A SEMINAR PAPER ON

Role of polyploidy breeding in crop improvement

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Abstract

This paper is a completely a review paper considering the basic role of polyploidy both natural and artificial and their formation, characteristics and application. Polyploid have a significant role on crop development and evaluation. Many significant crops are domesticated through polyploidy in nature. Wheat is the world's major staple food and this grass are cultivated for cereal food. Wheat is the best example of natural polyploidy plant. Triticale is the example of 1st man made polyploidy which is produce by the crossing between tetraploid wheat and diploid rye. Now a day's triticale is cultivated 37 countries and production is 17.1 million tons. Autopolypliod have a great contribution on fruit production especially seedless fruits formation which is produce by triploid polypliod as for example: Watermelon, Guava, and Grape.Gigas effect of polyploidy also give huge producrtion in cropsas for example: Strawberry, Cabbage, chrysanthemum and Rose. Industrial product also gift of polyploidy cotton and sugarcane give us high production every year.

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Chapter 1

Introduction

Polyploidy refers to more than two set of chromosomes. To understand polyploidy, a few basic notations need be defined. The basic set of chromosomes is “x” and the total number of chromosomes in a somatic cell is symbolized by “2n”. Chromosome numbers of in a somatic cell is twice the haploid number (n) in the gametes (Acquaah et al., 2007). Generally most species that have nuclei are diploid (2n), meaning they have two sets of chromosomes, one set inherited from each parent. Most of the eukaryotes have diploid somatic cells, but they produce haploid gametes by the process of meiosis.

Polyploidy refers to the presence of more than two complete sets of chromosomes per cell nucleus, which has been considered a ubiquitous phenomenon in plant evolution and diversification (Soltis et al., 2009). It is common in nature and provides a major mechanism for adaptation and speciation.

Polyploidy can happen spontaneously in nature by several mechanisms, including meiotic or mitotic failures, and fusion of unreduced (2n) gametes (Comai et al., 2005). Both autopolyploid (e.g. potato) and allopolyploids (e.g. canola, wheat, and cotton) can be found among both wild and domesticated plant species (Xun et al., 2011). The introduction of polyploidy is a frequent technique to overcome the sterility of a hybrid species during plant breeding. For example, *Triticle* is the hybrid of wheat (*Triticum turgidum*) and Rye (*Secale cereale*). It combines sought-after characteristics of the parents, but the initial hybrids are sterile. After polyploidization, the hybrid becomes fertile and can be further propagated to become triticale. Approximately 50-70% of angiosperms, which include many crop plants, have undergone polyploidy during their evolutionary process (Chen et al.,, 2007).

A large number of plant species have a polyploidy genome, many important crops are polyploids. Estimates of the frequency of polyploid angiosperm species range from '30–35% to as high as 80% (Stebbins et al., 1947). Most estimates are near 50% (Soltis et al., 2000) Levels of polyploidy may be even higher in pteridophytes, with some estimates of polyploidy in ferns as high as 95% (Soltis et al., 2000).

The clarification of the causes and consequences of polyploidy has been the focus of several reviews in the last hundred years (Stebbins 1947, 1971; Harlan and de Wet 1975; Levin 1983; Soltis and Soltis 1999, 2009; Ramsey and Schemske 1998; Otto and Whitton 2000; Wolfe 2001; Osborn et al., 2003; Yang et al., 2011; Ramsey and Ramsey 2014). These studies have provided a wide range of information about different aspects of polyploidy, including classification, frequency, and mechanisms of origin and ancient polyploidy events, as well as its ecological, genetic and evolutionary consequences.

Polyploids frequently different from those of their diploid parents, and have been proposed to live superior colonizers to diploids. On the contrary, although genome doubling has been reported from other major groups of eukaryotes it is not nearly as common in these groups as it is in plants. The revelation that a large number of plant species have a polyploid genome, including a number of important crops, has involved the awareness of plant breeders for the application of artificial polyploidy as an instrument for crop improvement. In this circumstance, the work at presents days focused on the applications of polyploidy in plant breeding, and why it is more successful and the methods for polyploidy induction and detection, as well as some examples of successfully induced polyploid crops of commercial relevance.

Objectives:

- To know why polyploidy are so common in nature and so successful
- To review some common application of polyploidy in plant breeding.

Chapter 2

Materials and Metods

The seminer paper is exclusively a review paper. So, there is no specific method involved to collect data. The data and relevant information were collected from the following secondary sources:

1. Different Agricultural Installation such as:

a. National journals

b. Books

c. Publications and Reports

2. Different Agriculteral Libraries:

a. Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU)

b. Bangladesh Agricultural University (BAU)

Good suggestion, valuable information and kind consideration from my honorable major professor, course instructors and other resources personnel were taken to enrich my paper.

3. Internet Browsing:

After collecting necessary information, I arranged data chronologically for better understanding and clarification.

Chapter 3

Review of Findings

Polyploidy, the presence of more than two genomes per cell, is a significant mode of species formation in plants. To understand polyploidy easily its classifie classified based on their chromosomal composition into either euploids or aneuploids. Euploids constitute the majority of polyploids.

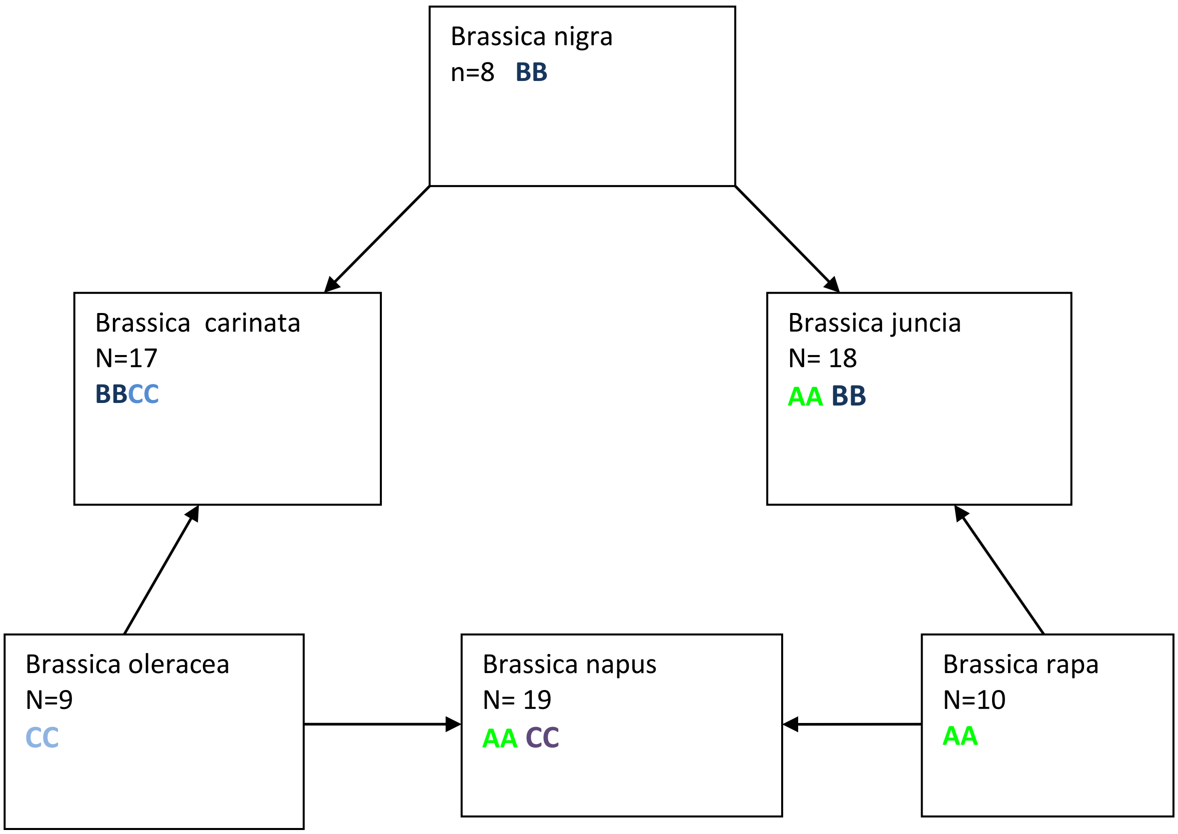
3.1 Classification

Euploidy

Euploids is polyploids with multiples of the whole set of chromosomes specific to a species. Depending on the composition of the ordering, euploids ar typically additional classified into either autopolyploids or allopolyploids (Comai, 2005).

Autopolyploids is containing over two copies of the essential set (x) of chromosomes of identical ordering (Acquaah, 2007; Chen, 2010). Natural autoploids embrace crops admire alfafa, peanut, potato, bananas. They occur impromptu through the tactic of body doubling (Acquaah, 2007). Seedless watermelon is that the instance of artificial autoploids that manufacture by in vitro body doubling.

Allopolyploids are combination of genomes from fully totally different species (Acquaah, 2007). They result from conjugation of two or extra genomes followed by body doubling or by the fusion of unedited gametes between species (Acquaah, 2007; Chen, 2010; Jones et al.,, 2008; Ramsey and Schemske, 1998). Genrally very significant natural alloploid crops embrace strawberry, wheat, seed rape and mustard (Acquaah, 2007; Chen, 2010).



(Sorces: Bellostas et al., 2007; Nelson et al., 2009).

Figure 1: Triangle of U showing the origin of cultivated mustard. To differentiate between the sources of the genomes in an alloploid, each genome is designated by a different letter.

Aneuploidy

Aneuploids is unit of polyploids that contain either an addition or subtraction of 1 or additional specific chromosome(s) to the entire range of chromosomes. Parenthetically, many studies have found that 30-40% of issue derived from autotetraploid maize aunit aneuploids (Comai, 2005).

Table 1: Classification of aneuploids where 2n diploid number of chromosome and the number indicate extra number or missing number of chromosome.

Term	**Chromosome number**
Monosomy	2n-1
Nullisomy	2n-2
Trisomy	2n+1+1
Tetrasomy	2n+2
Pentasomy	2n+3

(Sources: Meru, 2012).

3.2 Success of polyplidy:

Considered vegetative copy and also the perennial habit to be necessary factors promoting the institution of polyploids. In conjunction with an outcrossing system to permit for sexual union (between species, subspecies, races, populations, etc.) within the formation of the polyploid. It absolutely was additionally valuable half that convenience of recent ecological niches. Another hypothesis for the success of polyploids embodies broader ecological amplitude of the polyploid relative to its diploid folks, higher colonizing ability, higher selfing rates, and magnified state.(Soltis, 2005).

Table 2: Genetic variation (mean values) in diploid (2n) and tetraploid (4n) populations
P, proportion of loci polymorphic; **H**, observed heterozygosity; **A**, mean number of alleles per locus.

Species	*P*		*H*		*A*	
	2*n*	4*n*	2*n*	4*n*	2*n*	4*n*
Tolmiea menziesii	0.240	0.408	0.070	0.237	3.0	3.53
Heuchera grossulariifolia	0.238	0.311	0.058	0.159	1.35	1.55
Heuchera micrantha	0.240	0.383	0.074	0.151	1.41	1.64
Dactylis glomerata	0.70	0.80	0.17	0.43	1.51	2.36
Turnera ulmifolia						
var. *elegans*	0.459	0.653	0.11	0.42	2.20	2.56
var. *intermedia*	0.459	0.201	0.11	0.07	2.20	2.00

(Sources: Soltis et al., 1993)

Increased Heterozygosity:

(Roose et al., 1976) showed that allotetraploids in *Tragopogon* had mount state at isozyme loci, representing the mix of divergent genomes. Within the allotetraploids *Tragopogon mirus* and *Tragopogon miscellus*, thirty third and forty third, severally, of the loci examined were duplicated. Once there's no apparent citron divergence between the parental genomes, the body phase is additionally duplicated; these facts regarding duplicated genes area unit reviewed by (Wendel, 2000). All allopolyploid are basically heterozygous through nonsegregating, mounted state.

Empirical studies have showed that autotetraploid with tetrasomic have higher levels of state than do their diploid folks. (Soltis et al., 1989) For example: varied measures of genetic diversity were compared in natural populations of the 2 cytotypes (Soltis et al., 1989). These polyploids probably additionally maintain higher levels of state than do their diploid folks, just because of their mode of inheritance.

Outcrossing rate of polyploids

There is some reasons of polyploid success are attributed to improved colonizing ability, which can involve higher selfing rates than those of the diploid folks. In polyploids sexual union depression is pridect scale back relative to their diploid folks, as a result of the buffering impact of further genomes. Harmful alleles area unit cloaked by the additional genomes (Stebbins et al., 1971; Richard, 1986). Each allopolyploids and autopolyploids area unit expected to own reduced in breeding depresion (Barret et al., 1989; Charle et al., 1987). AN experiment was conducted between 2 empirical studies of sexual union depression in diploid and tetraploid pairs of ferns. In fern genus, 30–60% of selfed gametophytes of the diploid race fashioned sporophytes, whereas a hundred of all selfed gametophytes of the tetraploid race fashioned sporophytes. In Lepisorus, solely four of selfed gametophytes of the diploid race made traditional sporophytes, whereas 98–100% of the gametophytes of the tetraploid race fashioned sporophytes. This information were taken as proof for reduced sexual union depression within the tetraploid that indicate increasing selfing rates. (Masuyama et al., 1990).

Outcrossing rates also have been estimated in diploid and allotetraploid species of *Tragopogon* (Cook et al., 1999, 2000).The outcrossing rates in the allotetraploid *Tragopogon*. *mirus* (0.381 and 0.456 for two populations) were higher than those found in the diploid parent *Tragopogon dubius* (0.068 and 0.242), although significantly higher than only one of the two populations; the other parent*, Tragopogon porrifolius* (Ownbey, 1950; soltis et al., 1995). lacked segregating allozyme variation from which to estimate outcrossing rates. This outline is exactly the opposite of that predicted by population genetic theory, and one explanation offered to explain it is that rates of outcrossing were under estimated, particularly in *Tragopogon dubius*, because of limited polymorphic loci in all populations.

Genome Rearrangements in Polyploids

Another important source of genetic novelty in polyploids is genome rearrangements. Genomic changes in tetraploids relative to their diploid progenitors is an analysis of tobacco genome structure using genome *in situ* hybridization (GISH).(Leitch et al., 1997).Tobacco (*Nicotiana tabacum*) is an allotetraploid crossing between Nicotiana *sylvestris* and a T-genome diploid from section *Tomentosae* (Leitch et al., 1997). GISH system revealed numerous chromosomal rearrangements. Most of the chromosomes of tobacco are therefore mosaics, composed of regions of both parents. Also in *Brassica*, there is evidence that such genome rearrangements may occur very soon after the formation of the tetraploid. (Song et al., 1995). produced artificial tetraploids resulting from interspecific crosses between two parent *Brassica rapa* and *Brassica nigra* and between *Brassica rapa* and *Brassica oleracea*. They compared genome structure in the F5 derivatives of these crosses with their F2 ancestors and found genetic divergence in these few generations, with distances as high as almost 10%. (Song et al., 1995).

Ancient Polyploidy and Gene Silencing

It is estimates by some experiment that ancient polyploidy generally have relied on chromosome number alone; (Stebbins et al., 1971). For example, viewed those plants with a basic chromosome number of n =12 or higher to be polyploid. Based on this criterion, a large number of angiosperm families, and their rots angiosperm phylogeny, are considered to be the products of ancient polyploid events some of those diploid ancestors are now extinct. For example, the *Illiciales* have n = 14, and both the *Lauraceae* and *Calycanthaceae* of *Laurales* have a base number of n = 12. The lowest chromosome number in the *Magnoliaceae* is n = 19 and the family exhibits a range of numbers that are multiples of this base number. Some families of possible ancient polyploid origin, along with their chromosome numbers, are listed on the Table3. The high chromosome numbers of the basal angiosperm groups make it difficult to assume base chromosome numbers for those groups of angiosperms. All family which are mentioned on the table no 3 have chromosome numbers that are multiples of a single lower number, it happens, after polyploidization, diversification continued at the new polyploid level, with subsequent episodes of polyploidy superimposed on this initial polyploidy level. This pattern of divergent speciation at the polyploid level contradicts the view of polyploids as evolutionary dead-ends.

Table 3: Angiosperm families with high chromosome numbers, suggested being of ancient polyploid origin

Basal angiosperms	Chromosome number, n
Family	
Illiciaceae	14
Schisandraceae	14
Lauraceae	12
Calycanthaceae	12
Mangoliaceae	19

(Sources: Soltis et al. 2000).

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Homosporous Pteridophytes:

Homosporous pteridophytes are those which producing same type of spore rather than male and female spores in example ferns including Psilotum and Tmesipteris; lycophytes, and Equisetum. (Manhart, 1994; Wolf, 1997). All of these groups are the offspring of ancient plant lineages that extend back to the Devonian Period (Kenrick et al., 1997). The mean gametic chromosome number for homosporous pteridophytes is n = 57; for angiosperms, it is n = 16 (Klekowski et al., 1966). Although they have high chromosome numbers, however, homosporous pteridophytes exhibit diploid gene expression at isozyme loci (Soltis et al., 1988). At least two possible explanations can explain this phenomenon of high chromosome numbers and genetic diploidy. First, these plants are ancient polyploids that have undergone extensive gene silencing to produce genetic diploids, and second, they may have achieved high chromosome numbers through another mechanism, such as chromosomal fission.

The Genetic Implications of Recurrent Polyploid Formation:

Although morphological or cytologic variations among populations of some polyploid species prompt proof of polyploid formation most polyploid species, till recently, were thought-about to distinctive origin. the majority polyploid species of plants that examined with molecular markers they showed to be polyphyletic, having arisen multiple times from an equivalent diploid species Polyphyletic polyploid species angiosperms and embrace each autopolyploids e.g., genus Heuchera grossulariifolia (Segraves et al., 1999; ground et al., 1989; Soltis et al., 1989; Cook et al., 1998). Used random amplified polymorphic deoxyribonucleic acid (RAPD) markers to check the hypothesis that isozymically identical populations of *Tragopogon mirus* having an equivalent plastid deoxyribonucleic acid haplotype and rDNA repeat were of separate origin which ''identical'' populations of *Tragopogon miscellus* additionally were of separate origin. For *Tragopogon mirus* have 5 populations with isozyme multilocus genotype one (Soltis et al., 1995). 2 populations with isozyme genotype two (Soltis et al., 1995). Every population had a RAPD profile (and, infact, 2 populations were polymorphic), suggesting that every population may need a separate origin. Alternative knowledge, *Tragopogon mirus* might represent a group of as several as eleven lineages. *Tragopogon miscellus* incontestible that each one 3 were distinct and presumably of separate origin, raising the amount of genetically distinct populations of Tragopogon miscellus to 5 (Cook et al., 1998).

3.3 Common Application of Polyploidy in plant breeding:

Polyploidy is thus common in each nature and artificial. There's vast quantity of experiment of condition and its application among hundred year's history of crop science. What is more some side is extremely special and helpful for man history. Condition offers betterment on industrial product, crops, medicative plants, decorative plants and then on. The lists of some polypliod valuable plant that is productive in worldwide are given below:

Table 4: Examples of some polyploidy crops with their classification along with the commercial interest, origin (synthetic/natural), formation process (auto/allopolyploidization)

Common Name	**Specific Name**	**Commercial interest**	**Origin**	**Formation procss**
Bananna	*Musa acuminate*	Edible fruits	Natural	Autopolyploidy
Potato	*Solanum tuberosum*	Tubercle	Natural	Autopolyploidy
Sweet potato	*Ipomea batatas*	Tubercle	Natural	Autopolyploidy
Kiwifruit	*Actinidia chinensis*	Edible fruits	Natural	Autopolyploidy
Rapeseed	*Brassica napus*	Oil seed	Natural	Allopolyploidy
Plums	*Prunus domestica*	Edible fruits	Natural	Allopolyploidy
Tobacco	*Nicotiana tabacum*	Industrial	Natural	Allopolyploidy
Bread wheat	*Triticun aestivum*	Grain	Natural	Allopolyploidy
Cotton	*Gossypium histurum*	Industrial	Natural	Allopolyploidy
Coffee	*Coffea arabica*	Beverage	Natural	Allopolyploidy
Sugarcane	*Saccharum officinarum*	Industrial	Natural	Allopolyploidy
Triploid sugar beet	*Beta vulgaris*	Industrial	Synthetic	Autopolyploidy
Triploid watermelon	*Citrallus vulgaris*	Edible fruits	Synthetic	Autopolyploidy
Lilies	*Lilium spp.*	Ornamental	Synthetic	Autopolyploidy
Triticle	*Triticosecale wittmack*	Grain	Synthetic	Allopolyploidy
Tulip	*Tulipa spp.*	Ornamental	Synthetic/ natural	Autopolyploidy/ Allopolyploidy
Rose	*Rosa spp.*	Ornamental	Synthetic/ natural	Autopolyploidy/ Allopolyploidy
Grape	*Malus spp.*	Edible fruits	Synthetic/ Natural	Autopolyploidy/ Allopolyploidy

(Sources: Mariana, 2015).

Gigas effect of polyploidy:

Ploidy affects the structural and anatomical characteristics of the plant. In general, condition leads to increased leaf and flower size (Figure 2). stomatal density, cell size and plastid count (Dhawan et al., 1996). These phenomena are renowned to because the gigas result (Acquaah, 2007). it's involved in vegetative crop production and decorative breedings thus on.Physiological changes also are renowned to travel in conjunction with order duplication. This primarily results from modification of metabolism leading to a general increase in secondary metabolites (Levin, 1983). This property has found application within the breeding of medicative herbs within the production of prescription drugs, vegetative a part of edible vegetative portion, hybrid vigor ensuing from interspecies crosses in allopolyploids is one in every of the foremost
exploited benefits of polyploid in plant breeding. (Meru, 2012).

(Sources: Meru, 2012).

Figure 2: Differences between the leaf and flower of a (Left) diploid and (Right) induced tetraploid watermelon illustrate the gigas effect.

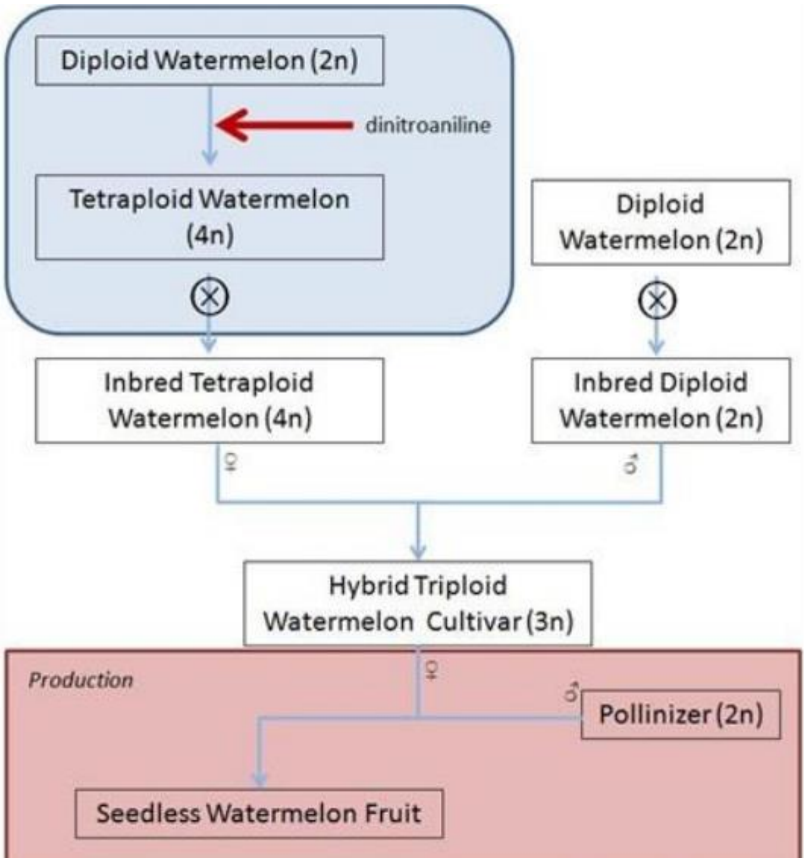
Polypliods used for mutation breeding:

polyploids ar ready to tolerate injurious cistron modifications postmutation, they need increased mutation frequency owing to their massive genomes ensuing from duplicated condition of their generous (Gaul, 1958). The high mutation frequencies ascertained with polyploids could also be exploited once making an attempt to induce mutations in diploid cultivars that don't manufacture enough genetic variation when a agent treatment. This approach has been employed in mutation breeding of hot water plant sp. (nut orchids). It's 1st forming autotetraploids through colchicine treatment and additionally the primary application of X-rays. During this study, the autotetraploids were found to own 20-40 times higher mutation frequency than the corresponding diploid variety frequency which have large genome (Broertjes, 1976).

Seedless fruit formation

Since autoploids contain quite 2 homologous chromosomes and once meiosis fashioned it gave univalents and multivalent, different in diploids wherever bivalents are sometimes fashioned (Acquaah, 2007). As an example throughout meiosis, autotetraploids might kind bivalents, quadrivalents and univalents. When univalents and trivalents manufacture it ensuing non-functional sterile gametes and are the foremost common in triploids, creating them sterile. That's why sterile alloploids arise from the pairing of homeologous bodys from separate genomes throughout meiosis rather than homologous chromosome (Chen et al.,, 2007; St. Matthew the Apostle et al.,, 2002). As a result non-functional gametes fashioned.

An allopolyploid needs a diploid-like meiosis behavior to determine viable gametes and full fertility. Fertility issues in allopolyploids additionally occur once crossing crops of various ploidy levels as results of formation of multivalents. The seedless attribute of triploids has been advantageous particularly in fruits. polyploid fruits is found in crops resembling watermelons, seedless banana. They need terribly high price in market place. Those ar made by artificial means by 1st developing tetraploids that ar then crossed with diploid fruits. so as to line fruit, the polyploid fruits ar crossed with a fascinating diploid spore donor. (Meru, 2012).



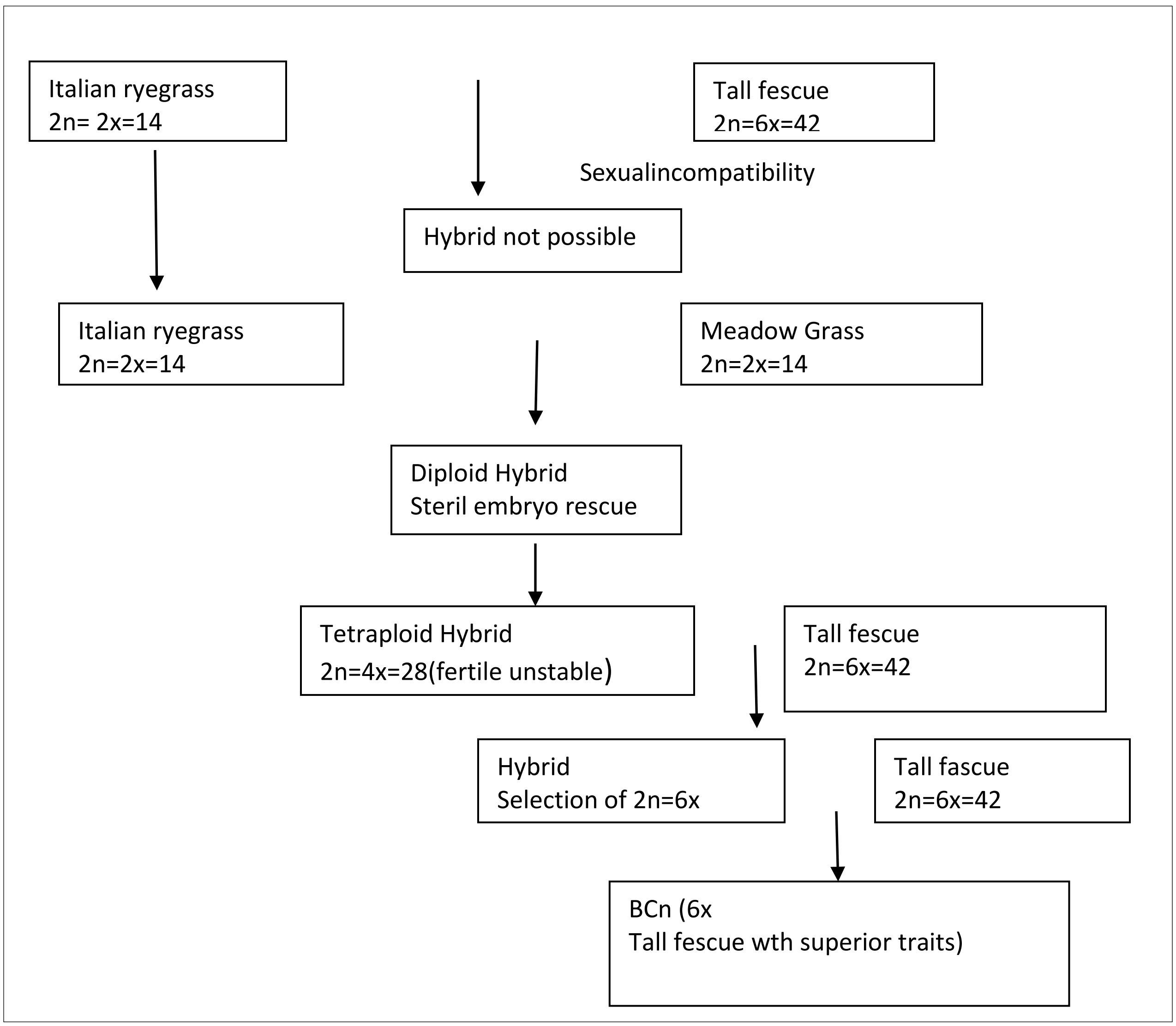
(Source: Meru, 2012).

Figure3: A flow diagram showing the production of seedless triploid watermelon.

An allopolyploid requires a diploid-like meiosis behavior to establish viable gametes and full fertility. Fertility problems in allopolyploids also occur when crossing crops of different ploidy levels as a result of formation of multivalents. The seedless trait of triploids has been advantageous especially in fruits. Triploid fruits can be found in crops such as watermelons, seedless banana. They have very high value in market place. Those are produced artificially by first developing tetraploids which are then crossed with diploid fruits. In order to set fruit, the triploid fruits are crossed with a desirable diploid pollen donor. (Meru, 2012).

Bridge crossing:

Another breeding approach that utilizes the reproductive advantage of polyploids is bridge crossing. When sexual incompatibilities between two species are due to ploidy levels, intermediary crosses can be carried out followed by chromosome doubling to produce fertile bridge hybrids. This method has been used to breed for superior tall fescue grass (*Fescue arundinacea*) from Italian ryegrass (2n=2x=14) and tall *fescue* (2n=6x=42) by using meadow grass (*Fescue pratensis*) as a bridge species (Acquaah, 2007). The same principle has been applied in fixing heterozygosity in hybrids by doubling the chromosomes in the superior progeny (Comai, 2005).



(Source: Meru, 2012).

Figure 4: The development of superior tall fescue grass through bridge crossing and induced tetraploidy.

Ornamental pant and forage breeding:

Artificial polyploidy more found in vegetative part, fruits and flower rather than cereal crops. Although chromosome doubling may result in significantly larger seeds and increased seed-protein content in cereal crops, this advantage is offset by low seed set (Dhawan and Lavania, 1996). Ornamental crops such as rose, chrysanthemum and marigolds have been bred through chromosome doubling to improve the quality and size of their blossoms (Emsweller and Ruttle, 1941).

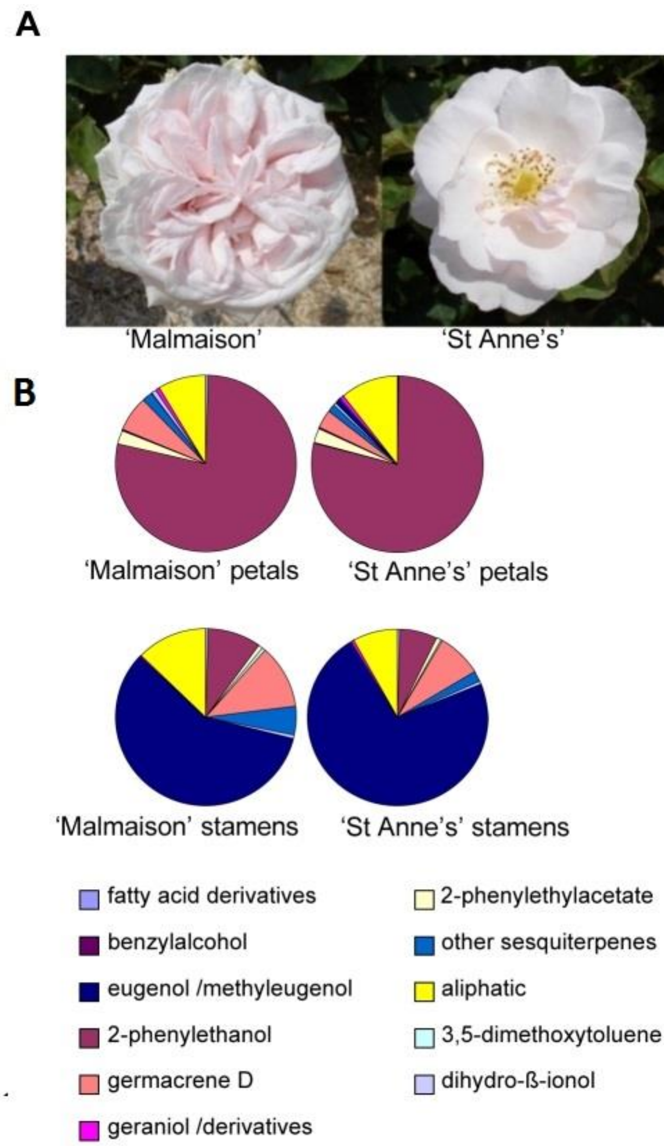


Figure 5: 'Malmaison' and 'St Anne's' rose varieties display phenotypes, and floral architecture. (A) Contrasting floral morphologies of 'Malmaison' (Tetraploid left) and its genetically related variety 'St Anne's' (Diploid flower, right). (B) Analysis on solid/liquid extracts of petals and stamens of 'St Anne's' and 'Malmaison'.(Annick el at., 2010).

Polypliody increase yield:

It increases the yield of potato in the variety Hagrai and Lalpakri at primary data of harvest at 70 DAPs, while late at 80 DAPs variety Shilbilati and Lalpakri yielded more. and they treated with colchicines. (Alam et al., 2011). Effect of polyploidy on number of tuber at several DAP were also studied like the effect of colchicine on the fresh weight of plant. The variety Hagrai and Lalpakri at all the intervals produced higher number of tubers, which explained that increased fresh weight of plant produced more number of tubers due to highest assimilation and distribution of photosynthesis but the results was statistically insignificant that is present in Graph. Other varieties have no correlation between fresh weight of plant and number of tuber per plant. (Alam et al., 2011).

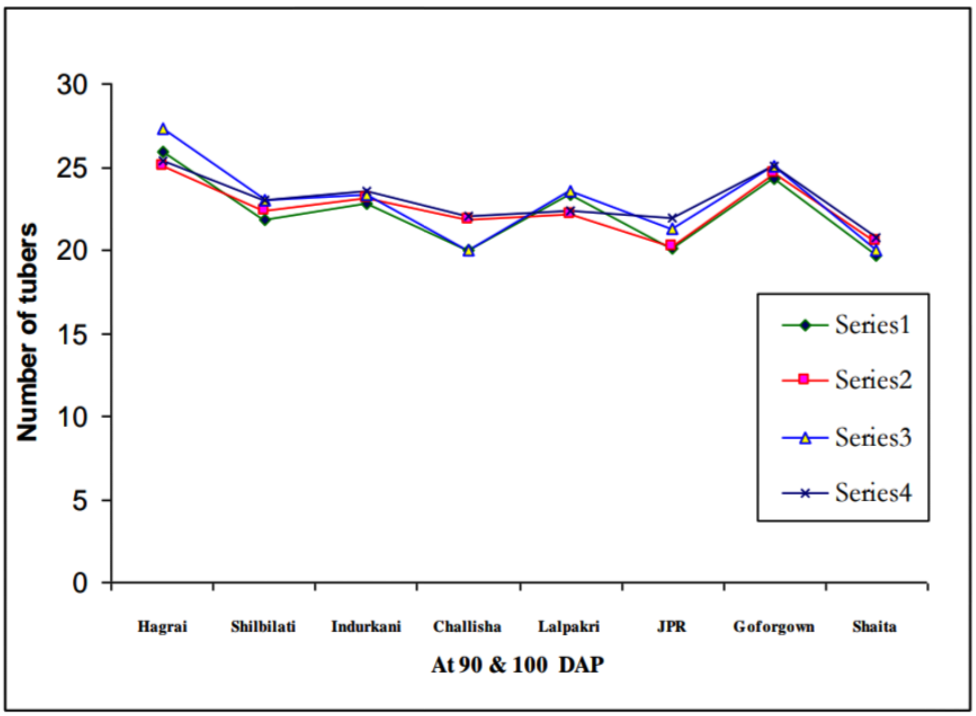


Figure 6: Effect of polyploids on tuber formation at different days of local potato cultivars. (Alam et al., 2011).

Chapter 4

Conclusions:

Evaluations of plant are one of the outputs of polyploids. The success rate of polyploidy depends on parental DNA sequencing, Gene silencing, maternal and paternal effect, larger ecological adaptation, higher heterozygosity. Higher percent of polyploidy plant present in nature and much popular and highly productive plant are polyploidy due to domestication, natural selection, and artificial section of plyiploidies.

Polypliodplants have broader genomic and genetic diversity. Polyploidy plant can use to produce early variety, seedless fruits, sterile line, productive crops, resistance and medicinal plants. Industrial crops also produce by polyploidy as for example: cotton, sugarcane, sugar beet. So polyploidy not only battle with hunger it also dispel proverty.

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