Tree Genetics and Molecular Breeding 2024, Vol.14, No.1, 1-7
http://genbreedpublisher.com/index.php/tgmb

Research Article Open Access

Genetic Diversity and Conservation Strategies of Apple Germplasm Resources

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Tree Genetics and Molecular Breeding, 2024, Vol.14, No.1 doi: 10.5376/tgmb.2024.14.0001
Received: 18 Dec., 2023
Accepted: 22 Jan., 2024
Published: 12 Feb., 2024

Preferred citation for this article:
Li J.X., 2024, Genetic diversity and conservation strategies of apple germplasm resources, Tree Genetics and Molecular Breeding, 14(1): 1-7 (doi: 10.5376/tgmb.2024.14.0001)

Abstract Apples, as one of the globally significant fruit trees, possess a rich array of germplasm resources and extensive genetic diversity. This review aims to delve into the genetic diversity of apple germplasm resources and the associated conservation strategies. It begins by outlining the origin and evolutionary history of apples, then focuses on elucidating the significance of genetic diversity in the apple industry, as well as evaluating the effectiveness and challenges of current conservation strategies. Addressing the shortcomings of existing strategies, the review further explores improvement measures including diversity maintenance, genomics-based conservation methods, and ongoing monitoring and management. By providing a comprehensive discussion, this review seeks to offer a holistic understanding of conserving genetic diversity in apple germplasm resources, serving as a reference for future research and conservation efforts.

Keywords Apple; Germplasm resources; Genetic diversity; Conservation strategies; DNA sequence analysis

The apple (*Malus domestica*) is one of the most important fruit trees in the world, not only providing people with a delicious fruit, it is also an important raw material for many foods and drinks, such as juices, jams and fruit wines (Bhargava and Bansal, 2021), but also plays an important role in the agricultural economy. In today's agricultural field, apple is not only a popular fruit, but also an extremely important genetic resource bank, the genetic diversity contained in this fruit, and its key role in the agricultural industry, has attracted extensive attention and research.

As a kind of fruit widely cultivated all over the world, apple not only meets people's demand for fruit with its rich varieties and potential adaptability, but also is a treasure house of agricultural genetic resources. These resources contain a wide range of genetic characteristics, ranging from fruit color, form, quality, and plant adaptation to the environment. The diversity of apple germplasm resources is very important for breeding new varieties, crop improvement and maintaining ecosystem stability.

The genetic diversity of apple is an important basis for its adaptation to various growing environments, stress resistance and quality improvement. In-depth understanding and utilization of this diversity will help to improve the resistance to pests and diseases of apple cultivars, adapt to different climatic conditions, and improve yield and quality (Basannagari and Kala, 2013). Genetic diversity also makes it possible to breed new, more competitive varieties.

This study aims to explore the genetic diversity of apple germplasm resources, examine the importance of these resources to the development of the apple industry from different perspectives, and analyze the effectiveness and shortcomings of existing conservation strategies. At the same time, this study will also evaluate the existing conservation strategies and analyze their effectiveness and shortcomings, in order to provide useful references for improving and formulating more scientific conservation strategies in the future. Research on the genetic diversity of apple and its conservation strategies is crucial to the sustainability and improvement of agricultural production, and an in-depth understanding of the value of these resources and the limitations of existing conservation strategies will help researchers to better protect and utilize apple germplasm resources and promote the sustainable development of the apple industry.

1 Genetic Diversity of Apple Germplasm Resources

1.1 The origin and evolution of apple

The apple (*Malus domestica*), as an ancient and precious fruit, has gone through a long history of its origin and evolution, containing rich traces of cultural and human activities. The origin of apple can be traced back to Asia and Europe, where wild apple trees initially grew in the high mountains of Asia, forming the earliest apple gene pool (Gao et al., 2015) (Figure 1).

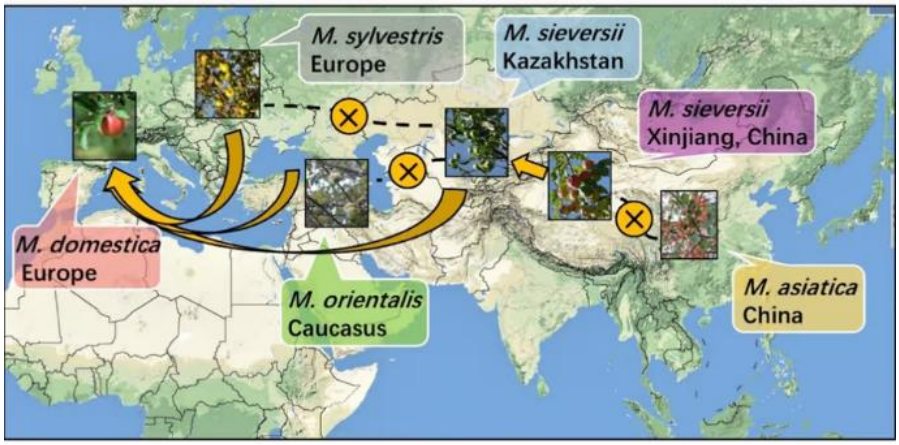

Figure 1 The distribution of apples around the world (Wang et al., 2018)

Note: *Malus sieversii* in Central Asia, *Malus sylvestris* in Europe, and *Malus orientalis* in Caucasus were originally proposed to be ancestors of cultivated apple (Wang et al., 2018)

These wild apple trees not only gradually evolved diversity in their natural environment, but also became an important part of human agricultural civilization. Early human communities began to recognize the edible value of wild apples, and gradually formed the earliest artificial varieties through selective breeding and cultivation practices. This process is not only the domestication and improvement of plants, but also the product of the interaction between man and nature.

With the expansion of cultural exchanges and trade, apples gradually spread to all parts of the world. The ancient trade and wars promoted the introduction of apples from Asia to Europe, and also gave birth to the traditions of apple cultivation in different regions. In this process, people through the continuous selection, breeding and reproduction to create a unique variety of apple.

The origin and evolution of the apple is not only the subject of botany and genetics, but also a story throughout the history of human civilization. Woven into the story is the wisdom of the mutual domestication of man and nature, as well as the diversity formed through cultural exchange. A thorough understanding of the origin of apple will help people better understand the role of this fruit in human civilization, and also provide scientific basis for subsequent discussions on apple genetic diversity and conservation strategies.

1.2 Methods for determining genetic diversity

The method of genetic diversity determination is very important for the conservation and utilization of apple germplasm resources. In exploring the genetic diversity of apple germplasm resources, scientists have adopted various methods. Among them, molecular marker technology is one of the most commonly used means to evaluate the genetic diversity of apple, by analyzing DNA or RNA sequences, such as random amplified polymorphic DNA (RAPD), simple repeat sequence (SSR), single nucleotide polymorphism (SNP), etc. It can reveal genetic differences and levels of diversity between different apple varieties (Ahmad et al., 2021).

Morphological characteristics are also one of the important methods to evaluate the genetic diversity of apple, and researchers reveal the differences and variations among different varieties through quantitative and qualitative analysis of fruit morphology, leaf characteristics, tree structure, etc. Assessment of biological characteristics is also key to determining genetic diversity. The observation and recording of growth habits, flowering period, fruiting characteristics, etc., can provide information about differences between varieties, and then judge their

genetic diversity.

1.3 Classification and characteristics of germplasm resources of apple

As an important fruit tree, apple has extensive and diverse germplasm resources, which show rich diversity in morphology, biological characteristics and genetic characteristics. The first is geographical classification, which refers to the classification of apple varieties according to their origin and distribution area. Apple varieties around the world can vary significantly in terms of growing environment, disease resistance and quality. For example, the Maras apple in Central Asia is considered to be the original wild species of apple, and apples from different countries and regions may also differ in fruit morphology and growth habits (Marconi et al., 2018).

The second is genetic classification, which is based on the genetic characteristics and genotypes of apple varieties. The genetic background of different apple varieties determines the characteristics of disease resistance, fruit size, taste and maturity. Older varieties often have higher genetic diversity, which is important in breeding and conservation efforts.

Another type of classification is based on fruit characteristics, such as size, color, shape and taste. This classification is often used to distinguish between different types of apples used for fresh food, for processing (making jams, juices, etc.), or for cooking purposes. Finally, there is the classification by use, which distinguishes apple varieties according to their different uses, including fresh food, processing or cooking purposes. Apple varieties used for different purposes may have significant differences in pulp texture, sugar content and taste.

2 Conservation Status of Germplasm Resources of Apple

2.1 Global apple resource bank and genetic resource conservation organization

A number of apple resource banks and genetic resource conservation organizations have been established around the world to collect, preserve and study apple genetic resources and provide support for the protection and utilization of apple germplasm resources. The most well-known of these are Apple repositories located around the world, such as the National Apple Collection in the United States, the European Apple Varieties Database in Europe, and the Apple Repository in Asia. These repositories collect and preserve apple germplasm from all over the world, including wild, traditional and modern cultivars. They not only preserve rich genetic diversity, but also provide an important material basis for breeding and research (Shaziya et al., 2018).

Apple Genetic Resources Conservation groups have also been established around the world, examples include the International Plant Genetic Resources Institute and the International Society for Horticultural Resources Science-Fruit Section. They promote the collection, evaluation and communication of apple genetic resources. Through collaboration and information sharing, these organizations contribute to the conservation, research and sustainable use of apple genetic resources worldwide.

2.2 Existing conservation measures and policies

Some countries and regions have special laws and regulations to protect crop genetic resources, including apples. These policies include building germplasm banks, protecting wild species, encouraging the preservation of traditional varieties, and encouraging the exchange and sharing of plant genetic resources (Shaziya et al., 2018). Some governments and ngos have also developed special apple conservation programs to ensure the long-term conservation and sustainable use of genetic resources. Existing conservation measures and policies provide important support for the conservation and management of apple genetic resources and are widely implemented around the world.

There are also a number of international cooperation mechanisms and agreements aimed at protecting plant genetic resources. For example, the International Plant Genetic Resources Treaty of the Food and Agriculture Organization of the United Nations (FAO) provides a framework and guidance for the conservation and sustainable use of plant genetic resources, facilitating resource sharing and exchange on a global scale. In addition to regulations and policies, scientific research institutions and agricultural organizations are also actively working on the conservation of apple genetic resources. These institutions are committed to the collection, preservation,

research and utilization of apple germplasm resources, and promote the protection and utilization of apple diversity.

2.3 Challenges and problems

At present, a series of challenges and problems facing Apple genetic resources will directly affect its long-term protection, utilization and sustainable development. One of the major challenges is the loss and reduction of genetic diversity. Commercial cultivation, which favors a small number of superior varieties, has led to the marginalization and loss of many traditional or wild apple varieties, exacerbating the decline in genetic diversity, which may lead to a decline in the overall genetic performance of apple germplasm, weakening disease resistance, adaptability, and other important characteristics (Wang et al., 2019).

Ecological pressure is also an important issue. Factors such as climate change, disease, insect pests and human activities have caused no small threat to the growing environment of apple, leading to the risk of endangered or even extinct apple genetic resources in some areas. The ongoing impact of these factors can cause lasting damage to the health and diversity of the apple population.

There are also numerous management and conservation challenges. The collection, conservation and management of genetic resources are inadequate, there is a lack of comprehensive monitoring and evaluation mechanisms, and there is insufficient attention to long-term conservation and use. The trend of commercial cultivation may also lead to the neglect of diverse varieties, thus compromising the diversity and cultural inheritance of apple genetic resources.

3 Case Study

3.1 Apple genetic resource conservation program in the United States

Many countries have set up conservation programs for Apple genetic resources, taking the United States as an example, the National Apple Collection is a typical apple genetic resource conservation program. This program, administered by the United States Department of Agriculture (USDA), aims to collect, preserve, and study apple germplasm from across the United States (Volk et al., 2023). The National Apple Collection is a research site located in Oregon, USA, that centrally preserves thousands of apple varieties and wild species from all over the country. These germplasm resources include traditional varieties, wild varieties and modern cultivated varieties, covering a rich genetic diversity.

One of the goals of the program is to protect and preserve the diversity of apple genetic resources to ensure their long-term conservation. By collecting, labeling, describing and preserving these germplasm resources, the National Apple Collection provides a valuable resource for future breeding efforts. The program also focuses on research and evaluation of disease resistance, adaptability and quality characteristics of different varieties. These studies provide an important scientific basis for apple breeding and cultivation, and provide useful information and resources for farmers, horticultural enthusiasts and researchers.

The National Apple Collection is a successful case that provides a feasible model and strategy for the protection and utilization of apple diversity through centralized management, conservation and research of apple genetic resources, and also provides useful experience and reference for the establishment of similar conservation programs in other parts of the world.

3.2 Background and objectives

The National Apple Collection is a major apple genetic resource conservation program administered by the United States Department of Agriculture (USDA), which began in the 1940s against the backdrop of commercial cultivation that led to the gradual marginalization and loss of many traditional or wild apple varieties. Given this situation, it is particularly urgent and important to protect and maintain the diversity of apple genetic resources (Volk et al., 2023).

The primary goal of this plan is to ensure the long-term preservation of apple's diversity. Through the collection,

preservation and labeling of various apple varieties, the project centrally preserves the rich genetic diversity and provides an important resource for future apple breeding efforts. The project also focuses on the research and evaluation of the characteristics of apple varieties, including disease resistance, adaptability and quality characteristics. These studies provide important information and reference for apple scientific research and industrial development, and help to choose more adaptable and better quality apple varieties to enhance the competitiveness and sustainable development of the industry.

The goals and motivations behind the National Apple Collection highlight the importance attached to the conservation of apple genetic resources. Through the centralized management, conservation and research of apple germplasm resources, the project provides a useful framework and strategy for the conservation and utilization of apple diversity, providing a solid foundation for scientific research and industrial development.

3.3 Effectiveness evaluation and challenge

The National Apple Collection Program has achieved some results in the conservation of apple genetic resources, but it also faces some evaluation and challenges. In terms of effectiveness evaluation, the program has successfully collected and preserved a large number of apple germplasm resources from all over the United States, ensuring the long-term preservation and utilization of these resources. This includes traditional, wild and modern cultivars, providing a rich resource base for conservation of genetic diversity and future breeding (Volk et al., 2023). At the same time, the research and evaluation of apple variety characteristics also provide important information and support for scientific research and industrial development.

However, the national apple collection program also faces some challenges. One of these is the challenge of resource management and maintenance. Long-term conservation and management of large amounts of apple genetic resources requires ongoing financial, human and technical support, and maintaining the quality and integrity of these resources requires constant updating and maintenance, which poses challenges for sustainable operation of the repository.

Another challenge is the question of adaptability and applicability. Although a large number of apple variety resources have been collected, how to effectively use these resources in breeding and actual industries to meet market needs and challenges is still a problem that needs to be solved. In-depth study of the characteristics of different varieties and effective docking with the industry are the key to promote the application of these resources.

4 Improvement Measures of Protection Policy

4.1 Diversity maintenance and introduction of new germplasm

Conservation of diversity and introduction of new germplasm are important for the conservation and development of apple genetic resources. Diversity conservation involves the protection and preservation of existing apple varieties, as well as the continuous maintenance of genetic diversity. This means protecting traditional and wild varieties from the pressures of commercial cultivation and ensuring that the diversity of apple germplasm is not lost. At the same time, it also includes maintaining and enhancing the diversity of existing varieties through innovative and scientific methods to enhance their disease resistance and adaptability, ensuring their growth and yield in different environments (Papp et al., 2020).

The introduction of new germplasm is to enrich the apple genetic resources. This may involve the exploration and collection of wild apples in search of new varieties with unique disease resistance, good taste or adaptability. The introduction of new germplasm also includes scientific breeding and genetic improvement research work, through mating or genetic improvement, new genotypes are introduced into existing varieties to improve their characteristics and quality.

4.2 A genomics-based approach to conservation

The genomics-based conservation approach brings new possibilities and prospects for the conservation and management of apple genetic resources. This approach utilizes advanced genomics techniques and molecular biology tools to contribute to a more comprehensive and in-depth understanding of the genetic relationships and diversity among apple varieties (Buiteveld et al., 2021).

Genomics technologies can provide a high throughput of genetic information to help identify and verify genetic differences and characteristics between different breeds. Through genomic analysis of apple genetic resources, we can accurately identify and describe the genetic relationships, genetic diversity and their differences at the genome level among different varieties. This will contribute to a better understanding of the structure and characteristics of apple genetic resources and help select suitable varieties for breeding and conservation efforts.

The genomics-based conservation method can also promote the digitization and informatization of apple genetic resources. By establishing the genomic database of apple germplasm resources, researchers can integrate and manage a large amount of genetic information to facilitate the long-term preservation and utilization of resources. This digital approach to management also facilitates the sharing and exchange of resources and promotes cooperation and collaboration on a global scale.

4.3 Continuous monitoring and management

Continuous monitoring and management makes an important contribution to the conservation of apple genetic resources. This approach involves long-term tracking and management of apple varieties and their diversity, with the aim of ensuring timely conservation and utilization of these resources. Continuous monitoring involves regular surveys and assessments of apple germplasm resources in different regions to understand their quantity, distribution and status (Gepts, 2006). This monitoring can help identify threatened varieties and take timely measures for protection and conservation, and the ongoing management of apple resources also includes the collection, preservation, classification and digital management of genetic resources to ensure the integrity and sustainability of resources.

Continuous monitoring and management methods also help to identify new varieties and potentially good resources. Through regular investigation and research, new apple varieties with disease resistance, adaptability and other excellent characteristics can be discovered, providing new resources and possibilities for the apple industry and breeding work.

However, the ongoing monitoring and management approach faces some challenges due to financial, technical and human resource constraints, as well as the issue of sustained investment and attention to long-term monitoring and management. In addition, the monitoring and management of apple resources on a global scale also requires international cooperation and information sharing, which is also a problem that needs to be solved.

5 Summary and Prospect

As an important species of fruit trees, the genetic diversity and conservation strategies of apple germplasm resources have attracted much attention. The diversity of apple genetic resources has been well understood by the existing research results. This diversity is not only reflected in morphological characteristics, but also in disease resistance, adaptability, taste characteristics and so on. Full recognition of these diversity provides an important genetic basis for the long-term development of the apple industry.

In order to protect and make full use of these valuable genetic resources, researchers have adopted a series of conservation strategies. The establishment of germplasm bank, the formulation of relevant laws and regulations, the research based on genomics and the continuous monitoring and management have provided a solid foundation for the long-term conservation and rational utilization of apple genetic resources.

However, there are still some challenges and issues to be addressed in the future. With the increasing impact of environmental change and globalization, apple resources may face more pressure and threats, which requires more targeted protection measures. Digital and information management needs more perfect system and technical

support to better manage and use these resources. The conservation and utilization of traditional and wild species, which often have rich genetic diversity and special adaptability, also need more attention and research.

In subsequent studies, researchers need to dig deeper into the potential of apple genetic resources, through genomics-based research methods, to better understand the genetic relationships and characteristics between different varieties, and provide a more scientific basis for breeding and protection. At the same time, strengthening international cooperation and information sharing can promote the protection and exchange of apple resources worldwide. In addition, follow-up research can also strengthen the research and protection of traditional varieties and wild varieties, and tap their genetic potential, which is of great significance to the sustainable development of the apple industry.

References

Ahmad R., Anjum M.A., Naz S., and Balal R.M., 2021, Applications of molecular markers in fruit crops for breeding programs-A Review, Phyton., 90(1): 17-34.
https://doi.org/10.32604/phyton.2020.011680

Basannagari B., and Kala C.P., 2013, Climate change and apple farming in Indian Himalayas: A study of local perceptions and responses, PLoS ONE, 8(10): e77976.
https://doi.org/10.1371/journal.pone.0077976
PMid:24205051 PMCid:PMC3813512

Bhargava A., and Bansal A., 2021, Classification and grading of multiple varieties of apple fruit, Food Anal. Methods, 14: 1359-1368.
https://doi.org/10.1007/s12161-021-01970-0

Buiteveld J., Putten H.J.K., Kodde L., Laros I., Tumino G., Howard N.P., van de Weg E., and Smulders M.J.M., 2021, Advanced genebank management of genetic resources of European wild apple, Malus sylvestris, using genome-wide SNP array data, Tree Genetics & Genomes, 17: 32.
https://doi.org/10.1007/s11295-021-01513-y

Gao Y., Liu F., Wang K., Wang D., Gong X., Liu L., Richards C.M., Henk A.D., and Volk G.M., 2015, Genetic diversity of Malus cultivars and wild relatives in the Chinese National Repository of Apple Germplasm Resources, Tree Genetics & Genomes, 11: 106.
https://doi.org/10.1007/s11295-015-0913-7

Gepts P., 2006, Plant Genetic Resources Conservation and Utilization: The Accomplishments and Future of a Societal Insurance Policy, Crop Science, 46(5): 2278-2292.
https://doi.org/10.2135/cropsci2006.03.0169gas

Marconi G., Ferradini N., Russi L., Concezzi L., Veronesi F., and Albertini E., 2018, Genetic characterization of the apple germplasm collection in central Italy: The value of local varieties, Front Plant Sci., 9: 1460.
https://doi.org/10.3389/fpls.2018.01460
PMid:30364143 PMCid:PMC6191466

Papp D., Gao L., Thapa R., Olmstead D., and Khan A., 2020, Field apple scab susceptibility of a diverse Malus germplasm collection identifies potential sources of resistance for apple breeding, CABI Agriculture and Bioscience, 1: 16.
https://doi.org/10.1186/s43170-020-00017-4

Shaziya H., Bhat K.M., Aarifa J., Sheikh M., Ahmad W.S., Din K.M.U., and Bisati I.A., 2018, Managing genetic resources in temperate fruit crops, Economic Affairs, 63(4): 987-996.
https://doi.org/10.30954/0424-2513.4.2018.23

Volk G.M., Carver D., Irish B.M., Marek L., Frances A., Greene S., Khoury C.K., Bamberg J., del Rio A., Warburton M.L., and Bretting P.K., 2023, Safeguarding plant genetic resources in the United States during global climate change, Crop Science, 63(4): 2274-2296.
https://doi.org/10.1002/csc2.21003

Wang N., Jiang S., Zhang Z., Fang H., Xu H., Wang Y., and Chen X., 2018, Malus sieversii: the origin, flavonoid synthesis mechanism, and breeding of red-skinned and red-fleshed apples, Hortic. Res., 5: 70.
https://doi.org/10.1038/s41438-018-0084-4
PMid:30345062 PMCid:PMC6186759

Wang N., Zhang J., Yu L., Zou Q., Guo Z.W., Mao Z.L., Wang Y.C., Jiang S.H., Fang H.C., Xu H.F., Su M.Y., Zhang Z.Y., Feng S.Q., Chen X.L., Wang Z.G., Jiang Z.T., Dong M.X., Xu Y.H., Li J.M., Mao Z.Q., and Chen X.S., 2019, Progress on the resource breeding of kernel fruits II : Progress on the germplasm resources, quality development and genetic breeding of apple in China, Zhiwu Yichuan Ziyuan Xuebao (Journal of Plant Genetic Resources), 20(4): 801-812.