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Nurturing nature's jewels: A holistic review of genetic and molecular strategies for fortifying pomegranate varieties

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Abstract

Pomegranates, frequently called "nature's jewels," are a tangible joy and a dietary force to be reckoned with. This comprehensive review explores genetic and molecular strategies to fortify pomegranates, celebrating their inherent value. Biofortification, improving harvest sustenance, holds incredible potential. These techniques raise moral and ecological worries, requesting thorough evaluations for practical biofortification. Enhanced pomegranates show promise in reducing chronic diseases and improving overall health. With growing consumer awareness and market potential, biofortified pomegranates have a bright future, serving as a testament to the synergy of science, nature, and nutrition.

Keywords: Biofortification, genetic, molecular, nutrients

Introduction

Pomegranates often referred to as "nature's jewels," hold a special place in the world of fruits. These vibrant, ruby-hued gems have captivated human senses for centuries, not only for their remarkable taste and visual appeal but also for their remarkable nutritional richness. Pomegranates have earned their reputation as a nutrition powerhouse, and their allure extends beyond their exotic appearance. The intricately packed arils within this fruit are not just bursts of flavour but also reservoirs of health benefits (Jahan and Happy 2022) [7]. They are renowned for their high content of antioxidants, such as polyphenols and flavonoids, which have been associated with various health-promoting properties, including anti-inflammatory and anti-cancer effects. Pomegranates are a natural source of vital nutrients, such as vitamin C, vitamin K, and dietary fibre, which play pivotal roles in human well-being (Jagdale, Mahale *et al.* 2021) [6].

As we delve into this review, we'll not only explore the genetic and molecular strategies employed to fortify pomegranate varieties but also celebrate the inherent nutritional value that makes these fruits stand out in the world of agriculture. Pomegranates are not just captivating due to their outward beauty but also for the nourishment they offer. In a world where the quest for healthier and more sustainable food sources is paramount, pomegranates emerge as a shining example of nature's gifts, bestowed with a plethora of benefits.

This journey is an ode to the harmonious coexistence of science, nature, and nutrition, where genetic and molecular strategies seek to enhance these already invaluable jewels (Plate No 1). Biofortification is a process of enhancing the nutritional content of crops, including fruits like pomegranates, through plant breeding, genetic engineering, or agronomic practices (Sheoran, Kumar *et al.* 2022) [11].

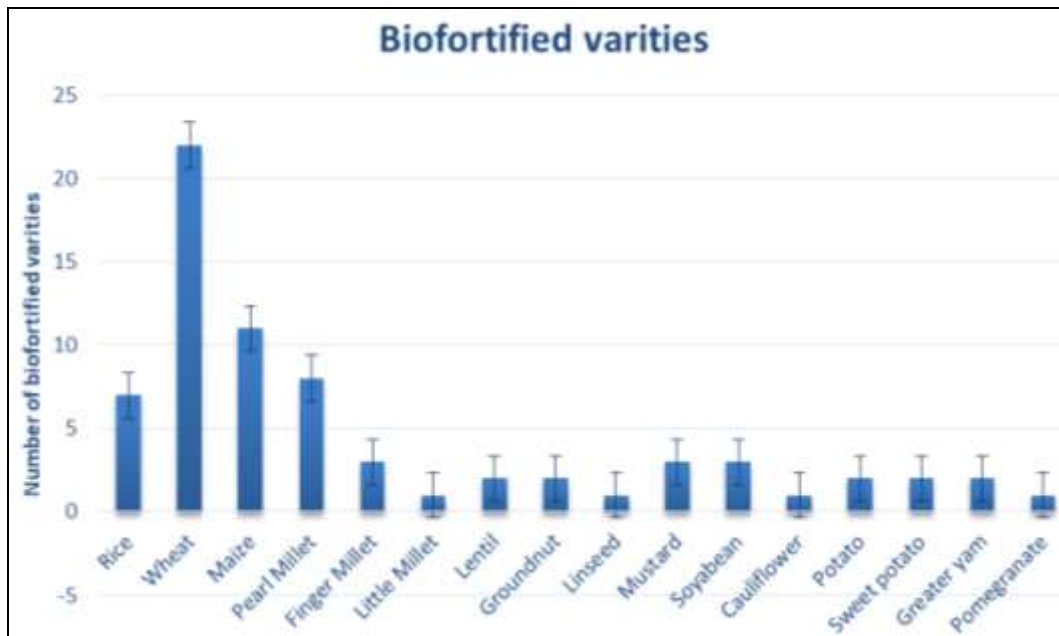


Plate 1: Crop-wise biofortified varieties developed through breeding

In the context of pomegranates, biofortification can be crucial for several reasons which mentioned as below

- 1. Nutritional deficiencies:** Pomegranates, while rich in antioxidants and certain vitamins, may lack other essential nutrients. Biofortification can help address specific nutritional deficiencies in pomegranates by increasing the levels of important vitamins or minerals, such as vitamin C, and vitamin K, or certain minerals like potassium and calcium.
- 2. Health Benefits:** Pomegranates are known for their potential health benefits, but biofortification can enhance these benefits. For example, increasing the vitamin C content in pomegranates can boost their immune-boosting properties, while higher levels of minerals like potassium can contribute to heart health.
- 3. Combatting malnutrition:** Pomegranates are consumed worldwide, and in regions where they are a dietary staple, biofortified varieties can play a crucial role in combating malnutrition. By increasing the nutritional content of pomegranates, they can contribute to improved dietary diversity and provide essential nutrients to vulnerable populations.
- 4. Enhanced agriculture:** Biofortification can also make pomegranate cultivation more sustainable. Varieties that are genetically or nutritionally fortified may be more resistant to diseases and pests, potentially leading to increased yields and reduced reliance on chemical inputs, which can be environmentally and economically beneficial.
- 5. Consumer choice:** Bio-fortified pomegranate varieties can offer consumers a broader range of options, allowing them to make healthier food choices. By providing more nutrient-rich varieties, consumers have the opportunity to select pomegranates that better suit their dietary needs.

The objective of this review is to provide a comprehensive overview of the current research on genetic and molecular approaches for bio-fortifying pomegranate varieties. It will encompass both traditional genetic breeding techniques and the latest molecular methods, including genetic modification

and genome editing. Throughout this review, we will explore successful case studies, challenges, and limitations associated with these approaches, and the documented impact on the nutritional value and potential health benefits of biofortified pomegranates (Garza-García, Hernández-Díaz *et al.* 2021) ^[3]. Additionally, we will examine consumer acceptance and the market potential of these enhanced fruit varieties. By shedding light on the genetic and molecular strategies used to fortify pomegranates and their implications, this review aims to contribute to the understanding of how biofortification can address nutritional deficiencies and promote healthier dietary choices (da Silva, Rana *et al.* 2013) ^[2]. Ultimately, the biofortification of pomegranates may pave the way for improved nutrition and health in regions where this fruit holds a significant place in the diet.

A. Genetic approach

Pomegranates, like many fruit crops, have benefited from traditional breeding techniques aimed at improving their nutritional content. These techniques have been employed to develop pomegranate varieties with enhanced nutrient profiles. In this section, we will delve into the different genetic approaches that have been used to achieve this goal (Holland and Bar-Ya'akov 2018) ^[5].

- 1. Traditional breeding techniques:** Traditional breeding techniques involve the controlled cross-breeding of different pomegranate varieties with desirable nutritional traits. This approach has been a cornerstone of agricultural practices for centuries. Breeder's select parent plants with specific attributes, such as high nutrient content, and then cross them to create offspring with the desired characteristics. Through successive generations of controlled breeding, new pomegranate varieties with improved nutritional value are developed. These varieties are often better adapted to local growing conditions, making them valuable resources for addressing nutritional deficiencies in specific regions.
- 2. Use of genetic markers and breeding programs:** In recent years, advances in genetic research have allowed for a more precise and efficient approach to

pomegranate breeding. Genetic markers, such as molecular markers or DNA sequences associated with specific traits, have become invaluable tools. These markers enable breeders to identify plants with the desired traits more quickly and accurately. Genetic markers can also assist in the development of breeding programs that focus on enhancing specific nutritional aspects of pomegranates, such as higher levels of antioxidants or certain vitamins.

3. **Successful case studies of bio-fortified pomegranate varieties:** Numerous successful case studies highlight the effectiveness of genetic approaches in bio-fortifying pomegranate varieties. For example, researchers have

developed pomegranate cultivars with increased levels of antioxidants, which are known for their potential health benefits. These biofortified pomegranates not only contribute to improved nutrition but also offer opportunities for enhancing consumer health.

Additionally, the development of pomegranate varieties with enhanced disease resistance and adaptability to different environmental conditions is another promising outcome of genetic approaches. These varieties not only ensure a more stable pomegranate crop but also contribute to food security in regions where pomegranates play a crucial role in the diet.

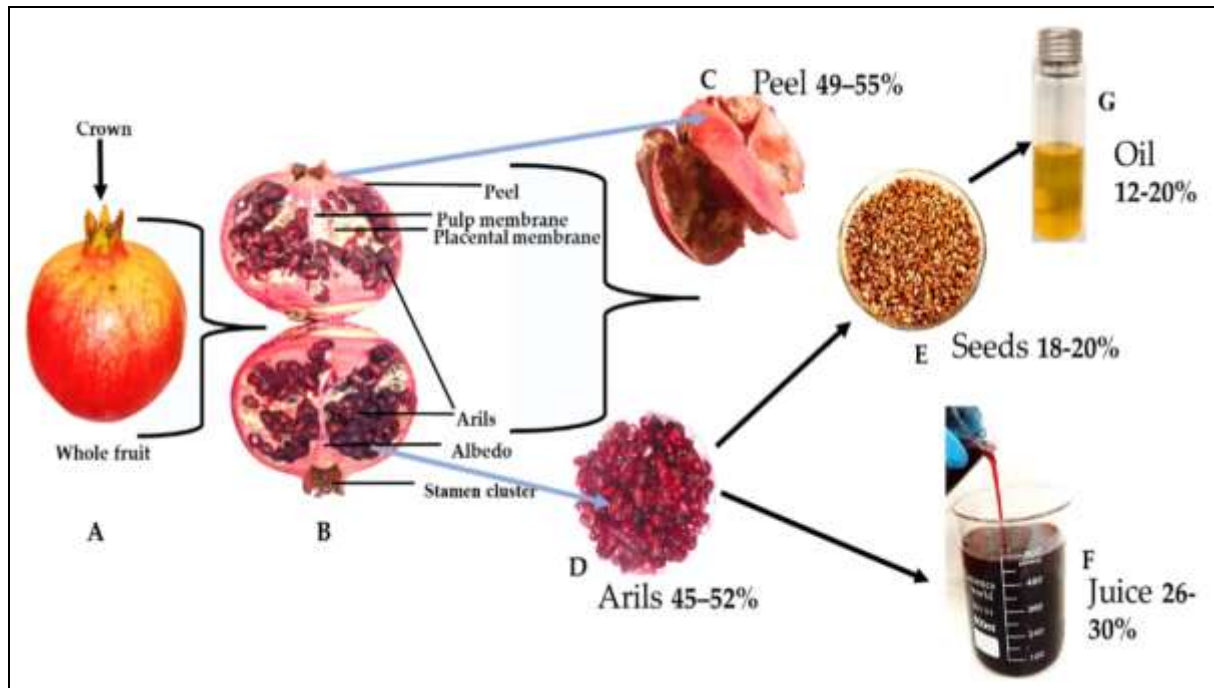


Plate 2: Nutrients contain in different parts of pomegranate

These successful case studies underscore the potential of genetic techniques to create pomegranate varieties that not only taste delightful but also offer heightened nutritional benefits. As we move forward, these genetic strategies will continue to play a pivotal role in addressing nutritional deficiencies and promoting healthier dietary choices, making pomegranates even more valuable in the realm of nutrition and agriculture (Plate No 2).

B. Molecular Approaches

In recent years, modern molecular techniques have revolutionized the field of crop biofortification, including pomegranates. These techniques offer a more precise and targeted way to enhance the nutrient content of pomegranates (Senjam, Chamling *et al.* 2021) [10]. In this section, we will explore the various molecular approaches, the specific genes and molecular pathways involved, and the implications of transgenic research in pomegranate biofortification.

1. **Modern Molecular Techniques:** Modern molecular techniques encompass a range of innovative methods that have been employed to bio-fortify pomegranates. These include genetic modification (GM) and genome editing technologies such as CRISPR-Cas9. Genetic modification involves the introduction of foreign genes

or the modification of existing genes to enhance specific nutritional traits in pomegranates. Genome editing, on the other hand, enables precise alterations in the pomegranate genome without introducing foreign genes, offering more control and accuracy.

2. **Specific Genes and Molecular Pathways:** Researchers have identified specific genes and molecular pathways related to nutrient enhancement in pomegranates. For example, genes responsible for the synthesis of antioxidants, like polyphenols, and key vitamins such as vitamin C, have been targeted for enhancement. Understanding these genes and pathways allows scientists to manipulate them to increase the nutritional content of pomegranates. By pinpointing these molecular components, researchers can selectively improve traits like fruit size, shelf life, and nutritional composition.
3. **Transgenic Pomegranate Research and Its Implications:** Transgenic research in pomegranates involves the introduction of genes from other species into the pomegranate genome to confer specific traits. For instance, genes that code for enzymes involved in the biosynthesis of bioactive compounds, like resveratrol or quercetin, have been introduced into pomegranates to elevate their nutritional value.

The implications of transgenic research are significant (Table No.1). Biofortified pomegranate varieties generated through these methods may offer enhanced nutritional benefits, potentially addressing malnutrition and diet-related health issues in populations that rely on pomegranates (Thoppurathu, Ghorbanzadeh *et al.* 2022) ^[12]. However, ethical considerations, ecological impact, and public perception are important factors to weigh when exploring

the use of transgenic approaches. Research should be conducted with a focus on safety and sustainability (Guha, Gopal *et al.* 2021) ^[4].

By combining modern molecular techniques, the knowledge of specific genes and pathways, and insights from transgenic research, pomegranate biofortification continues to advance, opening doors to the creation of highly nutritious pomegranate varieties that can make meaningful contributions to global nutrition and health.

Table 1: Pomegranate biofortification milestones

Sr. No.	Characters	Bhagwa	Solapur Lal
1.	Tree height (m)	Medium (1.8- 2.1)	Medium (2.0 -2.3)
2.	Calyx colour	Red	Red
3.	Fruit maturity (days)	180-185	160-165
4.	Yield (t/ha)	16-20	23-27
5.	Fruit weight (gm)	287-297	280-290
6.	Fruit colour	Red	Red
7.	Rind thickness(mm)	Medium (3.3-3.5)	Medium (3.3-3.5)
8.	100 Aril weight (gm)	35-36	40-41
9.	Aril colour	Red	Dark red
10.	Seed texture	Soft	Medium
11.	Juice % (ml/100 gm)	43-48	45-50
12.	TSS(°Brix)	15.7-15.9	17.5-17.7
13.	Vitamin-C (mg/100 gm)	14.2-14.6	19.4-19.8
14.	Anthocyanin(mg/100 gm)	355-365	385-395
15.	Iron (mg/100 gm of fresh aril)	2.7-3.2	5.6-6.1
16.	Zinc (mg/100 gm of fresh aril)	0.50-0.54	0.64-0.69

C. Challenges and Limitations

While genetic and molecular approaches have shown great promise in biofortifying pomegranate varieties, there are several challenges and ethical considerations that need to be addressed in this context. Additionally, potential environmental and safety concerns must be carefully considered (Wallenstein, Myrold *et al.* 2006) ^[14].

Challenges and Ethical considerations

- 1. Genetic diversity preservation:** One challenge in genetic approaches is the potential reduction in genetic diversity. Repeated selection of a few highly biofortified varieties may lead to a loss of genetic diversity, which is essential for a crop's ability to adapt to changing environmental conditions and resist diseases.
- 2. Intellectual property rights:** The use of patented genetic modifications and transgenic methods can lead to intellectual property disputes. Access to biofortified pomegranate varieties and related technologies may be limited, which could hinder their widespread adoption, particularly in developing regions.
- 3. Ethical concerns:** The introduction of foreign genes into pomegranates or other crops can raise ethical concerns. These concerns may include the impact on local biodiversity, traditional farming practices, and cultural or religious beliefs.

Potential Environmental and Safety Concerns

- 1. Environmental impact:** Genetic modification and transgenic approaches can potentially lead to unintended environmental consequences. For instance, the release of genetically modified organisms into the environment may affect non-target species or disrupt local ecosystems.

- 2. Safety of transgenic varieties:** The safety of transgenic pomegranate varieties is a critical consideration. Rigorous testing is necessary to ensure that biofortified pomegranates are safe for human consumption. Additionally, comprehensive environmental risk assessments must be conducted to evaluate the potential ecological impact of transgenic plants.
- 3. Allergenicity and Unintended Effects:** There is a need to assess the allergenic potential and unintended effects of genetic modifications. The introduction of novel proteins into pomegranates may pose risks related to allergenic reactions in sensitive individuals.

Addressing these challenges and ethical concerns, along with rigorous safety and environmental assessments, is essential to ensure that genetic and molecular approaches for biofortifying pomegranate varieties are conducted responsibly and sustainably. Ethical considerations should prioritize equitable access to the benefits of biofortified crops and safeguard the environment for future generations. This balance between innovation and responsibility is key to the success of biofortification efforts.

D. Nutritional Impact and Health Benefits

One of the primary goals of biofortification in pomegranates is to enhance their nutritional content, and this section delves into the documented improvements in nutritional content and the potential health benefits for consumers (Cooper and Adams 2023) ^[1]. Studies on biofortified pomegranates have demonstrated significant improvements in their nutritional content. For instance, researchers have reported increased levels of various nutrients and bioactive compounds in biofortified varieties (Monte 2001) ^[8].

- 1. Higher antioxidant content:** Bio-fortified

pomegranates often exhibit elevated levels of antioxidants, particularly polyphenols such as anthocyanins, flavanols, and tannins. These antioxidants are known to combat oxidative stress, reduce inflammation, and contribute to overall health.

2. **Enhanced vitamin content:** Some bio-fortified pomegranates have shown increased levels of essential vitamins, including vitamin C and vitamin K. Higher vitamin C content, in particular, can boost the immune system and support collagen production.
3. **Increased mineral content:** Nutrient enhancement efforts have also resulted in pomegranates with improved mineral content, such as higher levels of potassium and calcium, which are essential for maintaining healthy blood pressure and bone health.
4. **Elevated nutrient ratios:** Bio-fortified pomegranates often have improved ratios of nutrients. For example, a better balance of antioxidants and vitamins can provide a synergistic effect on health.

Potential Health Benefits for Consumers

The enhanced nutritional content in biofortified pomegranates translates into potential health benefits for consumers:

1. **Reduced risk of chronic diseases:** Increased levels of antioxidants in biofortified pomegranates may reduce the risk of chronic diseases like heart disease, cancer, and diabetes. These compounds help protect cells from damage caused by free radicals.
2. **Improved immune function:** Higher vitamin C content can strengthen the immune system, making consumers more resilient to infections and illnesses.
3. **Enhanced bone health:** Elevated calcium levels in some biofortified pomegranates can contribute to better bone health, reducing the risk of osteoporosis and fractures.
4. **Anti-inflammatory effects:** The bioactive compounds in biofortified pomegranates have anti-inflammatory

properties, which can help mitigate inflammation-related health issues.

5. **Overall well-being:** The improved nutrient profile of biofortified pomegranates can support overall health and vitality, promoting well-being among consumers

E. Consumer acceptance of bio-fortified pomegranates
 Consumer acceptance of biofortified pomegranate varieties has shown positive trends in recent years (Reda 2022) [9]. While a comprehensive analysis is beyond the scope of this document, several factors suggest a growing interest and receptiveness among consumers (Plate No 3).

1. **Health awareness:** Consumers are increasingly health-conscious, seeking foods with enhanced nutritional value. Biofortified pomegranates, with their higher nutrient content, align with these preferences.
2. **Promotion of health benefits:** Public awareness campaigns and educational efforts have highlighted the potential health benefits of biofortified crops, including pomegranates. These efforts have contributed to positive consumer perceptions.
3. **Cultural significance:** In regions where pomegranates hold cultural or traditional significance, consumers are more inclined to embrace biofortified varieties if they maintain the taste and qualities they appreciate.
4. **Marketing and Labelling:** Effective marketing strategies, clear product labelling indicating enhanced nutrition, and claims of superior health benefits have influenced consumer perceptions.
5. **Consumer-driven demand:** The demand for nutrient-dense and functional foods is driven by consumer preferences. Biofortified pomegranates have emerged as a response to this demand.
6. **Access to nutrition:** In regions with a high prevalence of nutrient deficiencies, consumers are likely to view biofortified pomegranates as a source of essential vitamins and minerals.

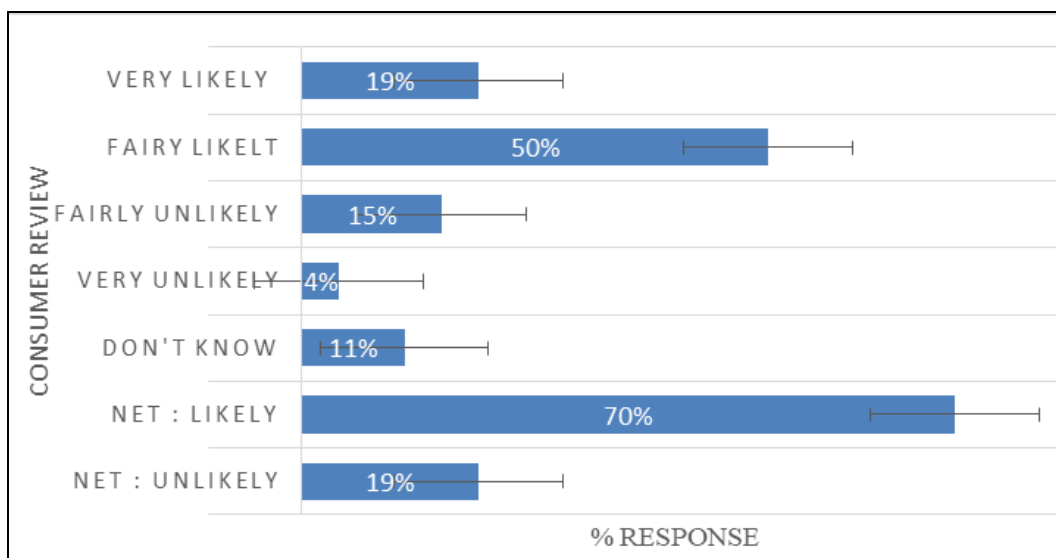


Plate 3: Consumer purchase intent of product containing nutrient-rich crops

F. Market potential

The market potential of biofortified pomegranates is significant and offers promising opportunities.

Here are some key factors contributing to their market

potential

1. **Nutritional awareness:** Growing consumer awareness and interest in nutrition and health has created a demand for foods with enhanced nutritional profiles.

Biofortified pomegranates, which offer higher levels of essential nutrients and antioxidants, align well with this trend.

2. **Global health initiatives:** Government and non-governmental organizations often promote biofortification as a strategy to combat nutrient deficiencies, making biofortified crops like pomegranates attractive for addressing public health issues.
3. **Nutrient-deficient regions:** In areas where malnutrition and nutrient deficiencies are prevalent, biofortified pomegranates can serve as a valuable source of essential vitamins and minerals, potentially improving the health of local populations.
4. **Export opportunities:** As consumer acceptance grows, there are export opportunities for biofortified pomegranates. These fruits can find markets beyond their regions of production, expanding their reach to international consumers.
5. **Functional Foods and Nutraceuticals:** Biofortified pomegranate derivatives, such as juices, extracts, and supplements, can cater to the growing functional foods and nutraceutical markets. These products offer a concentrated source of health-promoting compounds.
6. **Collaboration with the Food Industry:** Collaboration with the food industry can lead to the development of new products, such as fortified snacks, beverages, or dietary supplements. This diversification can tap into existing distribution networks and expand market potential.
7. **Government support:** Support from governments in terms of subsidies, research funding, and promotion of biofortified crops can drive market growth.
8. **Consumer awareness campaigns:** Education and awareness campaigns about the benefits of biofortified pomegranates can create a more informed and receptive consumer base, further boosting market potential.
9. **Increased crop yield:** Bio-fortified pomegranates may exhibit improved crop yield and product quality, which can be an attractive feature for both consumers and growers.
10. **Health and Wellness market:** The rising focus on health and wellness, along with the demand for natural and organic products, positions biofortified pomegranates as appealing choices for health-conscious consumers.
11. **Sustainability and Environmental concerns:** Biofortification can contribute to sustainable agriculture by improving crop productivity and reducing the need for synthetic nutrient supplementation, aligning with eco-conscious consumer preferences.

G. Promising areas for future research and development

1. **Targeted nutrient enhancement:** Future research will focus on precise nutrient enhancement, tailored to address specific nutrient deficiencies prevalent in different regions. This approach ensures that biofortified pomegranates address local nutritional needs effectively.
2. **Flavor optimization:** Maintaining or even enhancing the appealing taste and aroma of pomegranates is an essential aspect of future research. Biofortified varieties should continue to be delicious and attractive to

consumers.

3. **Diversification of products:** Exploring novel product developments, such as pomegranate-based functional foods, dietary supplements, or fortified beverages, presents innovative opportunities to deliver biofortified pomegranates to a broader consumer base.
4. **Sustainability and Environmental impact:** Future research will continue to assess the environmental sustainability of biofortified pomegranate cultivation. Reducing pesticide usage, enhancing crop resilience, and minimizing the ecological footprint are essential considerations.
5. **Unlocking pomegranate's anti-cancer potential:** Pomegranates have emerged as a promising subject for future research due to their potential anti-cancer properties. Research findings indicate that these fruits are rich in compounds like polyphenols and ellagic acid, known for their antioxidant and anti-inflammatory effects, which could play a role in inhibiting cancer cell growth and angiogenesis. Further investigations are crucial to deepen our understanding of these mechanisms and to uncover the potential applications of pomegranates in cancer prevention and treatment, potentially leading to novel therapeutic strategies and dietary recommendations for cancer patients.

These methods refine pomegranate qualities, while molecular methodologies, as genetic alteration and genome altering, offer accuracy.

Conclusion

In this comprehensive review, the potential of pomegranates as nutritional powerhouses is explored through genetic and molecular approaches, aiming to address deficiencies and promote healthier diets. Through traditional breeding techniques and advanced methods like genetic modification and genome editing, researchers have successfully enhanced pomegranate varieties, elevating their antioxidant levels, vitamins, and minerals. However, this pursuit is not devoid of challenges. Preserving genetic diversity, navigating ethical considerations, and ensuring safety and sustainability are crucial aspects that demand careful attention. Despite these challenges, biofortified pomegranates have shown promising results, offering reduced risks of chronic diseases, improved immune function, enhanced bone health, and overall well-being for consumers. Positive trends in consumer acceptance, driven by health awareness and effective marketing, indicate a growing demand for these nutrient-dense varieties. As a testament to the harmonious coexistence of technology, tradition, and nature, biofortified pomegranates exemplify the potential synergy between human ingenuity and the gifts of the Earth, paving the way for a healthier future and reaffirming the intricate interplay between science, nutrition, and the natural world.

References

1. Cooper GM, Adams KW. *The cell: A molecular approach*. Oxford University Press; c2023.
2. da Silva JAT, Nesi N, Alvarenga AA, *et al*. Pomegranate biology and biotechnology: A review. *Scientia Horticulturae*. 2013;160:85-107.
3. Garza-García JJ, Martínez-Santos R, Flores-Cano JV, *et al*. The role of selenium nanoparticles in agriculture and food technology. *Biological Trace Element Research*.

- 2021:11-21. DOI:10.1007/s12011-021-02858-y
4. Guha T, Pal S, Paul S, *et al.* Nanoprimering with zero-valent iron synthesized using pomegranate peel waste: A “green” approach for yield enhancement in *Oryza sativa* L. cv. Gonindobhog. *Plant Physiology and Biochemistry*. 2021;163:261-275.
DOI:10.1016/j.plaphy.2021.05.007
 5. Holland D, Bar-Ya’akov I. Pomegranate (*Punica granatum* L.) breeding. In: Al-Khayri JM, Jain SM, Johnson DV, eds. *Advances in Plant Breeding Strategies: Fruits: Vol. 3*. Springer; c2018. p. 601-647.
 6. Jagdale YD, Giri AP, Waghmare RT, *et al.* Nutritional profile and potential health benefits of super foods: A review. *Sustainability*. 2021;13(16):9240.
DOI:10.3390/su13169240
 7. Jahan F, Happy AA. Revolutionizing plant-based extracts for skin care and therapeutics. In: *Nanotechnology for the Preparation of Cosmetics Using Plant-Based Extracts*. Elsevier; c2022. p. 75-130.
 8. Monte E. Understanding Trichoderma: between biotechnology and microbial ecology. *International Microbiology*. 2001;4(1):1-4.
 9. Reda C. Pre-breeding of Kale (*Brassica oleracea* var. acephala) - Organic adaptation and shelf life; c2022.
 10. Senjam BD, Oulkar DP, Jadeja GC, *et al.* Chapter-9 Biofortification in Fruit Crops. In: Ahirwar MK, ed. *Chief Editor Manoj Kumar Ahirwar*, 2021, 141.
 11. Sheoran S, Singh A, Yadav V, *et al.* Current status and potential of biofortification to enhance crop nutritional quality: An overview. *Sustainability*. 2022;14(6):3301.
DOI:10.3390/su14063301
 12. Thoppurathu FJ, Pandey P, Vadez V, *et al.* Unravelling the treasure trove of drought-responsive genes in wild-type peanut through transcriptomics and physiological analyses of root. *Functional & Integrative Genomics*. 2022;22(2):215-233.
DOI:10.1007/s10142-022-00809-1
 13. Vala AKG, Patel DP, Patel VR, *et al.* Transcriptome analysis identifies novel gene (s) and pathways for salt stress responses in Dandi cultivar. *Cereal Research Communications*. 2023;51(2):351-365.
DOI:10.1007/s42976-022-00354-0
 14. Wallenstein MD, Myrold DD, Firestone MK, *et al.* Environmental controls on denitrifying communities and denitrification rates: insights from molecular methods. *Ecological Applications*. 2006;16(6):2143-2152.