Chapter

The Unique Existence of Chromosomal Abnormality in Polyploidy Plants

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Abstract

It is commonly acknowledged that chromosomal abnormality is the popular natural phenomenon especially with polyploidy plants. The unique existence in plants has actually become one of major forces for speciation and evolution. This means that plants existing chromosomal abnormality developing through sexual and asexual pathways shed light on increasing biomass, adapting ecology so these benefits are more important and worth exploring. With regard to the former, chromosomal abnormality plants lead to not only gigantic effect but also increasing phytochemical compounds. As far as ecological perspectives are concerned, this abnormality enhances biotic and abiotic tolerance to adapt to climate change. These things also answer a question why plants can commonly exist with many kinds of chromosomal abnormalities. Based on aforementioned benefits, this review provides human beings with several chances when they need in developing the food security strategies.

Keywords: chromosomal abnormality, polyploidy, evolution, climate change, reproductive

1. Introduction

To start with, message being conveyed an in-depth analytical discourse on the popular evolutionary theory, named natural selection theory developed by Darwin. It was natural selection that maintains the polymorphism existing gross chromosomal alternation in plant as a way to reciprocally translocate along with change in segregation of pairs of chromosomes to ensure heterozygosity maintained and limitation of the expression of lethal genes. The theory is categorically not as such as discussion has been intensively dealt with countless studies. Since time immemorial, human beings has been investigating for a means to maintain their life especially with eventual goal of achieving aim of food security. Yet the demand for it remains elusive for thousand years. Everyday living organisms keep ingesting all kinds of food, taking energy and nutrient to nourish, maintain and develop their body. Yet after several centuries or maximum of more than ten thousand years, humanity continue studying and finding new sustainable food resource for securing demand of food security to those living on this planet. The answer might lie in genetic mechanism regulating reproductive process, a jargon denoting a preprogramed pathway to create offspring. Each organism has a different reproductive way dictating next generation by either sexual combining of male and female gametes or asexual. Without no doubt, asexual reproductive generating a new plant from using part of the parent plants. Some artificial asexual reproduction has used some popular methods such a grafting, layering and micropropagation. A genetically identical to the progenitor plant is outstanding features of new plant as well as thriving development in stable environments of asexually reproducing plant also have a hugely positive impact on creatures. Yet sexual and asexual reproductive still play much more critical role in deciding how adaptive plant species can exist on this planet. The interesting facts about the plant Kingdom when studied the karyotypes of distinct plant species is chromosomal abnormality in productive processes. Those reproductive have been happening chromosome abnormality deriving from mistaking meiosis and mitosis [1]. For instance, observing meiotic processes revealed the evidence that trio of *SMG7, SDS*, and *MS5* interrelated with both other chromatin organizing factors and proteins functioning DNA repair-related, involving in *MSH6* and *DAYSLEEPER*. The convergent tasks detected (other meiotic pathway, chromosome arrangement or remodeling, ABA cues and ion transport) offer initially insights into the noticeable challenges related to polyploidization. Another example, investigating the meiosis of autotetraploid potato *S. tuberosum* revealed variety of challenges in correct segregation and recombination of multiple homologous chromosomes that constraints on meiotic chromosomal configuration [2].

With advances in genetic engineering and continual elucidation of genes governing the reproductive pathway, humanity is on the verge of making our dream a reality by controlling the expression and regulation of those genes [1, 3]. To be more precise, key genes related to flowering such as *CO, CRY2, FT, FPF1, FD, GA1, ELA1…* have been studied [3]. Scientists and breeders are implemented biotechnology as a means to study as it bases on many well-established fundamental grounds. It may be attempted to speculate that everywhere around the world researching on reproductive process is being conducted in laboratories and field trials sponsored by not only private enterprises but also governmental agencies. Human being is the most intelligent species of all. Since time gradually moves on. It is believed that technology will progressively develop as it has been happening in various aspects of our modern society for such researching on reproductive to be implemented. What would happen to the future of humanity when not securing food security? Besides those that are over-population development, pollution is not controlled in the condition's climate variability. The tendency of sustainable agricultural development is required to increase crop diversity, high stability of yield and resilience of environment based on accelerating development of several crops containing desired traits which are capacity of adaptation to and mitigation of consequence from climate change [4, 5].

Concerning to the biodiversity, speciation and evolution, thousands of plant species popularly exist in this planet and adapt in various topographies and climates. This means that plant species not only increase plenty of genetic but enhance the ability of adaptation to boost genome evolution in harsh environments [1, 6]. The best example of which are those which involve autopolyploid, allopolyploid and aneuploidy. A case in point is that potato contributes over 4,000 native varieties including more than 180 wild potato relatives detailed [7]. To be more specific, potato, one of the most multifaceted genetic modes with the variety of ploidy levels such as 76% were recognized diploids, 3% triploids, 12% tetraploids, 2% pentaploids, and 7% hexaploids, among which the highest yield is tetraploid due to further level of genetic heterogeneity [8–10]. Based on the practically empirical proofs, it is categorized two clusters of cultivated potato, one called the Andigenum group located in high Andes of northern and central South America consists of wide range of ploidy level, and the others exist in the lowlands southern Chile named

Species	n	2n	Source
S. edule	11, 12, 13, 14	22, 24, 26, 28	[13–17]
Curcuma parviflora Wall.	14, 14, 16	28, 30, 32	[18]
C. zedoaria Rosc.	21	63, 64	[19–23]
C. longa L.	21	62, 63, 64	[19–22, 24]
Paspalum aff.arundinellum Mez	10	50, 51	[25]
J. vulgaris	20	30, 31	[26]
B. rapa L. ssp. *pekinensis*	10	20, 24	[27]

Table 1.
Summary of plant species having chromosome abnormality.

the Chilotanum group with tetraploid only [11]. Studying chromosomal arrangement and the plant karyotypes in the individual, the species, genera exist abnormal number of chromosomes. A typical example is that Chayote (*S. edule* (Jacq.) Sw.) is variable chromosome numbers n = 12, 13, 14 resulted by cytological analysis [12] is mentioned in **Table 1**. In the score of the review only focuses on chromosomal abnormality in whole genome doubling such as autopolyploid, allopolyploid and aneuploidy plants and then discuss the effects and importance of its benefits to evolution and ecological adaptation at individual and population level. Some advantageous and disadvantageous aspects of polyploid animals in comparison with polyploid plants are mentioned in this review.

2. Chromosomal abnormality affects to gigantic effects and alternative natural secondary metabolites

That chromosomal abnormality outranks other plants in terms of parts of plant size and biochemical compounds characteristically states that gene regulating plays an important role. As far as up-regulation of genes is concerned, cell division and cell expansion related to genes consisting of ARGOS, *ANT (AITEGUMENTA), CYCD3;1*, *Growth Regulating Factor 1* (*AtGRF1*) and *EXPASIN 10* (*AtEXPA10*) [27–29], *EXPB3* and *TCP* [30]. Alongside above genes, lipid transport genes such as *wbc11–2* and *cer5–2* was as a way to make large body size of autotetraploid plants [31–33]. Moreover, proteins involving in cell proliferation, glutathione metabolic pathways and cellulose, chlorophyll, pectin, lignin synthesis engage in this gigantic effect [34, 35]. Cytosine methylation in whole genome also contribute to change organ size in polyploidy plants that can be effectively improve potential and complex agronomic traits in many crops [36, 37]. Cell size in polyploidy plant plays an important role in changing phenotype is apparent [38]. Enlarged organ size in chromosomal abnormality usually clues to increased yield and production of cultivated plants can be seen [39]. Studying autotetraploid *V. cracca* L. revealed that seed size and germination of tetraploid are more dominant than diploid one [40]. Although aforementioned advantages, chromosomal abnormality leading large size of plants, autotetraploid Birch plant (*B. platyphylla)* and apple plants (*M. domestica*) have happened a dwarf phenotype caused by reducing growth regulation signals [41, 42].

Similarly, chromosomal abnormality also alters secondary metabolites especially with phytochemical compound in a number of plant species [43], the typical case in point of which are those which involve natural components in plants observing in tetrasomic tetraploid opium poppy (*P. somniferum* L.) enhanced morphine content 25–50% by changing the expression of several genes regulating alkaloid biosynthesis pathway [44]. Another example is that cytosine methylation happens in genome-wide makes autotetraploid *Cymbopogon* enhancing phytochemical [36]. Autotetraploids *A. thaliana* Col-0 alters metabolites and genes regulating TCA (tricarboxylic acid cycle) and GABA (γ –amino butyric acid) in compared with its diploid is a good example [45]. Lycopene significantly increased autotriploid watermelons because of a regulation of phytohormone on metabolic pathways and upregulation of genes controlled biosynthetic lycopene [46]. Interestingly, polyploidisation is a promising approach for gaining a significant value addition especially with medicinal plants by producing secondary metabolite [47]. Upregulating genes contributing to biosynthesis pathway of PTOX in autotetraploid *Linum album* enhanced content of podophyllotoxin (PTOX) plays a good example here [48]. Aiming to vitamin A enriching in triploid banana has been initiated by inducing tetraploid one from serval types of diploid and then conducting hybrid between them [49]. Much contents of total flavonoid and gastrodin significantly produced in Autotetraploid *Anoectochilus formosanus* Hayata [50]. Tetraploid type of *Physalis angutala* Linn. from Rajasthan alters palmitic acid, linoleic acid and linolenic acid, for instance [51]. In the last decade, many plant studies have given objects based on the outstanding benefits of chromosomal abnormality. Those breeders have been observing chromosomal abnormality as a way to gain elite plant cultivars due to the fact that the increment in plant organs size derived from some of the most significant consequence of chromosomal abnormality [52, 53].

The chromosomal abnormality mentioned above in light of level of ploidy variation that is useful for breeding both within and among plant species belonging to autopolyploid and allopolyploid [25]. Other view is that chromosomal abnormality contributes better detrimental environment condition in terms of suitability for certain species and the benefits of physiological response. As far as the first idea is concerned, a chromosomal abnormality is not appropriate to sexual reproductive in aneuploidy due to chromosomal abnormality in gametes. Another utilizing of polyploidy is that grafted crops can use artificial polyploidy as parts of rootstock and scion having potential agronomic traits in the context of climate variability [54].

3. Chromosomal abnormality enhances abiotic and biotic tolerance

That chromosomal abnormality in plants enhanced abiotic stress tolerance and biotic resistance was clearly witnessed in coping with harmfully environmental conditions. Many studies proved that several pathways to response to salinity stress, and chromosomal abnormality flora used several processes to adapt to high salt concentration condition involving in cumulating Na + extrusion in root, rising Na + transport to leaf, regulating osmotic, enhancing the genes expression related to antioxidant, mitigating ROS, photosynthesize cues, changing SNP marker related to salt stress, up-regulating aquaporin genes, phytohormone transduction cues, protein processing, regulating transcription factors, up-regulating ATP synthase to enhance ion transport changing proton; and using miRNAs [55–64]. To adapt with water insufficiency, chromosomal abnormal plants through miRNAs mechanisms and target genes controlling transcriptional regulation, hormone metabolism and plant defense, a rise in ABA content cope with drought stress in several polyploidy plants were observed in several plant species such as *Paulownia fortunei*, *Paulownia australis, P. tomentosa, Lycium ruthenicum* [65–70]. Antioxidant defense systems were activated to support heat tolerance sufficiently in *Dioscorea* and *Arabidopsis* [71, 72]. Chromosomal abnormality plants might be tolerance of cold stress via growing antioxidant and epigenetic [73, 74]. Changing root anatomical characters support autotetraploid to dapt high concentration of boron in soil and enhancing Cu transport gene, activation of anti-oxidation defense, positive regulation of expression ABA-responsive genes is a way to survive in environment containing high concentration of copper [75, 76]. Enhancing expression of target genes regulated proline biosynthesis to support autopolyploid birch plant (*B. platyphylla)* in capacity of $NaHCO_3$ stress tolerance is investigated [77]. Besides, biotic resistance was demonstrated in autotetraploid *Malus* × *domestica* and *S. chacoense.* To be more specific, significantly increasing *Rvi6* resistance gene-locus was observed as a way to assist autopolyploid enhanced to resistance of *Venturia* [78]. Similarly, autotetraploid potato have been capacity of common scab resistance by crossing 2n gametes from diploid *S. chacoense* [79].

4. Chromosomal abnormality adapts to ecological invasion and climate variability

Chromosomal abnormality is one of the major adaptation ecologies and climate changes such by fixing on growth, potential morphological traits as well as ecology invasion, pollinators, the factors supporting pollinating in nature [80]. After chromosomal abnormality appearance in some rare cases, the increasing cell size leads to alteration of physiological manners with their environmental condition as well as augmenting multiple novel alleles and changing regulatory pathways can create new potentially beneficial phenotypic variation. For instance, studying transcriptome in aneuploidy maize revealed qualitative changes in gene expression in comparison to wild-type plants [81]. The number of expanding ecological space to polyploidy plants are recorded in various studies [82]. Polyploidy *A. thaliana* contained adaptive potential plant caused by the increase resources of TE insertions in higher ploid- level and enhance gene expression related to reproductive [83, 84]. There are several studies to prove that chromosomal abnormality adapts to ecological invasion and climate variety. A good illustration is that biological invasions in the *Brassicaceae* proved to be evolutionary processes to adapt and widespread in central Europe [85]. Another example is that the native range of distribution of *L. salicaria* distributes several cytotypes as 2x, 3x, 4x, 6x variation rigorous in the Middle Eastern regions, while only tetraploids one located in North America. Besides, the invasive spread of North American populations lacks differences in ploidy level [86]. Studying potato germplasm demonstrated markers related to unique geographic identity associated to traits of abiotic stresses tolerance [87]. One of priorities in genotype development is to gain through combination of potential traits which benefits in stress tolerance and nutritional aspects as a way to reduce the effects of climate change as a challenge of the 21st century [88, 89]. The view is that polyploidization contributes to better adapting environment in terms of suitability for growth and other benefits of cell size. Breeders and human beings can benefit immensely from more ecological adapting after chromosomal abnormality since it improves potential traits being exploited for breeding experiments as a whole.

For the most part, it is probably that polyploidy is less popular in animal kingdom than in plant kingom. To be more specific, it is observed that in amphibia (Africa clawed frog-*Xenopus spp*) and different species of fishes exist polyploid [90]. This is due to the fact that polyploid animal species mentioned above can overcome meiosis and exist a parthenogenesis that an egg cell can develop into an individual without fertilizing. In addition to this, polyploidy animal kingdoms are similar plant kingdoms and they have had their beneficial and detrimental effects and reason for meiotic imbalance. Concerning the benefits of polyploidy animal, the most advantage is that polyploid offspring are shielded from the deleterious effects of recessive mutation. As far as harmful effects are concerned, chromosomal abnormality may lead to congenital diseases and pregnancy loss in animal, especially in human beings. With regard to meiotic imbalance, the reason related to this is that spindle irregularities might occur in polyploid resulting in leading the chaotic segregation of chromatids and aneuploid cells was produced. Abnormal number of chromosomes in aneuploid cells might obtain three or more sets of chromosomes produced in meioses were different from diploid cells. This can explain that polyploidy animal could form multiple arrangements of homologous chromosomes in metaphase I resulting in abnormally or randomly segregating to produce aneuploid gametes or to form imbalanced gametes [90, 91].

5. Conclusion

In brief, it is unquestionable that chromosomal abnormality deriving from whether sexual or asexual is essential for successfully existing of organisms on this planet. With climate variability becoming more alarming than ever, chromosomal abnormality has been happening like a commonly natural events as a way to redress the issue assuring food security to those existing on our world based on crop improvement by expanding breeding opportunities to develop seedless triploid plants, increase ornamental features, adversely environmental tolerance, enhance biomass etc. Chromosomal abnormality is also vital to human beings mainly because it can open door of opportunities for secure the food security to those living on this planet. A case in point is that breeders who are experienced in hybrid development are more likely to find desired agronomic traits rather than on a minimum requirement. More importantly, a number of breeders today require at least a desired trait of novel crops before considering a utilization for production. This means that chromosomal abnormality has credential to provide insight into an ample opportunity for securing food resource to humanity. It is without a doubt that chromosomal abnormality is essential for success in adapting ecology and plays a vital role in evolution due to generating variation in a natural population.

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