploidy, on the other hand, entails a change in the entire set of the genome, which is an exact multiple of the species’ basic chromosome number. It is commonly referred to as polyploidy. An autopolyploid is a polyploid with identical genomes across the board. Allopolyploids, on the other hand, contain two or more distinct genomes. Euploids may have 3, 4, 5, 6, 7, 8, or more somatic chromosomes, which are made up of different genomes. Table 1. provides a summary of the heteroploidy terminology that is frequently used.

**Table 1: Type of variations in chromosome number**

|  |  |  |  |
| --- | --- | --- | --- |
| **S.N.** | **Term** | **Type of change** | **Symbol** |
| 1 | Aneuploid | One or few chromosomes or missing from 2n | 2n±few |
| 2 | Nullisomic | One chromosome pair missing | 2n-2 |
| 3 | Monosomic | One chromosome missing | 2n-1 |
| 4 | Double monosomic | One chromosome from each of the two different chromosome pairs missing | 2n-1-1 |
| 5 | Trisomic | One chromosome extra | 2n+1 |
| 6 | Double trisomic | One extra chromosome from each of the two different chromosome pairs | 2n+1+1 |
| 7 | Tetrasomic | One extra chromosome pair | 2n+2 |
|  | Euploid | Copies of a single genome more or less than two |  |
| 8 | Monoploid | One copy of a single genome | x |
| 9 | Haploid | The Gametic chromosome complement of the species | n |
|  | Polyploid | More than two copies of one genome |  |
|  | Autopolyploid | Genomes identical with each other |  |
| 10 | Autotriploid | Three copies of one genome | 3x |
| 11 | Autotetraploid | Four copies of one genome | 4x |
| 12 | Autopentaploid | Five copies of one genome | 5x |
| 13 | Autohexaploid | Six copies of one genome | 6x |
|  | Allopolyploid | Two or more distinct genomes |  |
| 14 | Allotetraploid | Two distinct genomes | 2x1 + 2x2 |
| 15 | Allohexaploid | Three distinct genomes | 2x1 + 2x2 + 2x3 |
| 16 | Allooctaploid | Four distinct genomes | 2x1 + 2x2 + 2x3 + 2x4 |

Source: Singh B.D. (2012). Plant breeding, Principles and Methods.

**III. ORIGIN OF POPYPLOIDY**

Different factors can cause polyploidy to develop. Some of the fundamental processes that result in polyploidy include somatic doubling during mitosis, nonreduction in meiosis resulting in the generation of unreduced gametes, polyspermy (fertilization of the egg by two male nuclei) and endoreduplication (DNA replication without cytokinesis). several authors have claimed that endoreduplication and somatic doubling are more similar than distinct mechanisms. Chromosome duplication can result in polyploidy chimaeras (a kind of cartilaginous fish) and full polyploids, depending on whether it happens in the zygote or certain apical meristems. Some non-meristematic plant tissues show somatic polyploidy, according to Ramsey and Schemske (1998) (*eg*., tetraploid and octoploid cells in the cortex and pith of *Vicia faba*). Somatic doubling is mostly caused by mitotic non-disjunction, according to Grant (1981). Early embryonic divisions, branches that could bear flowers, and purely vegetative tissues can all experience somatic doubling (Grant 1981). The heat shock studies, in which immature embryos were temporarily exposed to high temperatures, provided the best explanation for how chromosome doubling in the zygotes occurred (Lewis 1980).

There are two types of polyploidies which are mentioned as follows;

1. Autopolyploidy
2. Allopolyploidy
3. **Autopolyploidy:**

Autopolyploids are polyploids that develop through the multiplication of chromosome of a single species and this situation is referred to as autopolyploidy. Low frequency spontaneous occurrences of autopolyploids are possible in nature, and they can also be artificially created using a variety of techniques, including decapitation, heat and chemical treatments, and selection from twin seedlings. Autopolypoidy occurs when meiosis fails, resulting failure of splitting of the chromosomes. As, gametes have twice as many chromosomes as normal (2n) thus, unreduced 2n gametes that are created as a result of gametic nonreduction or meiotic nuclear restoration during microsporogenesis and megasporogenesis can develop into autopolyploids. Fig. 1. Shows the origin of autopolyploidy from two non reduced gametes. Triploids (3x), tetraploids (4x), pentaploids (5x), hexaploids (6x), septaploids (7x), octaploids (8x) and further polyploids are examples of autoploids. It is also referred to as single species polyploids or simple polyploids. Let’s discuss this theory in more details,

1. **Autotriploids:**
* They can be created experimentally by crossing autotetraploid and diploid species, or in some cases they can arise naturally.
* They have the three sets of chromosomes that are specific to the species.
* Triploids usually have faulty gamete production thus, makes them infertile. Only asexually reproducing plant species, such as banana, sugarcane, and apple benefits from triploids.
1. **Banana:**Bananas are triploid and seedless cultivars. The fruits of such bananas are larger than those of diploids species
2. **Apples:** Certain triploid apple types are propagated asexually through budding or grafting.
3. **Sugarbeet:** Triploid sugarbeet species contain more sugar than diploids and are typically mold-resistant.
4. **Watermelon:** Triploid watermelons are either seedless or have little, cucumber-like seeds. Tetraploid females and diploid males are crossed to create these seedless watermelons. However, a reciprocal cross does not work.
5. **Autotetraploids:**
* They can develop naturally or can be intentionally produced by doubling the chromosomes of a diploid species with colchicine therapy.
* They have four copies of the DNA of the same species. Because pairing partners are accessible during meiosis, tetraploids are typically stable and fruitful.
* Diploid gametes (2n) are developed in such plants. Rye, grapes, alfalfa, groundnuts, potatoes, and coffee are a few well-known examples of autotetraploid plants. They are typically larger and are vigorous than diploid species.
1. **Rye:** Germany and Sweden both grow autotetraploid rye. They have larger seeds and greater proteins than diploids.
2. **Grapes:** Tetraploid grapes with larger fruits and fewer seeds per fruit than diploids have been developed and using in USA and Japan.
3. **Alfalfa:** Tetraploid cultivars of alfalfa yield more and recover faster from grazing than diploid ones do.



Fig 1: Illustration showing the origin of autopolyploid from unreduced gametes

1. **Allopolyploidy:**

Allopolyploidy is the term used to describe a polyploidy organism that results from the union of whole chromosomal sets from two or more species. A tetraploid individual is created by the subsequent mating of a reduced ‘1n’ gamete with a ‘3n’ gamete in the following generation, which results from the fusion of a reduced ‘1n’ gamete with an unreduced ‘2n’ gamete. Sometimes referred to as a triploid bridge, this two-step method allows to the formation of allopolyploid. In the other example it was discovered that the elongate gene on chromosome 3 in maize increased the proportion of diploid eggs, serving as an illustration of how genotype can influence the development of nonreduced gametes (Grant 1981; Lewis 1980). Studies on unreduced gametes in both plants and animals benefit from the use of quick screening techniques such as flow cytometry, chromosomal pairing, and other genomic approaches (Mable 2003). Except for some orchids, Ramsey and Schemske (1998) claim that the contribution of polyspermy as a process of polyploidy generation is uncommon. Endosperm as well as the cotyledons of growing seeds, leaves, and stems of bolting plants have all been documented to experience endoreduplication (Larkins *et al.* 2001). The diagrammatic representation of allopolyploidy formation was shown in Fig. 2.



Fig. 2: Illustration showing the origin of allopolyploid from unreduced and reduced gametes

**I. Natural Allopolyploids:**

Let’s try to understand the concept of natural allopolyploids with the following examples,

1. **Wheat:**

The bread wheat's evolutionary origin has received the greatest attention till date because it’s one of the major cereals in the world. Numerous researchers have looked into the identity of the diploid species that contributed to the three distinct genomes (A, B, and D) of *Triticum aestivum*, most notably pioneer work demonstrated by Kihara (1944), McFadden and Sears (1944, 1946) in the identification of *Aegilops tauschii* (syn *Ae. squarrosa*, *Triticum tauschii*) as the progenitor of the D genome of hexaploid wheat (*T. aestivum*) for more than 75 years now. The genome A found in diploid wheat is thought to be similar to that found in tetraploid and hexaploid wheat. Furthermore, the tetraploid emmer wheat genome B is similar to the hexaploid wheat genome B. This is demonstrated by chromosome pairing in crosses between wheat, which are diploid, tetraploid and hexaploid. While hybrids between tetraploid and hexaploid wheat display around 14II and 7I, those between diploid and tetraploid wheat display 7II and 7I. *Triticum monococcum* is thought to have provided the wheat genome A, *Triticum tauschii* the genome D and an unidentified source that most likely provided the genome B (2n = 14).



Fig 3. Evolution of allohexaploid wheat (*T. aestivum*) (Image is created in ‘Lucidchart’).

1. **Tobacco:**

About 76 currently identified naturally occurring species are included in the genus *Nicotiana*, which is classified into 13 sections (Knapp *et al*. 2004). The typical allotetraploid species *Nicotiana tabacum* (2n=4x=48) resulted from interspecific hybridization between *Nicotiana sylvestris* (female donor) and *Nicotiana tomentosiformis* (male donor), both of which are diploid with 2n=24. This hybridization took around 200,000 years back (Leitch *et al* 2008). *Nicotiana sylvestris* has been identified as the section Tomentosae's maternal parent and the, another donor of the S genome (Bland et al. 1985; Olmstead and Palmer 1991; Aoki and Ito 2000; Yukawa et al. 2006), while *Nicotiana tomentosiformis*, *Nicotiana otophora*, or an introgressive hybrid between the two has been identified as the section Tomentosae's donor (Kenton *et al*. 1993; Riechers and Timko 1999; Lim *et al*. 2000; Kitamura *et al*. 2001; Ren and Timko 2001).

1. **Cotton:**

All of the diploid species in the genus *Gossypium* have 13 haploid chromosomes and fall under one of seven different genome types that were created from A to G using chromosome pairing interactions (Beasley 1942; Endrizzi *et al.* 1984). *Gossypium* contains a total of five tetraploid species (n=2x=26). All tetraploid species have disomic chromosomal pairing, according to Kimber (1961). Tetraploid cotton may have two distinct genomes that resemble the A genome of *G. hirsutum* (n = 13) and the D genome of *G. raimondii* (n = 13), according to chromosome pairing in interspecific crosses between diploid and tetraploid cotton. About 6–11 million years ago, the A and D genome species separated from a common ancestor (Wendeil 1989). About 1.1–1.9 million years ago, the putative A x D polyploidization event took place in the New World, and the female parent was the old world-native A gene donor (Wendeil 1989; Wendeil and Albert 1992). It is believed that the five allotetraploid species (*G. hirsutum*, *G. barbadense*, *G. darwini*, *G. mustelinum*, and *G. tomentosum*) developed through polyploidy-level diversification.

1. **Oat:**

The allohexaploid, cultivated oat (n=21), is thought to have developed *via* a hybrid between the tetraploid *A. barbata* (n=14) and the diploid *A. strigosa* (n=7).

1. ***Brassica* spp.:**

Nagaharu (1935) suggested a theory for the evolution and development of the six most common members of plants belonging to *Brassica* species. This theory is commonly known as *Brassica* triangle or the ‘Triangle of U’. The Brassica triangle provides an intriguing illustration of the part that allopolyploidy played in the evolution of several *Brassica* species. According to his theory,Indian mustard [*Brassica juncea* (n=18)] is an amphidiploid produced by an interspecific cross between Black mustard [*Brassica nigra* (n=8)] and Turnip/Field mustard [*Brassica campestris* (n=10)], whereas amphidiploid Rapeseed/Canola [*Brassica napus* (n=19)] was produced by an interspecific cross between Wild cabbage [*Brassica oleracea* (n=9)] and Turnip/Field mustard [*Brassica campestris* (n=10)] andWild cabbage [*Brassica oleracea* (n=9)] and Black mustard [*Brassica nigra* (n=8)] were interspecifically crossed to produce Ethipian mustard [*Brassica carinata* (n=17)].



Fig4. Brassica triangle showing the relation between diploid and naturally occurring amphidiploidspecies of *brassica*. Three diploid species can be seen on the tips of the triangle, while amphidiploids are represented in the middle of two parents.

(Image is created in ‘Lucidchart and Vecteezy’).

**II. Artificial Allopolyploids:**

1. ***Raphanobrassica:***

This is a classic instance of an allopolyploid that was created artificially. In 1928, Russian geneticist Karpechenko created this cross between the radish (*Raphanus sativus*, 2n=9) and the cabbage (*Brassica oleraceae*, 2n=9). He sought to create a fruitful cross between these two species using cabbage leaves and radish roots. However, he was able to produce a fertile amphidiploid (4n=36) through spontaneous chromosomal doubling, which tragically had radish leaves and cabbage roots. It was therefore useless.



Fig 5: Evolution of *Raphanabrassica* (Artificial allopolyploid) from cross between Radish x cabbage (Image is created in ‘Lucidchart’).

1. ***Triticale*:**

A new crop species called *triticale* was the first man-made artificially created cereal crop. Depending upon whether tetraploid (2n=4x=28) or hexaploid (2n=6x=42), derivations are different as shown in figure 5. Hexaploid triticale (2n=42) is created using *Triticum durum*(2n=28) and Secale cereale (2n=14). This crossing programme results in the formation of sterile F1 hybrid (2n=21). After colchicine treatment, chromosomes getdoubled in number and we get hexaploid triticale (2n=42). Similarly,octoploid triticale (2n=56)is obtained using *Triticum aestivum* (2n=42) and *Secale cereale* (2n=14). This crossing programme also sterile F1 hybrid (2n=28) and after colchicine treatment, we get stable and fertile octoploid *triticale* (2n=56). Hexaploid*triticale*(2n=6x=42)and octoploid *triticale*(2n=8x=56) are generated using wheat that is tetraploid (2n=4x=28) and hexaploid (2n=6x=42), respectively. Nowaday, triticale is widely farmed in Canada, Mexico, Hungary and other nations.



Fig. 5: Evolution of *triticale*. Left side (A) illustration of evolution of the hexaploid *triticale* and the right side (B) illustration of evolution of octoploid *triticale*

(Image is created in ‘Lucidchart and Vecteezy’).

1. **Wheat:**

McFadden and Sears (1944) recreated hexaploid wheat as an amphidiploids of wild or domesticated emmer with *A. tauschii*. The synthetic hexaploid wheat looked like spelt (*T. aestivum* sp. spelta, genomes BBAADD). That’s why they concluded that spelt was the ancestor of *T. aestivum* and that free-threshing *T. aestivum* evolved from spelt.

**IV. INDUCTION TO POLYPLOIDY**

Colchicine slows the development of spindle fibers and momentarily halts chromosomes at the anaphase stage, it was discovered in the 1930s (Blakeslee and Avery 1937). The chromosomes have duplicated at this point, but cell division has not yet occurred, leading to the formation of polyploidy cells. Oryzalin, trifluralin, amiprophos-methyl, and N2O gas are some more mitotic inhibitors that have been discovered and utilized as doubling agents (Bouvier *et al*. 1994; Van Tuyl *et al.* 1992; Taylor *et al.* 1976). These doubling agents can be applied in a variety of ways. Working with a lot of seedlings with small, active meristems is one of the simplest and most efficient approaches. Different concentrations, times or frequencies of a particular doubling agent can be applied to seedlings or the apical meristems. Although older plants shoots can be treated, doing so frequently has less success and produces more cytochimeras. Sometimes it is more successful to treat smaller axillary or sub-axillary meristems. By dipping branch tips into a solution for a stipulated period of time and using cotton, agar, or lanolin can be used to apply chemical solutions to buds. To increase efficacy, surfactants, wetting agents and other carriers (dimethyl sulfoxide) are occasionally used. X-ray, gamma rays and heat or cold treatment can also cause polyploidy in low frequencies. In Datura, triploid branches have been created by applying cold treatment. During the initial zygotic division, when maize plants or ears are exposed to extreme heat (38–45 °C), 2-5% of the progeny are tetraploid (Randolph 1941). Barley, wheat, rye, and a few more crop species have all been successfully heat-treated to induce polyploidy.

**V. APPLICATIONS OF POLYPLOIDY**

1. **Mutation breeding:**

In contemporary breeding methods like tilling, high frequencies of chromosomal mutations are desired as they offer new sources of variety. There are numerous benefits to polyploid loci's multiallelic nature that are helpful in breeding. Polyploids are protected against deadly conditions frequently associated with inbred diploid crops by the dominant forms of any potentially harmful alleles that may result from induced mutation (Gaul, 1958). This idea has played a crucial role in the evolution of polyploids during bottlenecks where forced inbreeding occurs (Comai, 2005). In polyploid crop improvement, mutation breeding uses the ideas of gene redundancy and mutation tolerance in two different ways. As a result of their enormous genomes, which are the result of their genes being duplicated, polyploids are able to survive harmful allele alterations after mutation and also have an enhanced mutation frequency (Gaul, 1958). When trying to cause mutations in diploid cultivars that don't yield enough genetic variety following a mutagenic treatment, the high mutation frequencies seen with polyploids may be taken advantage of. This method has been used to breed mutations in *Achimenes spp.* by first creating autotetraploids by the use of colchicine, then using fast neutrons and X-rays. Due to their huge genomes, it was discovered in this study that autotetraploids had mutation frequencies that were 20–40 times greater than those of the corresponding diploid cultivars (Broertjes, 1976).

1. **Seedless fruits:**

Triploids seedlessness has been favored, particularly in fruits. Commercially useful triploid fruits like watermelon are created artificially by first creating tetraploids, which are then crossed with diploid species. The triploid watermelon is crossed with a desired diploid pollen donor in order to set fruits.

1. **Bridge crossing:**

Bridge crossing is another breeding method that makes use of polyploids superiority in reproduction. When ploidy levels between two species cause incompatibilities in sexual reproduction, transitional crossings can be performed, followed by chromosomal doubling, to create fertile bridge hybrids. Using meadow grass (*Fescue pratensis*) as a bridge species, this technique has been utilized to breed for superior tall *fescue* grass (*F. arundinacea*) from Italian ryegrass (2n=2x=14) and tall fescue (2n=6x=42. (Acquaah, 2007). By increasing the number of chromosomes in the superior progeny of hybrids, the same theory has been used to fix heterozygosity in those hybrids (Comai, 2005).

1. **Ornamental and forage breeding:**

One of the most noticeable and immediate effects of polyploidy in plants is a rise in cell size, which results in larger plant organs. This phenomenon is known as the gigas effect (Acquaah, 2007; Levin, 1983; Stebbins, 1971). Chromosome doubling may produce noticeably larger seeds and more seed protein in cereal crops, but this benefit is countered by reduced seed set (Dhawan and Lavania, 1996). The gigas effect, on the other hand, has been studied in the breeding of trees, ornamentals, feed crops, and fruits (Emsweller and Ruttle, 1941; Schepper *et al*., 2001). The quality and size of the blooms on ornamental plants like snapdragons and marigolds have been enhanced through chromosomal doubling breeding (Emsweller and Ruttle, 1941). Numerous authors have discovered a substantial inverse relationship between plant development rates and DNA concentration (Levin, 1983; Smith and Bennett, 1975). Less auxin, a lower surface-to-volume ratio, and a different nuclear surface-to-cell volume ratio have all been linked to it (Acquaah, 2007; Levin, 1983). Polyploids are able to flower later and for a longer length of time than their diploid ancestors due to their slower growth rate (Levin, 1983). This trait may be particularly valuable in breeding ornamental plants.

1. **Production of apomictic crops:**

Another way to employ polyploids in breeding is through apomixis. Through parthenogenesis, apomixis offers a method for the asexual generation of seeds. Although most polyploid plants are not apomictic, the majority of apomictic plants are polyploid (Otto and Whitton, 2000). In plants that can reproduce asexually as well as sexually, polyploidy favors the latter (Dhawan and Lavania, 1996; Levin, 1983). The most coveted hybrids are termed apomicts, but little progress has been made in their advancement. However, it has been proposed that the growth of plants with extremely high ploidy levels may be used to create obligate apomicts (Levin, 1983). The octoploid of the grass *Themedatriandra* is a prime example of an obligatory apomict produced at a high ploidy level (Levin, 1983).

1. **Disease resistance through aneuploidy:**

By inserting an additional chromosome into the progeny genome, aneuploidy has been used in plant breeding to create disease-resistant plants. One illustration is the backcrossing of *Tricum aestivum* with *Aegilops umbellulata* to impart its resistance to leaf rust. Additionally, alternative breeding techniques involving aneuploidy, such as chromosome deletion, chromosome replacement and supernumerary chromosomes, have been investigated (Acquaah, 2007).

1. **Restoring fertility in wide hybrids:**

Hybrids between different taxa do not always need to be sterile. Chromosome sterility, or the inability of the chromosomes to pair properly during meiosis, is a common cause of this. A broad hybrid's fertility can be recovered by doubling its chromosomal count. This strategy has been employed with effectiveness in × *Chitalpatashkentensis* and *Rhododendron* (Contreras 2006; Olsen 2006). However, in certain instances, such as with tetraploid hybrids of *Alstroemeria aurea* and *A. caryophyllaceae*, this strategy has been successful in restoring fertility (Lu and Bridgen 1997).

1. **Increased allelic diversity and heterozygosity:**

Increased allelic copy number and heterozygosity have contributed significantly to the emergence of new traits. When two (or more) distinct genomes coexist in the same nucleus, a process known as allopolyploidy, allelic diversity likewise rises. According to Osborn *et al.* (2003), intergenomic heterozygosity has a favourable impact on the development of oil seeds in *B. napus*. Intergenomic heterozygosity also affects the QTL for seed yield and other variables in different populations of *B. napus* (Udall *et al*. 2006; Quijada *et al.* 2006). Due to their ability to produce fabric that is longer, finer, and stronger than their diploid siblings, tetraploid cotton also controls the global market for textiles. Jiang *et al.* (1998) reported that a number of QTL found on the D genome revealed that D genome loci had been employed for the synthesis of fibre after polyploidy formed.

**VI. LIMITATIONS OF POLYPLOIDY**

1. **Limited applications:** The single species polyploidy has few uses. It is typically helpful in crop species that reproduce asexually, such as grapes, potatoes, bananas, and sugarcane.
2. **Difficult to maintain:** In the case of crop species that reproduce sexually, maintaining monoploids and triploids is impossible.
3. **Unwanted traits:** In bispecific or multispecific polyploids, traits come from both parental species. In some cases, such as in the case of *Raphanobrassica*, these characters may be undesirable.
4. **Additional flaws:** Numerous flaws, including low fertility, genetic instability, slow development, late maturation, etc., are present in induced polyploids.
5. **Opportunities:**There are very few opportunities for allopolyploidy to create new species.

**VII. CONCLUSION**

It is currently unclear how polyploidy affects a species evolutionary path, despite the fact that it occurs frequently in nature and leaves its mark on all angiospermic genomes. With the help of modern genomic technologies, old concerns like how polyploidy responds to environmental stress or whether genome doubling is beneficial or detrimental to evolutionary survival are being explored. Studies at the molecular level have shown that polyploidization related genomic alteration occurs at many different regulatory levels. In many cases, the implications of polyploidy on fitness under various environmental settings are still unknown, and there is few evidence that the observed transcriptional and genomic modifications in natural populations actually speed up evolution or increase adaption. In terms of physical, ecological, physiological, and cytological traits, polyploids generally differ from their progenitors, which can both help them fill a new niche and cause reproductive isolation. Polyploidy is a key process for adaptability and speciation in plants, as a result. Polyploidy breeding can be used to track the evolution of new crops, interspecific gene transfer, as well as the source of new crops. In order to show how agricultural plants have evolved and to take advantage of their variability in crop breeding, polyploidy is an intriguing area of study.

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