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, creation of sterile lines, the recovery of hybrid fertility, growth and increased vigour, an increase in allelic diversity, 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 with all of their chromosomes duplicated (instead of only some) 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, Ploidy and Polyploidy.

I. INTRODUCTION

"Polyploidy" means an organism possesses more than two basic sets of chromosomes (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. As suggested by Chen et al., (2007) a large number of crop plants have undergone polyploidy as part of their evolutionary process and the key examples of this are *Raphanabrassica*, Hexaploid wheat, *triticale* etc. 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.

The current chapter aims to shed light on polyploidy's use and consequences in plant breeding and other commercial endeavors, based on numerous studies. 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 (1947) described three different types of polyploids in the plants *viz.* autopolyploidy, allopolyploidy, and segmented allopolyploidy. Every genome within a species is similar and develops through genome duplication (Stebbins 1947; Lewis 1980). Several genomes can exist in allopolyploids, some of which are different from one another (Stebbins 1947; Grant 1975). As a third type of allopolyploidy, segmental allopolyploidy consists of more than two incompletely different genomes that are capable of creating both bivalents and multivalent following chromosome pairing (Stebbins 1947; Levin 2002).

II. HISTORICAL APPROACH IN POLYPLOIDY BREEDING

The term polyploidy is made up of two Greek words: *poly* meaning many/more than two, and *ploideus* meaning a term which is derived from the Greek word *idios* (peculiar or individual) is related to the number of chromosomes set. Weismann coined the term *Id*, in German in 1893 to denote the hereditary in germplasms. Strasburger terms haploid and diploid were introduced in German in 1905 (Stearns 1992). This was one of the oldest traits which are related to cytogenetics and was thoroughly examined for several years (Stebbins 1950). Early in the 20th century, the occurrence of polyploidy became much more significant. Hugo De Vries was the first person to identify that, Oenothera (*Oenothera gigas*) was developed as a tetraploid mutant of ‘Evening Primrose’ (*Oenothera lamarckiana*) (Lutz 1907; Gates 1909). Early interest in possible chromosomal duplication in maize (*Zea mays*) was firmly discussed by Kuwada (1911).

When Winkler created a synthetic tetraploid variant of European black nightshade (*Solanum nigrum*) in 1916, he has credited with coining the term ‘polyploidy’. And this may have been the first instance of a polyploid type being created in a lab. While this was happening, parallelly numerous plant genera, including *Chrysanthemum* (Tahara 1915), *Drosera* (Rosenberg 1909) and *Dahlia* (Ishikawa, 1911), as well as multiples of a basic chromosomal number, were discovered. By doubling the chromosome number in a sterile *Pedicularis verticillata* x *Pedicularis floribunda* interspecific hybrid, Digby (1912) discovered that the fertile *Primula kewensis* can grow. While working on chromosomal counts of *Chenopodium* and *Chrysanthemum* related species Winge (1917) discovered that both species share multiple basic chromosome numbers. As a result, he came up with the intriguing theory that the formation of the species can be attributed to hybridization followed by polyploidy. The artificial production of several other species through interspecific hybridizations, most notably the traditional Radish (*Raphanus*) and Cabbage (*Brassica*) hybrid *Raphanobrassica* (Karpechenko, 1927, 1928), and the evidence that Townsend's cordgrass (*Spartina townsendii*) is descended from the cross of Saltwater cordgrass and wand goldenrod (*Sporobolus alterniflorus* x *Solidago stricta*), greatly supported Winge's hypothesis (Huskins 1931 a, b). Interspecific hybridization was also reported in some other significant genera, including *Triticum* (Sakamura 1918; Sax 1922) and *Nicotiana* (Clausen and Goodspeed 1925). Some scientists like Muntzing (1936) and Darlington (1937) provided the earliest reviews of polyploids in plants. During the same period of time Dustin *et al.*, (1937) discovered colchicine treatment for doubling the chromosomes in the plants. Blakeslee and Avery (1937) practically used this method and validated this treatment for chromosomal doubling.

Meanwhile, it was discovered that several of our most valuable agricultural plants, including wheat (*Triticum aestivum*), oats (*Avena sativa*), cotton (*Gossypium hirsutum*), tobacco (*Nicotiana tabacum*), potato (*Solanum spp.*), banana (*Musa acuminata*), coffee (*Coffea arabica*), and sugar cane (*Saccharum officinarum*), are polyploids either as a result of intentional hybridization and selective breeding (such as some blueberry varieties) or an ancient polyploidization event such as maize (Ramsey and Schemske 2002). These discoveries were also reviewed by Clausen *et al*. 1945; Love and Love 1949; Stebbins 1940, 1947, 1950). Studies by Crane and Darlington (1927), Crane (1940), Thomas (1940 a, b), Yarnell (1936), Darrow *et al*. (1944), and Darrow and camp (1945) all noted the significance of polyploidy in the plant breeder's ability to create new varieties.

Studies on polyploidy continued with increased attention after the publication of Stebbins (1950) renowned book *Variation and Evolution in Plants* and the subject has drawn significant interest worldwide (Lewis 1980). With the exception of gymnosperms, all the major groupings of plants are now recognized to exhibit polyploidy as a distinguishing property that is extremely prevalent (Stace 2000). It has been discovered that plant lineages throughout their evolutionary history have also undergone genome duplication. Because of this, applying species definitions to polyploids is challenging because of the complexity of their relationships with one another and their diploid ancestors (Rieseberg and Willis 2007; Soltis *et al*. 2007). Long-lived perennials with a range of vegetative mechanisms of propagation (such as Fragaria, Rubus, Artemisia and Potamogeton, etc.) and those with frequent occurrences of natural interspecific hybridizations seem to benefit greatly from polyploidy (Hilu 1993).

III. 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. On the other hand, allopolyploids have two or more unique genomes. Three, four, five, six, seven, eight or more somatic chromosomes-made up of several genomes may be present in euploids. Table 1 and Figure 1. summarizes the commonly used terminology related to heteroploidy.

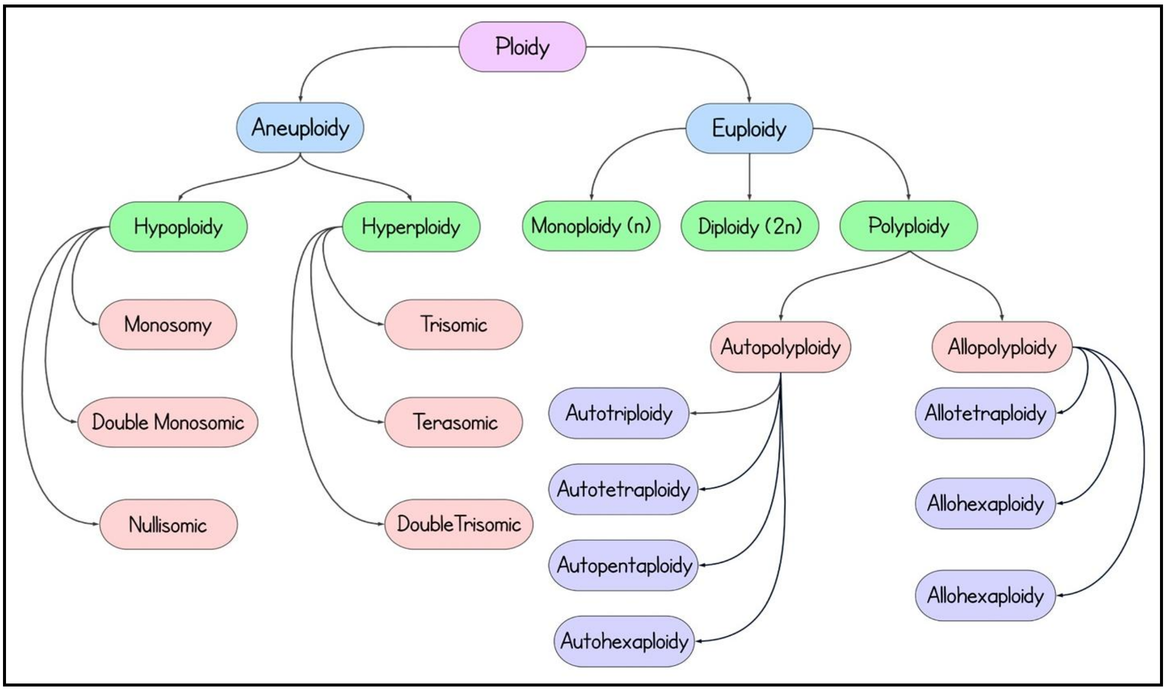

Figure 1. Illustration showing flowchart of Ploidy (Image is created in 'Lucidchart').

Table 1: Type of variations in chromosome number

S.N.	Term	Type of change	Symbol
1	**Aneuploid**	Chromosomes 1, 2, or a few may be absent in 2n	2n±few
1.1	Nullisomic	Lacking one set of chromosomes	2n-2
1.2	Monosomic	Lacking one chromosome	2n-1
1.3	Double monosomic	One missing chromosome from each of the two pairs of chromosomes	2n-1-1
1.4	Trisomic	An additional one chromosome	2n+1
1.5	Tetrasomic	An additional two chromosomes	2n+1
1.6	Double trisomic	Each of the two chromosome pairs has one additional chromosome.	2n+1+1
1.6	Tetrasomic	One additional pair of chromosomes	2n+2
2	**Euploid**	More than two copies of a same genome	
2.1	Monoploid	Only one genome's copy exists	x
2.2	Haploid	Whole set of gametic chromosomes	n
2.3	Polyploid	One genome has more than two copies	
2.3.1	Autopolyploid	Genomes that are similar to one another	
2.3.1.1	Autotriploid	One genome has three copies	3x
2.3.1.2	Autotetraploid	One genome has four copies	4x
2.3.1.3	Autopentaploid	One genome has five copies	5x
2.3.1.4	Autohexaploid	One genome has six copies	6x
2.3.2	Allopolyploid	Two or more different genomes	
2.3.2.1	Allotetraploid	Two distinct genomes	$2x_1 + 2x_2$
2.3.2.2	Allohexaploid	Three distinct genomes	$2x_1 + 2x_2 + 2x_3$
2.3.2.3	Allooctaploid	Four distinct genomes	$2x_1 + 2x_2 + 2x_3 + 2x_4$

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

IV. ORIGIN OF POPYPLOIDY

There are numerous reasons that might lead to polyploidy. Somatic doubling during mitosis, nonreduction in meiosis leading to the production of unreduced gametes, polyspermy (fertilization of the egg by two male nuclei), and endoreduplication are some of the essential processes that lead to polyploidy (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) (e.g., tetraploid and octoploid cells in the cortex and pith of *Vicia faba*). Grant (1981) claims that the primary cause of somatic doubling is mitotic non-disjunction. 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

1. Autopolyploidy

Autopolyploids are polyploids that develop through the multiplication of chromosomes 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. Autopolyploidy occurs when meiosis fails, resulting failure of splitting of the chromosomes. Due to the fact that gametes (2n) have twice as many chromosomes as regular gametes, unreduced 2n gametes produced as a result of gametic nonreduction or meiotic nuclear restoration during microsporogenesis and megasporogenesis can eventually grow into autopolyploids. Fig. 2. Shows the origin of autopolyploidy from two non-reduced gametes. Autoploids include triploids (3x), tetraploids (4x), pentaploids (5x), hexaploids (6x), septaploids (7x), octaploids (8x), and more polyploids. It is also known as simple polyploids or single species polyploids. Let's discuss this theory in more details,

A. 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.
    - a) **Banana:** Bananas are triploid and seedless cultivars. The fruits of such bananas are larger than those of diploids species
    - b) **Apples:** Certain triploid apple types are propagated asexually through budding or grafting.
    - c) **Sugar beet:** Triploid sugar beet species contain more sugar than diploids and are typically mold-resistant.

d) **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.

B. Autotetraploids

- They can be artificially created by doubling the number of chromosomes in a diploid organisms via colchicine therapy, or they can occur naturally.
- 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.
  a) **Rye:** Germany and Sweden both grow autotetraploid rye. They have larger seeds and greater proteins than diploids.
  b) **Grapes:** These grapes have larger fruits and fewer seeds per fruit than diploids. In the USA and Japan, tetraploid grapes have been developed and are in use.
  c) **Alfalfa:** Tetraploid cultivars of alfalfa yield more and recover faster from grazing than diploid ones do.

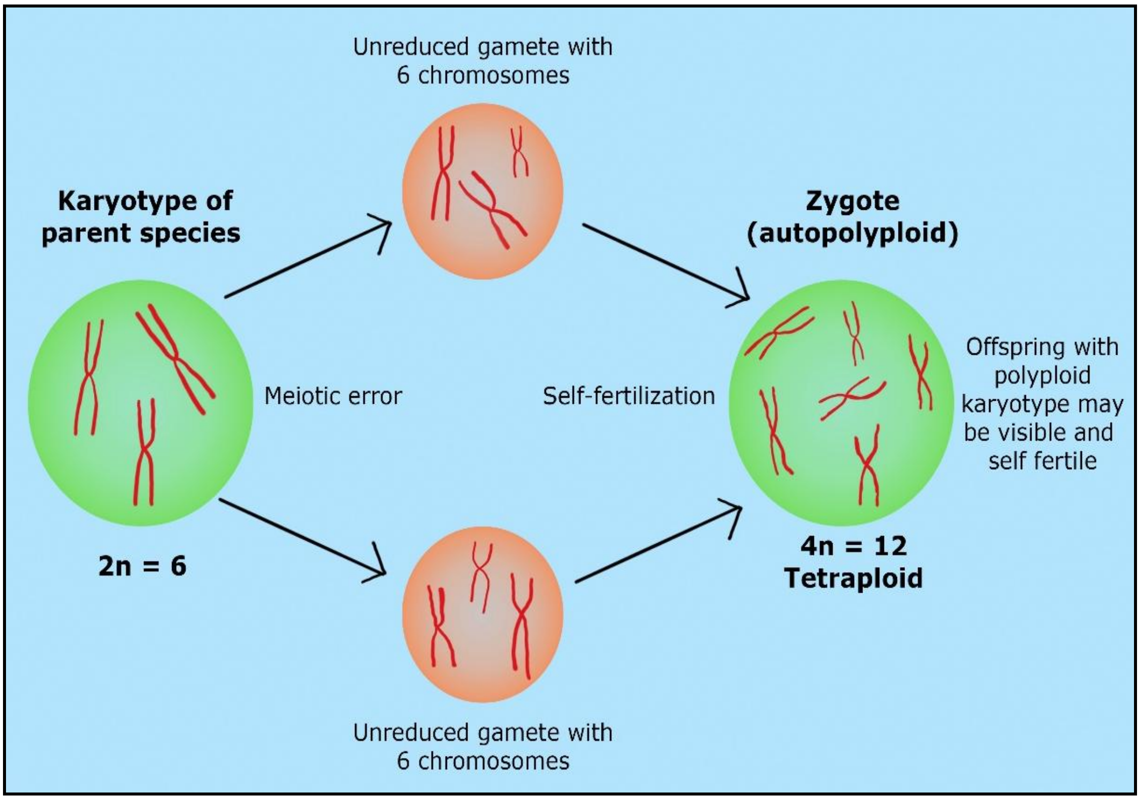

Figure 2: A diagram demonstrating how unreduced gametes can produce autopolyploidy

2. 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 reduced "1n" gamete and a "3n" gamete, which are produced by the union of a reduced "1n" gamete and an unreduced "2n" gamete, are mated to produce a tetraploid individual in the following generation. 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). Quick screening methods like flow cytometry, chromosomal matching, and other genomic methodologies are useful for studies on unreduced gametes in both plants and animals (Mable 2003). Ramsey and Schemske (1998) assert that the contribution of polyspermy as a method of polyploidy generation is unusual, with the exception of some orchids. 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). Fig. 3 provided a diagrammatic representation of the development of allopolyploidy.

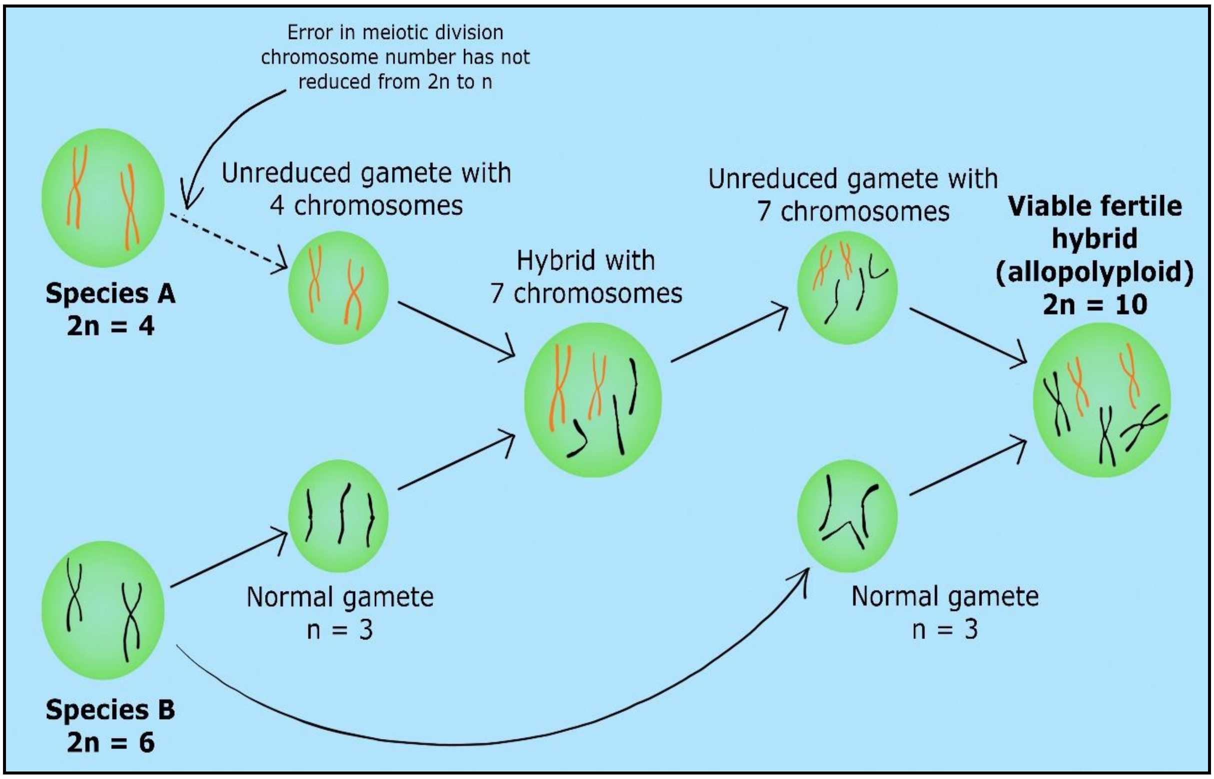

Figure. 3: Illustration demonstrating the genesis of allopolyploid from both unreduced and reduced gametes.

A. 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 *T. aestivum*, most notably pioneer work demonstrated by Kihara (1944), McFadden and Sears (1944, 1946) in the identification of *Aegilops tauschii* (syn *Ae. squarrosa*, *T. 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. *T. monococcum* is thought to have provided the wheat genome A, *T. tauschii* the genome D and an unidentified source that most likely provided the genome B (2n = 14).

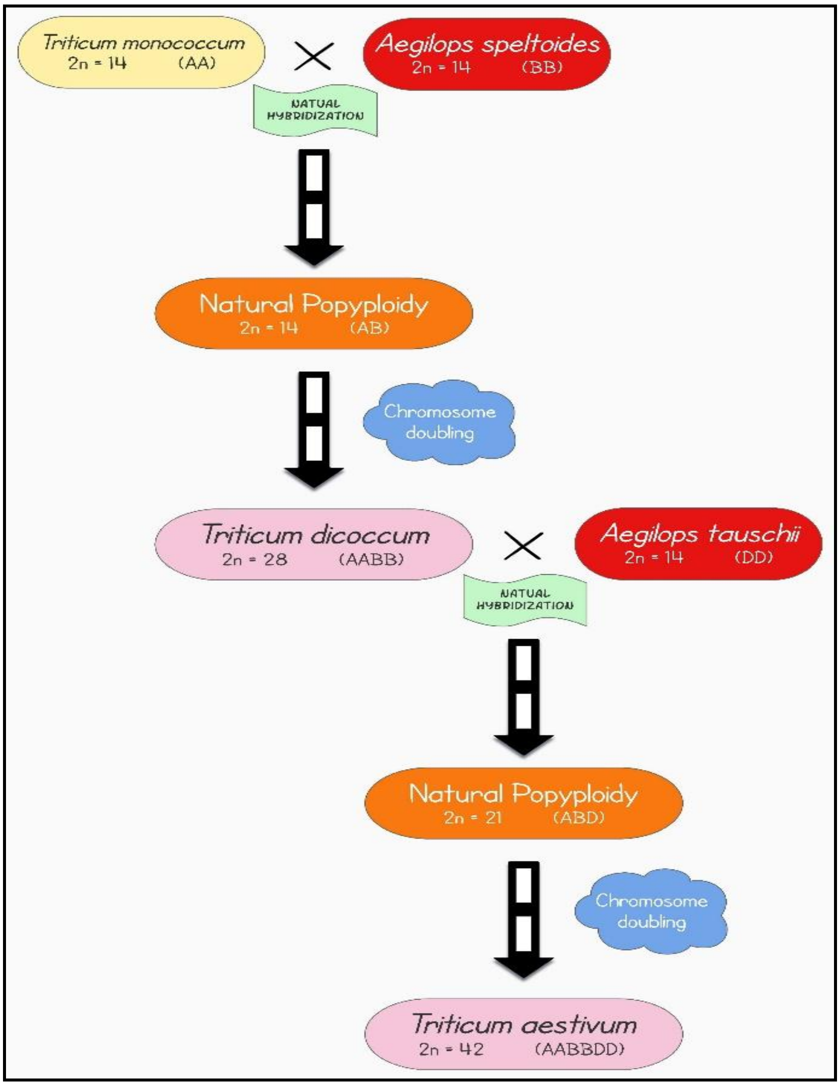

Figure 4. Evolution of allohexaploid wheat (*Triticum aestivum*)
(Image is created in 'Lucidchart').

2. 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 *N. tabacum* (2n=4x=48) resulted from interspecific hybridization between *N. sylvestris* (female donor) and *N. tomentosiformis* (male donor), both of which are diploid with 2n=24. This hybridization took around 200,000 years back (Leitch *et al* 2008). *N. 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 *N. tomentosiformis*, *N. 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).

3. 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). Chromosome pairing in interspecific crosses between diploid and tetraploid cotton suggests that tetraploid cotton may have two separate genomes that resemble the A genome of *G. hirsutum* (n = 13) and the D genome of *G. raimondii* (n = 13). 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 thought that polyploidy-level diversification led to the emergence of the five allotetraploid species (*G. hirsutum, G. barbadense, G. darwini, G. mustelinum*, and *G. tomentosum).*

4. 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).

5. *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)] and Wild cabbage [*Brassica oleracea* (n=9)] and Black mustard [*Brassica nigra* (n=8)] were interspecifically crossed to produce Ethipian mustard [*Brassica carinata* (n=17)].

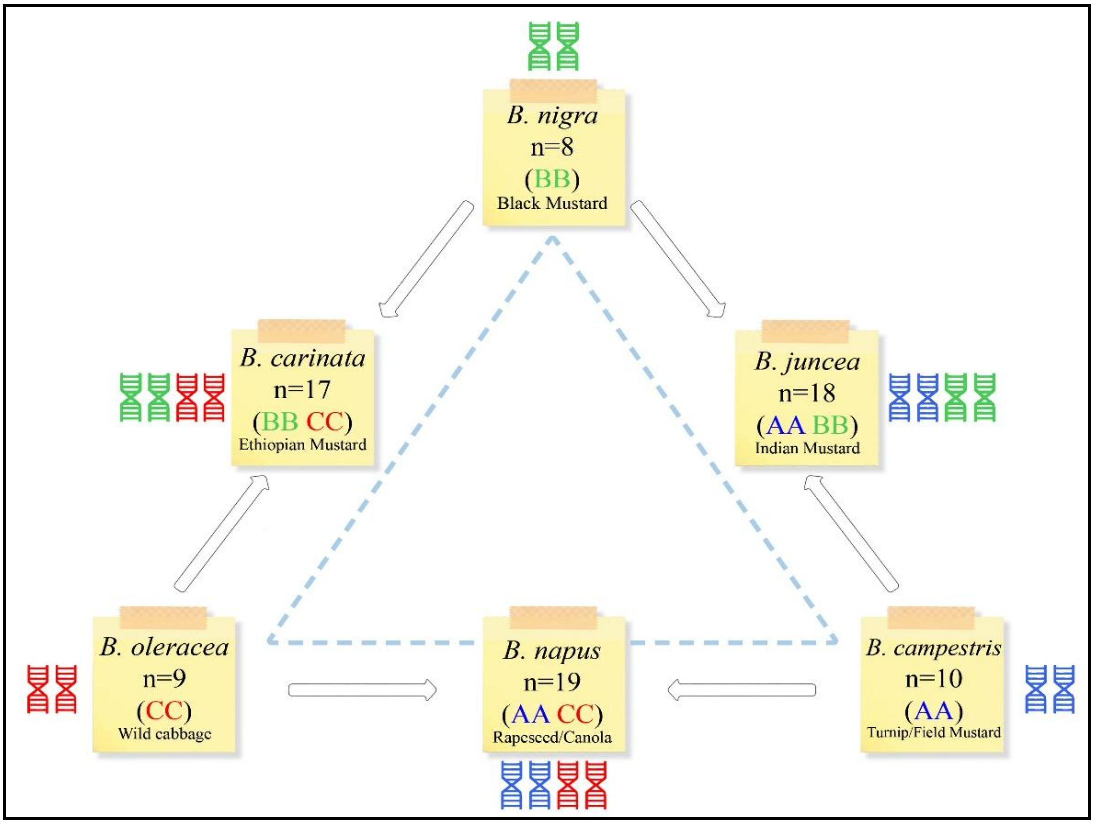

Figure 5. Brassica triangle showing the relation between diploid and naturally occurring amphidiploid species of *brassica*. Three diploid species can be seen on the tips of the triangle, while amphidiploids are represented in the middle of two parents. (Image is created in 'Lucidchart and Vecteezy').

B. 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.

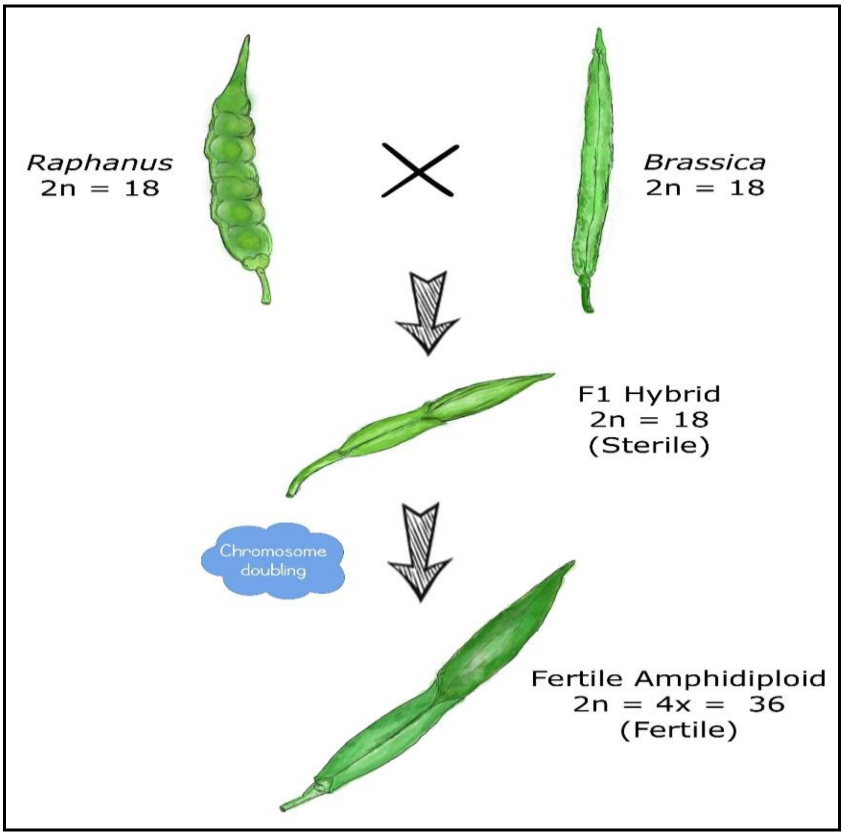

Figure 6: Evolution of *Raphanabrassica* (Artificial allopolyploid) from cross between Radish x cabbage (Image is created in 'Lucidchart').

2. *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 7. 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 F_1 hybrid (2n=21). After colchicine treatment, chromosomes get doubled 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 F_1 hybrid (2n=28) and after colchicine treatment, we get stable and fertile octoploid *triticale* (2n=56). Tetraploid (2n=4x=28) and hexaploid (2n=6x=42) wheat are used to produce hexaploid (2n=6x=42) and octoploid (2n=8x=56) triticale, respectively. Now a day, triticale is widely farmed in Canada, Mexico, Hungary and other nations.

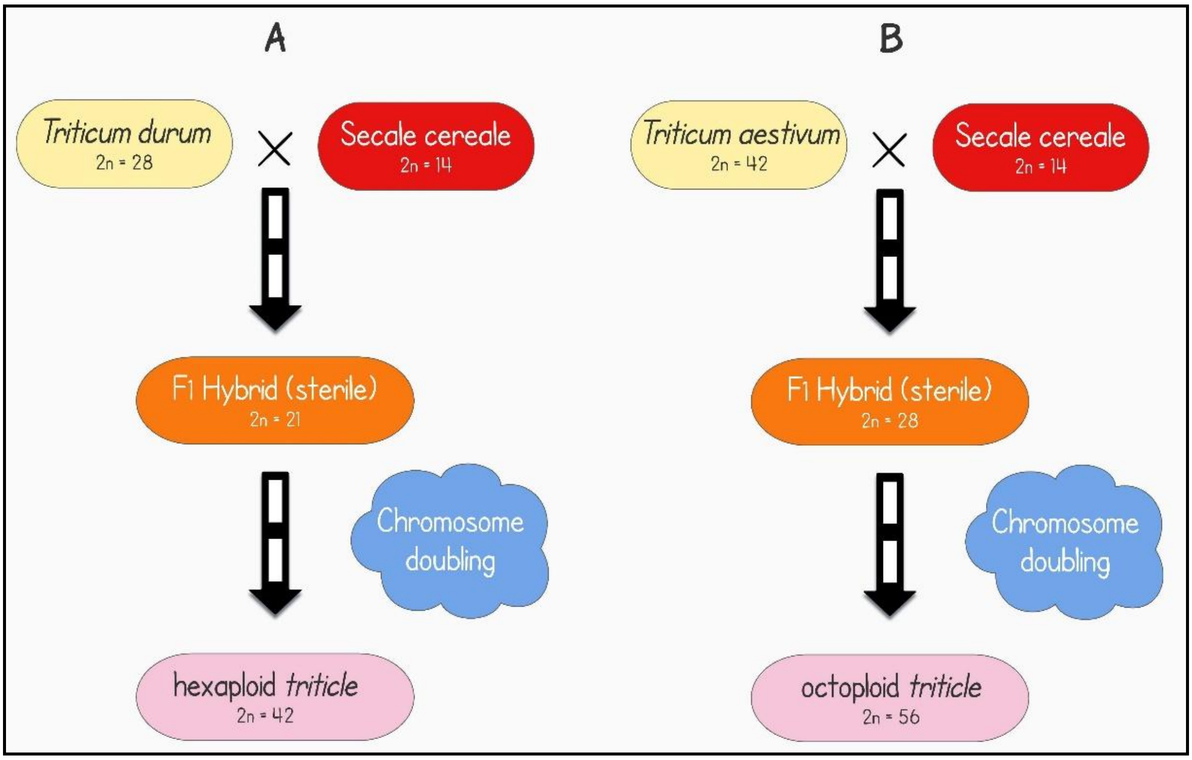

Figure. 7: Evolution of *triticale*. Left side (A) illustration of evolution of the hexaploid *triticale* and the right side (B) illustration of evolution of octoploid *triticale* (Image is created in 'Lucidchart and Vecteezy').

3. Wheat:

As an amphidiploid of wild or farmed emmer with, McFadden and Sears (1944) recreated hexaploid wheat, *A. tauschii*. The artificial wheat was hexaploid and resembled spelt (*T. aestivum* sp. *spelta*, genomes BBAADD). This led them to the conclusion that *T. aestivum*'s ancestor was spelta and that unrestricted *T. Spelta* gave rise to *T. aestivum*.

V. 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. Mitotic inhibitors like as oryzalin, trifluralin, amiprophos-methyl, and N_2O gas have also been found and used 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). *H. vulgare, T. aestivum, S. cereal* and a few more crop species have all been successfully heat-treated to induce polyploidy.

VI. 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. The dominant alleles of any potentially dangerous alleles that may arise from forced mutation in polyploids provide protection against the lethal circumstances typically associated with inbred diploid crops (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).

2. 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.

3. 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).

4. 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.

5. 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 *Themeda triandra* is a prime example of an obligatory apomict produced at a high ploidy level (Levin, 1983).

6. Biotic 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 *Triticum 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).

7. 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 × *Chitalpa tashkentensis* 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).

8. Helps to 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*. The QTL for seed yield and other variables are similarly impacted by intergenomic heterozygosity in several populations of *B. napus* (Udall *et al*. 2006; Quijada *et al*. 2006). Tetraploid cotton also leads the world textile market because it can create fabric that is longer, finer, and tougher than its diploid relatives. According to Jiang *et al*. (1998), several QTLs on the D genome showed that D genome loci have been used for fibre synthesis after polyploidy developed.

VII. 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.

VIII. 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 varies 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 interspecific gene transfer, evolution of new crops 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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