Dean&Francis
ISSN 2959-409X

The Relationship between Genome Size and Plant Adaptability to the Environment

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Abstract:

Genome size (GS) can predict the functional shape of plants and is closely related to the adaptability of plants to the environment. GS can also predict the strategy of plant domestication and invasion, but there are few studies on how the size of genome affects the environmental adaptability of plants. This paper analyzes the research on the size of plant genome and temperature, humidity and nutrients. It is found that plants with small GS have stronger adaptability to high temperature and drought environment and nutrient deficient environment, while plants with large GS are suitable to grow in high humidity and nutrient sufficient environment. This paper also analyzed the relationship between plant GS and plant invasion and domestication. Finally, this paper analyzed the relationship between polyploid and GS and its application in breeding, and obtained that the GS can be changed by changing plant ploidy, so as to improve the adaptability of plants to the environment. This provides a reference for future research on the adaptability of genomes and plants to the environment, as well as in breeding. Additionally, the unclear relationship between GS and more environmental factors such as heavy metals and high-altitude pollution remains unresolved. Future research can focus on studying the relationship between GS and more environmental factors, as well as the application direction of gene editing technology in changing GS.

Keywords:—genome size, adaptability to the environment, environmental factor

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I. Introduction

Genes affect plant adaptability to the environment through various mechanisms, among which genome size (GS) is closely related to plant adaptability to the environment. GS is also known as C-Value, refers to the total amount of DNA contained in a haploid genome of a species, and genome size is a measurable quantity, usually expressed in units of picograms (pg) or the number of nucleotide base pairs, expressed in millions, written as Mb.

GS is the material carrier of biological genetic in-formation, and its variation range is very wide in plants, from about 100 Mb to over 100 Gb. Through long-term research by scientists, it has been found that there is a lack of direct correlation between the total amount of genomic DNA, i.e. GS, and biological complexity, but it is closely related to the environmental adaptability of species, which is the famous "C-value paradox". The essence of this paradox lies in the fact that plants, in the process of long-term adaptation to the environment, adjust their adaptability to the environment by changing the size of their genomes.

Generally speaking, GS is positively correlated with cell size, positively correlated with stomatal size, and negatively correlated with density. Studies have also shown that GS affects the utilization and conversion rates of CO_2 and water in plants, thereby affecting their photosynthetic metabolism rate [1].

Furthermore, it affects the adaptability of plants to temperature, humidity, and other environmental factors such as nutrients in the environment, but the mechanisms involved still need to be further studied. In stressful environments, such as high temperatures and dry environments, plants usually behave as smaller genomes, while the adaptability of large genome plants in stressful environments is poorer than that of small gene plants. Generally speaking, small gene plants are more adaptable to stress environment, while large gene plants are more adaptable to suitable environment. GS is also closely related to plant invasion and domestication. GS is an inherent limitation of plant invasion and domestication through ecological strategies and native range.

This paper will study the relationship between GS and plant environmental adaptability, and the relationship between GS and plant invasion and domestication. By studying the relationship between GS and plant environmental adaptability and the relationship between plant ploidy and GS, we can change GS by changing plant ploidy to optimize related traits in breeding, so as to improve the environmental adaptability of plants, so that plants can survive in some extreme environments, and improve ecological diversity.

II. GS affects plant adaptability to the environment

A. GS Affects the Adaptability of Plants to High-Temperature Environment

Plant GS adapts to high-temperature and low temperature environments by regulating stomatal size and density, and small genome plants form high stomatal density and small stomata, while large genome plants have large stomata and poor adaptability to high temperatures and environment.

The stomatal size of plants with larger GS increased significantly due to the expansion of cell volume. Barry et al. Measured the GS of 39 Allium species, and found that the GS was 2C=22934~2C=92861 MBP, and its genome was larger, and the guard cell size was 28~100 μ m, and the guard cell size was larger. The larger the GS, the larger the size of stomatal guard cells, resulting in the expansion of single stomatal opening area.

Generally, plants with larger GS have smaller stomatal density. It is concluded that GS is positively correlated with stomatal size and negatively correlated with stomatal density [2]. Zhanglirong et al. Studied the effects of warming on stomatal morphological parameters of Kobresia humilis, Thalictrum alpina, Elymus nutans and Gentiana straminea. The results showed that the stomatal length of the four species decreased consistently in high temperature environment, and the stomatal size was reduced to adapt to high temperature environment [3].

Bure š's research on 16017 angiosperms shows that plants with small GS are mainly distributed in the regions with the lowest and highest average temperatures, while plants with large GS are distributed in a smaller range than plants with small GS [4]. In higher temperature environment, plants need to close stomata to avoid water loss, and smaller stomata is more conducive to stomatal closure, which can better control water balance. For example, desert plants such as Cactaceae have high stomatal density and small stomata because of their small GS. This feature is used to reduce water loss, and rapid stomatal closure is used to deal with high temperature stress (Figure 1).

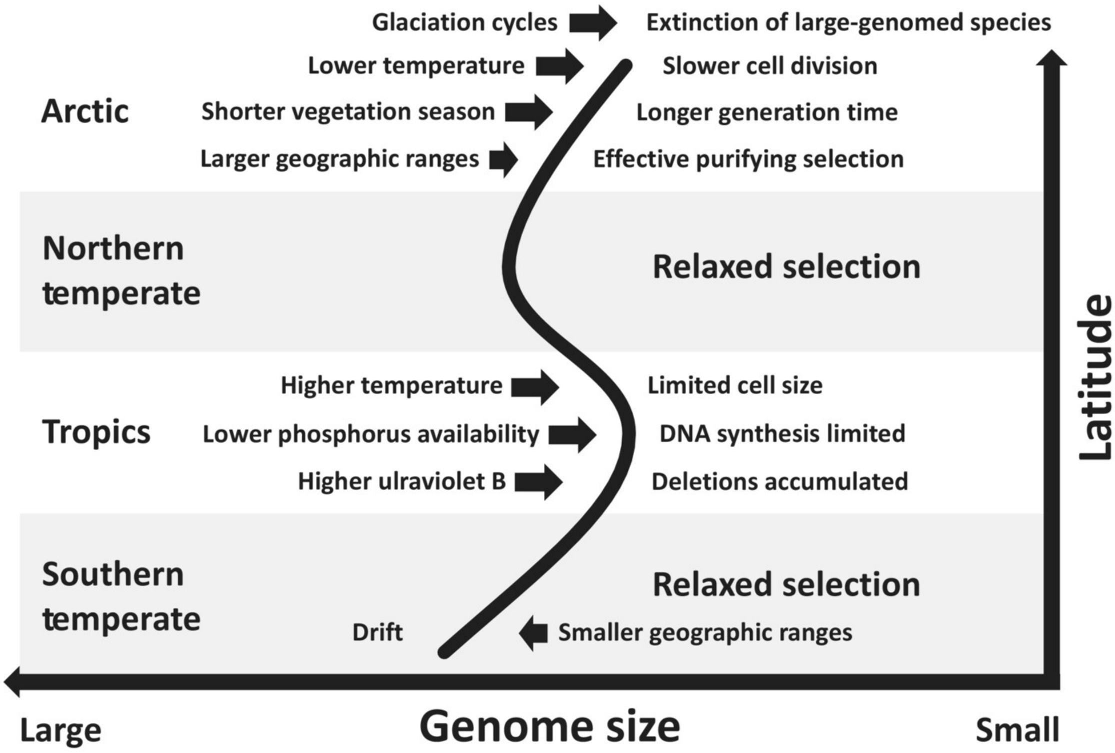

Figure 1. Latitudinal Variation in Genome Size: Key Drivers and Responses Shaping an S-Shaped Global Pattern [4].

Therefore, in high temperature environment, small GS plants are more adaptable than large GS plants in high temperature environment. And in high temperature environment, plants can improve gas exchange efficiency by increasing stomatal density to meet the demand of photosynthesis for carbon dioxide. Jumrani et al. Studied soybean and found that with the increase of temperature, the stomatal density of soybean leaves increased significantly on the front and back of leaves [5].

Other studies have shown that in high temperature stress environment, some desert plants shrink their GS through transposon silencing, gene loss and other mechanisms, which not only improve the DNA stability, but also reduce the stomatal size and increase the density. Transposons are DNA fragments that can move in the genome, and their activities may lead to genomic instability. Desert plants inhibit the movement of transposons through transposon silencing mechanism, so as to improve the stability of genome. For example, in Populus alba, the genes inserted by long terminal repeat retrotransposons (LTR RTs) showed higher protein evolution rate and gene expression [6].

Reducing the GS to reduce the stomatal size can reduce water loss, and increasing the stomatal density can ensure the efficiency of gas exchange to a certain extent, so that desert plants can survive better in the high temperature environment. Plant GS adapts to high temperature environment by regulating stomatal size and density to form high-density and small pores.

B. GS Affects Plant Adaptability to Humidity

GS profoundly affects the adaptability of plants to humidity by regulating stomatal size, density and photosynthesis rate, making large GS plants more suitable for survival in high humidity environment, and small GS plants more suitable for survival in dry environment.

Roddy and other studies have shown that GS affects the photosynthetic metabolic rate of plants by affecting cell size and density, and plants with smaller GS usually show faster photosynthetic rate [7]. The cells of small GS plants are small, so the ratio of cell surface area to cell volume is large, resulting in the efficiency of transporting CO_2 and water to metabolic sites and outputting metabolites [8].

However, large GS plants have smaller cell surface area to cell volume ratio, which reduces the efficiency of CO_2 and water transportation to metabolic sites and the output of metabolites. Therefore, plants with large GS exhibit lower photosynthetic rates and growth rates in an environment of water scarcity. In a dry environment, small GS plants can achieve rapid growth by maximizing water use efficiency and CO_2 absorption; Large GS plants with large cells tend to improve water use efficiency by reducing growth rate. Therefore, species growing in humid environments have larger GS, while plants growing in dry environments have smaller GS.

The size and density of plant stomata also affect the adaptability of plants to humidity. Larger stomata and lower stomatal density are beneficial to improve the absorption capacity of CO_2 and water use efficiency of plants in high humidity environment.

Pavel et al. studied 16 pairs of species with buried leaves and found that all of them had larger stomata, and 13 pairs of species with buried leaves had larger genomes than those with upright leaves. In the species with small guard cells (<1 PL), stomatal density and theoretical maximum conductance were lower, but there was no systematic difference in the species with large guard cells (>1 PL). Giant stomata were only observed in iris bicolor (stomata length 89-137 μ m) of Voldemort leaf, although its genome was relatively small (2C=9gbp), other genomes and stomata were larger. It indicates that species growing in humid environment have larger stomata and genome [9]. Small GS plants usually have higher stomatal density and smaller stomatal density, which can adapt to humidity fluctuation and dry environment by rapidly adjusting stomatal opening and closing. Therefore, large GS plants with larger stomata and smaller stomatal density have stronger adaptability in high humidity environment than small genome plants.

C. Adaptability of GS to Other Environmental Factors such ss Nutrients

GS is an important trait for predicting plant response to nitrogen. Nitrogen fertilizer promotes the dominance of large genome species. Nitrogen addition significantly changed the composition and structure of grassland plant community, compared with small genome species, the coverage of plants with larger genome increased more significantly after nitrogen application, resulting in a significant increase in the “coverage weighted GS” (i.e., the weighted average of GS of dominant species) of the community as a whole.

GS was negatively correlated with leaf cell density. Large GS species had larger cell volume and lower cell density. Larger cells may accumulate biomass more efficiently when nutrients are sufficient by reducing the number of divisions and energy consumption. Nitrogen fertilizer may lead to community homogenization by preferring large GS species, small GS species are gradually eliminated in competition, especially in dry and low seasonal environment, which may accelerate the decline of biodiversity.

Under long-term eutrophication, GS can be used as an important trait to predict species competitiveness and community structure changes. Morton et al. Confirmed for the first time that GS is an important trait for predicting plant response to nitrogen through cross regional grassland experiments. Nitrogen fertilizer promotes the dominance of large genome species, especially in the dry, low-temperature seasonal environment, C3 grass is the large gene grass, while phosphorus fertilizer has a weak effect and is limited by nitrogen [10]. In regions with intensified nitrogen deposition or frequent drought, macrogenomic species (such as C3 herbs) may become dominant species, changing the carbon sink capacity, water cycle and species coexistence mode of grassland ecosystem. The integrated model combining GS and functional traits (such as photosynthetic pathway and water use efficiency) can improve the prediction ability of ecosystem response to global change.

III. The relationship between plant GS and plant invasion and Domestication

Biological invasion is an important challenge threatening global ecological security. The naturalization (forming self-sustaining populations) and invasion (causing ecological hazards) of alien plants have a significant impact on biodiversity and human well-being. GS, as the core genetic characteristics of species, affects the invasion process by affecting plant functional traits and ecological strategies.

Guo K, et al. Selected 1612 vascular plants as the analysis object, covering 1545 angiosperms, 32 gymnosperms and 35 ferns, and built the following database for GS: the data of aneuploidy (1C, total nuclear DNA) and haploid (1Cx, haploid genome DNA) were obtained from the plant DNA C value database. The former reflected the total nuclear DNA, while the latter excluded ploidy interference to analyze the inherent characteristics of the genome [11].

The results showed that there was no significant correlation between the size of euploid genome and the incidence of naturalization, but there was a negative correlation between the size of euploid genome and the range of naturalization - the number of naturalized regions of large GS plants was small; The haploid GS has a significant negative impact on the incidence, range and invasion range of naturalization, which supports the “big genome constraint” hypothesis: a larger genome leads to an increase in cell size, a decrease in division rate, a restriction on plant resource utilization efficiency and diversity of reproductive strategies, and a reduction in habitat adaptation. GS indirectly affects invasion by shaping CSR strategy and native range.

Large genome plants tend to have high C score (competitive strategy, relying on stable resources and environment), but low S score (stress tolerance) and R score (weed reproduction), and narrow native range, which ultimately reduce the naturalization and invasion potential. GS indirectly affects invasion through CSR strategy. Large GS plants tend to adopt competitive strategy due to long growth cycle and low reproductive investment, but their slow growth characteristics may be at a disadvantage in the resource competition at the early stage of invasion, while small GS plants have more advantages in diverse environments due to their strategic flexibility.

IV. The relationship between polyploid and GS and its application in breeding

Whole genome duplication (WGD) is one of the important mechanisms of polyploidy formation in angiosperms. Polyploidy is an important driving force for the evolution of angiosperms. Almost all angiosperms' ancestors have experienced WGD at least once, but the GS of most species is significantly smaller than the expected value of polyploid ancestors, which shows that there is a common phenomenon of genome shrinkage. The ancestral genome of angiosperms is about 1.70 GB/1c in size. Despite several WGD events, such as three WGD at the base of monocotyledons, the GS of existing species is generally small, with a model value of 0.58 GB/1C.

For example, the actual GS of Arabidopsis after multiple WGD is 0.16 GB/1C, but its theoretical value is 82 GB/1C, showing strong DNA loss. In contrast, gymnosperms have a large GS and a normal distribution due to the low frequency of WGD, with an average of 17.95 GB/1C. This indicates that the GS of angiosperms generally shrinks after polyploidization, while the GS of gymnosperms is relatively stable.

Zhao, et al. Combined with more than 10000 plant genome data, studied and summarized that the reduced genome after polyploidy is closely related to the DNA double-strand break (DSB) repair pathway [12]. Homologous recombination (HR) repairs DSB by homologous sequences, which can lead to genome stabilization, expansion, or reduction. Non homologous end joining (NHEJ) directly connects the broken ends, often accompanied by small deletion (<30 BP), which is the main driving mechanism of genome shrinkage. For example, DSB repair in Arabidopsis tends to be widely deleted, while barley tends to be inserted, resulting in a 35-fold difference in GS between Arabidopsis and barley [12]. The study also showed that the preference for repair pathway, the degree of excision and the activity of repair protein jointly determine the gain and loss of DNA, and long-term accumulation leads to GS differentiation among species [12].

By changing plant ploidy to change the size of plant genome, and then change the adaptability of plants to the environment. Large GS species need to allocate more resources for DNA synthesis, repair and transcription in a nutrient limited environment.

Experiments show that artificial tetraploid has competitive advantage only when nitrogen and phosphorus are sufficient, while in the oligotrophic environment, small GS species are selected for higher resource utilization efficiency [13]. GS is positively correlated with cell size. Large cells lead to sparse stomata and large pore size, and reduce CO ɑ absorption efficiency and water use efficiency. And the small stomata close faster, which can reduce transpiration water loss [7]. In arid or low CO ɑ environments, selection pressure tends to be small GS to optimize stomatal density and response speed and improve photosynthetic efficiency.

V. Conclusion

This paper analyzed the relationship between GS and plant environmental adaptability, plant invasion and domestication, and the relationship between polyploid and GS and its application in breeding. The size of plant genome is closely related to the size of plant cells, the size and density of plant stomata and photosynthetic rate, which profoundly affects the adaptability of plants to temperature, humidity and other environmental factors such as nutrients in the environment. The flexible strategy of small GS plants makes them more advantageous in diverse environments, but large GS plants are limited by GS, and only in resource rich environments can they be competitive. In breeding, plant GS can be changed by changing plant ploidy, so as to improve environmental adaptability and make it survive in different environments. However, studies based on other environmental factors such as altitude and heavy metal pollution are relatively few, and are not involved in this paper. Second, the current research on gene editing technology in changing GS needs to be further studied. If gene editing technology can be used to change the GS and clarify the relationship between GS and more environmental size in subsequent scientific research, it can provide a way and theoretical basis for introducing species to improve ecological diversity and ecological restoration.

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