Sea buckthorn (*Hippophae rhamnoides* L.) Resources in China

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Sea buckthorn (*Hippophae rhamnoides* L.), as an economically and ecologically valuable plant with rich nutritional and bioactive compounds, has garnered significant interest. The demand for *Sea buckthorn* has explosive growth, highlighting the urgent need for the cultivation of fast-growing, high-quality *Sea buckthorn* seedlings. However, there are still some controversies in *Sea buckthorn* germplasm resource research.

Sea buckthorn | propagation | flavonoid | carotenoid | vitamin

1. Introduction

Sea buckthorn (*Hippophae rhamnoides* L.) is a shrub or small tree belonging to the Elaeagnaceae family and is known for its inducible rooting characteristics [1][2]. It is also commonly referred to as vinegar willow, sour thorn, and blackthorn. Every part of this plant, including its fruits, leaves, stems, branches, roots, and thorns, has traditional uses in traditional medicine, nutritional supplements, soil and water conservation, and the establishment of wildlife habitats. In recent years, it has played a significant role in afforestation in the Tibet region; however, *Sea buckthorn* still holds untapped potential that requires further development [3]. *Sea buckthorn* exhibits a wide distribution, primarily in temperate, cold-temperate, and subalpine regions of the Eurasian continent [4]. In China, *Sea buckthorn* is extensively found in provinces and autonomous regions such as Qinghai, Tibet, Gansu, Ningxia, Inner Mongolia, Xinjiang, Sichuan, Yunnan, Guizhou, Liaoning, Jilin, and Heilongjiang. Tibet and Qinghai are the primary distribution areas. *Sea buckthorn* is a highly stress-resistant and ecologically adaptable plant, and it has found extensive applications in the fields of soil and water conservation and ecological construction [5]. The fundamental plan for *Sea buckthorn* resource development should be based on existing natural and artificial resources, actively utilizing the excellent *Sea buckthorn* resource varieties available in China, establishing high-quality *Sea buckthorn* industry parks, and rationally optimizing the layout of enterprises.

2. Overview of *Sea buckthorn* Plant Resources

2.1. Species of *Sea buckthorn*

Sea buckthorn is a dioecious, deciduous perennial small tree or shrub, and it is an emerging fruit-bearing tree. Depending on the classification system used, *Sea buckthorn* plants have different classification methods, and the results obtained from different classification methods are not entirely consistent. Moreover, there are limitations to the classification methods. In 1996, according to the latest classification system by Chinese *Sea buckthorn* botanist

Lian Yongshan [6], the *Sea buckthorn* genus was divided into 6 species and 12 subspecies based on different morphological characteristics of *Sea buckthorn* plants, categorized into two groups: those with skin and those without skin. In China, there are 6 species and 8 subspecies, earning it the title of the “Kingdom of *Sea Buckthorn*”. In 2003, based on the different morphological characteristics of *Sea buckthorn* plants, Chen Xuelin, Ma Ruijun, and others [7] classified the *Sea buckthorn* genus into 7 species and 11 subspecies, with China having 7 species and 7 subspecies. *Sea buckthorn* is an ideal crop for regions south of the Indian Himalayas and other marginal areas with extreme weather conditions. Additionally, cultivated varieties of *Sea buckthorn* are found throughout the country. The majority of *Sea buckthorn* taxa are concentrated in the Himalayas and adjacent regions [8]. Based on the convergence of several key factors, it is concluded that the Himalayan region and its vicinity are not only the center of distribution for *Sea buckthorn* genus plants but also the center of differentiation and the origin of the primitive groups within this genus. Therefore, it can be inferred that *Sea buckthorn* plants likely originated in this region [8]. Chinese scientist Hu updated and improved the classification system, revising the *Sea buckthorn* genus to include 6 species and 17 subspecies [9].

2.2. Habitat and Geographical Distribution of *Sea buckthorn*

Sea buckthorn has a very wide distribution range and is primarily found in Asia, Europe, and North America. According to the statistical data, as of December 2020, *Sea buckthorn* fruits have been distributed in 52 countries worldwide, covering a total area of 2.33 million hectares. China accounts for approximately 2.1 million hectares, with the remaining area distributed across other countries [10]. As shown in **Figure 1**, in China, *Sea buckthorn* is primarily distributed in the northern regions, including Liaoning, Inner Mongolia, Hebei, Shanxi, Shaanxi, Ningxia, Qinghai, Gansu, Xinjiang, and other provinces and autonomous regions. Additionally, it can be found in high-altitude areas such as Tibet, Sichuan, and Yunnan. Due to its ability to thrive in adverse environments, *Sea buckthorn* has an extensive distribution range, particularly flourishing in arid, cold, and high-altitude areas. Furthermore, *Sea buckthorn* exhibits some unique growth environments and distribution patterns.

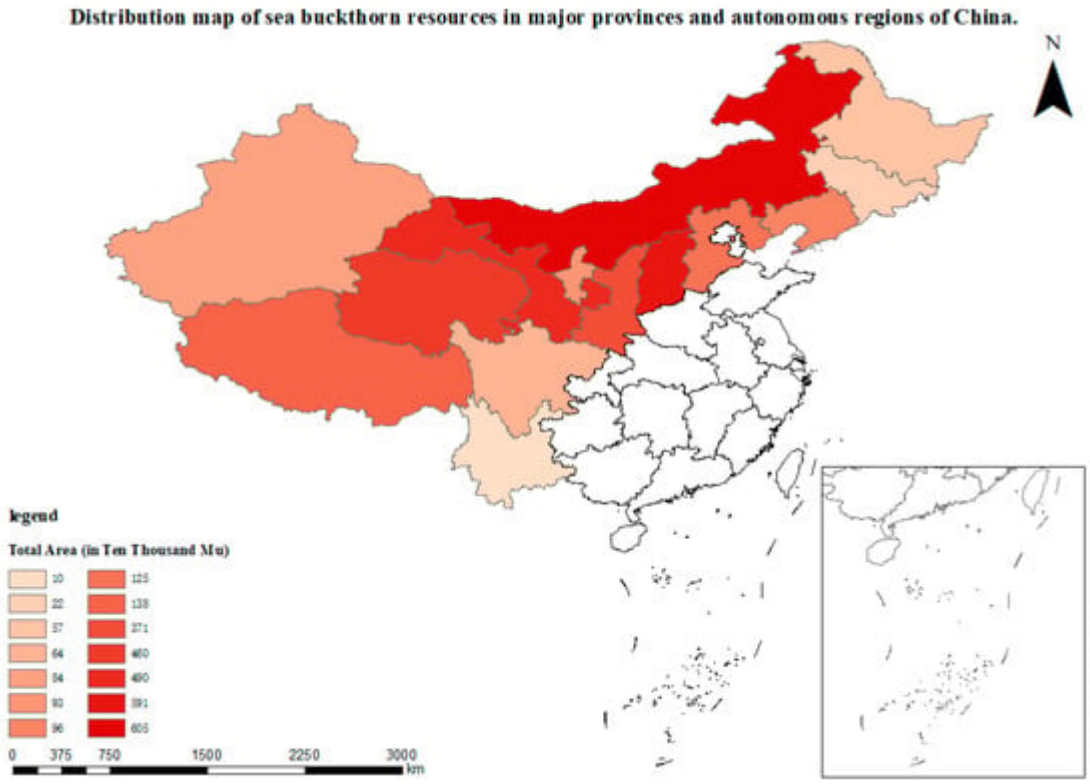

Figure 1. Distribution map of *Sea Buckthorn* (*Hippophae rhamnoides* L.) in various provinces (autonomous regions) of China.

3. Propagation System in *Sea buckthorn*

With the discovery of *Sea buckthorn*'s nutritional and economic value, the demand for it has been steadily increasing. It is widely used in the fields of medicine, food, cosmetics, beverages, water conservation, and soil protection as part of afforestation efforts. Simultaneously, it has expedited the development of local agriculture. Therefore, there is a need for a detailed analysis of *Sea buckthorn* seedlings and afforestation techniques to enhance their survival rate. This is crucial for cultivating high-quality *Sea buckthorn* with high survival rates and for maximizing its ecological and economic value. Due to *Sea buckthorn*'s strong adaptability, conventional tree propagation methods can be applied to *Sea buckthorn*. Currently, there are two main methods of *Sea buckthorn* propagation: sexual reproduction and asexual reproduction. Each propagation method comes with unique advantages and disadvantages, as shown in **Figure 2**.

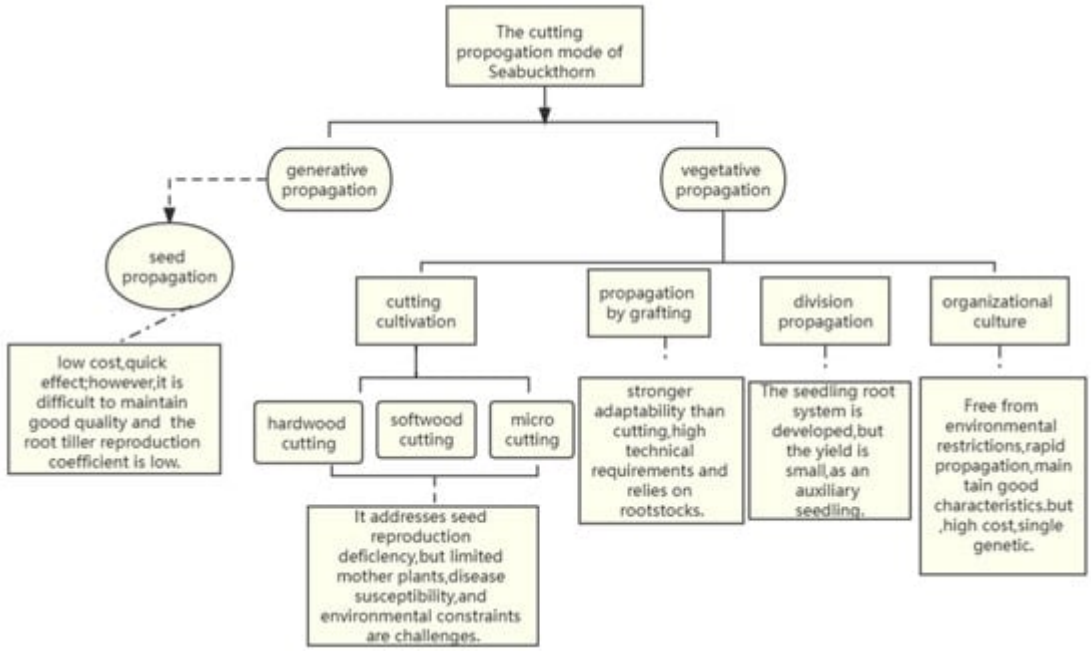

Figure 2. The main reproduction method of *Sea buckthorn*.

3.1. Sexual Reproduction

Sexual reproduction, also known as seed propagation, is suitable for large-scale expansion and is a commonly used method for propagating *Sea buckthorn*. It involves the use of seeds to germinate and develop into mature *Sea buckthorn* plants. Seed propagation is characterized by its low cost, minimal labor input, well-developed root systems, and strong adaptability. However, due to the predominantly male population of *Sea buckthorn*, which affects fruit production, it is not suitable for economic and artificial forest plantations. *Sea buckthorn* seeds are small, with thick and hard skins, and are coated with an oily adhesive film, which hinders water absorption [11]. The following are the steps involved in *Sea buckthorn* seed propagation:

- Harvesting: *Sea buckthorn* has many thorns, so during collection, it is advisable to either knock the fruits off during the winter or prune the branches before processing [12]. After harvesting the ripe *Sea buckthorn* fruits, they are soaked in clean water for approximately half an hour to remove surface dust and impurities. The fruits are then placed in a well-ventilated area to air dry until the surface is free of moisture.

- Removal of fruit skins: The dried *Sea buckthorn* fruits are processed to remove the fruit skins, and the seeds are extracted. The seeds are then cleaned and subjected to disinfection to eliminate surface bacteria and viruses, improving the germination rate.

- Soaking: Typically, the cleaned seeds are soaked in warm water for 24 h to promote germination.

- Sowing: The soaked seeds are sown in various containers, such as seedling trays, nursery boxes, or flowerpots. The seeds should be evenly sown to avoid overcrowding and competition among seeds. A layer of well-draining soil or leaf mold can be used as a covering.

- Placement and care: The sown containers are placed in direct sunlight, maintaining suitable temperature and humidity. Regular watering and ventilation are necessary. *Sea buckthorn* seeds take a relatively long time to germinate, typically requiring 2–3 weeks or even longer.

- Transplantation and cultivation: Once *Sea buckthorn* seedlings reach a certain stage of growth, they can be transplanted and cultivated until they become mature plants.

3.2. Asexual Reproduction

The ways of asexual reproduction for *Sea buckthorn* include cutting, layering, division, grafting, and tissue culture. Among these, cutting and layering have relatively lower success rates and are typically used for specialized seedling production and research purposes. Division propagation is suitable for mature *Sea buckthorn* plants and involves cutting the root system of mature plants into several parts for transplantation and reproduction. Grafting propagation allows for the combination of *Sea buckthorn*'s resilience and salt tolerance with other tree species, creating new varieties with significant practical value. By controlling the nutrient components, hormones, and other environmental conditions of the growing medium, tissue growth and differentiation can be stimulated to produce new plants.

4. Research on the Functions of *Sea buckthorn*

The functional research on *Sea buckthorn* has yielded promising results, covering multiple areas of application, as shown in **Figure 3**. In the medicinal field, *Sea buckthorn* has been extensively studied for its fruit, which is rich in vitamin C, vitamin E, beta-carotene, polyphenolic compounds, and catechins, among other antioxidant substances. These components provide it with various biological activities, such as antioxidant, anti-inflammatory, antimicrobial, and antitumor properties. These qualities make *Sea buckthorn* a potential complementary treatment option for various chronic diseases, including cardiovascular diseases, cancer, and inflammatory conditions. In the beauty industry, *Sea buckthorn* oil has garnered attention due to its high content of antioxidants and fatty acids. It is widely used in skin care products and contributes to reducing skin inflammation, accelerating wound healing, and improving skin elasticity and hydration, thereby reducing wrinkles and dryness. *Sea buckthorn* oil has already made a mark in the beauty industry, offering a natural and effective solution for skin care. Furthermore, *Sea buckthorn* has extensive applications in the food industry. Its berries are used to make juices, jams, wines, and health foods, enjoying popularity due to their unique sweet–sour taste and rich vitamin content. *Sea buckthorn* juice is rich in nutrients, providing people with a healthy dietary choice.

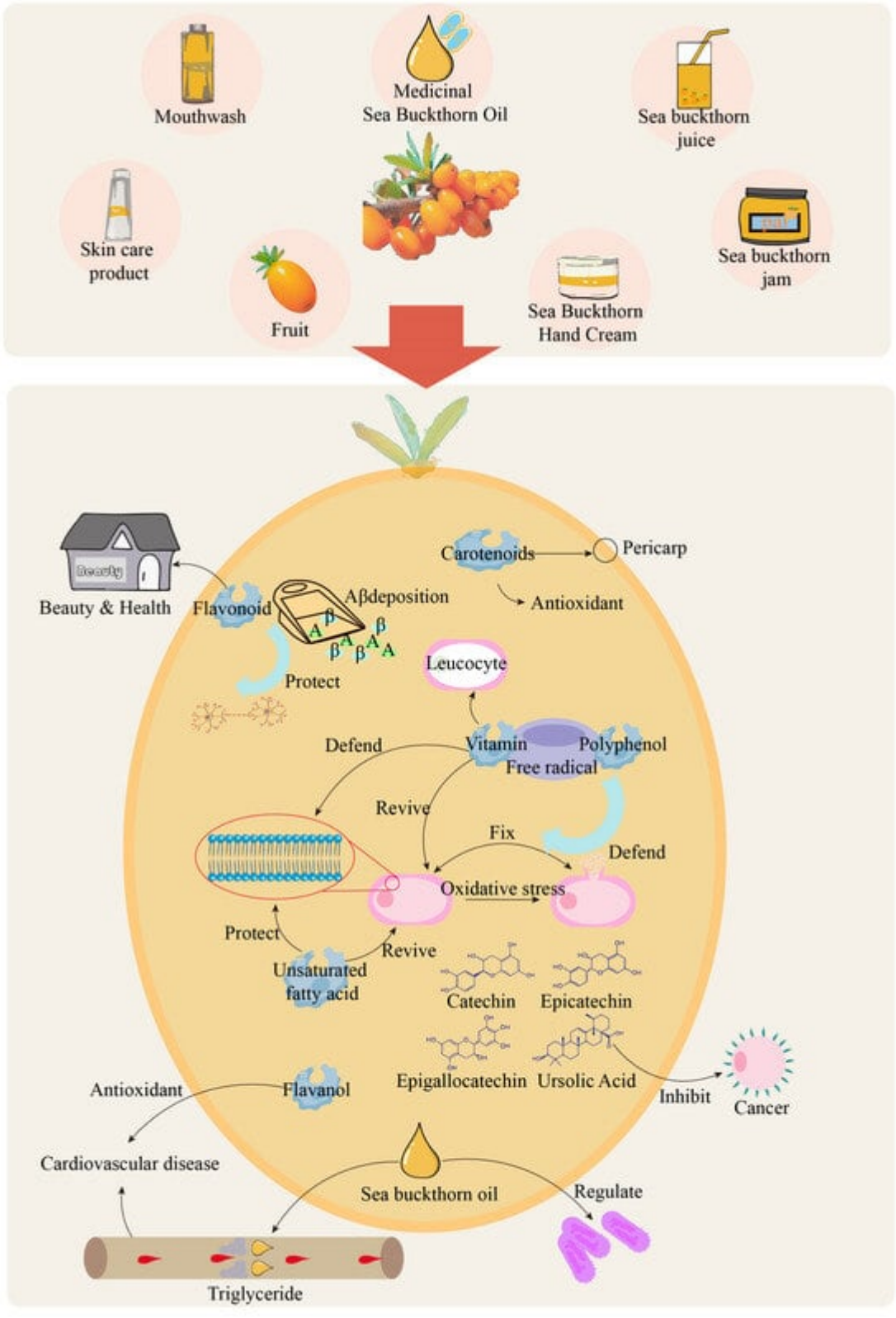

Figure 3. The functional applications of *Sea buckthorn*.

4.1. Medical Functions of Sea buckthorn

Sea buckthorn has many characteristics that are beneficial to human health, and its roots, stems, leaves, flowers, and fruits have good medicinal value potential. China has a long history of the medicinal use of *Sea buckthorn*,

which has been widely used in the field of national medicine. It is a commonly used medicinal material for Tibetan medicine and Mongolian medicine. Many famous medical classics also record the medicinal efficacy of *Sea buckthorn*. It is a guiding theory of medication accumulated by ancient working people and medical experts through a large number of clinical practices for a long time, which plays an important guiding role in the mining of *Sea buckthorn* efficacy and product development. There are many metabolic pathways in the whole life cycle of *Sea buckthorn*. These metabolic pathways lead to the production of many secondary metabolites, which have certain medicinal value, such as flavonoids and phenolic acids. Studies have found that these components have a wide range of health benefits by exerting antioxidant, anticancer, anti-inflammatory, antibacterial, and antiviral effects, as well as protective effects on the cardiovascular system, skin, nerves, and liver. The extensive research by many scholars has focused on these bioactive compounds, which primarily function by neutralizing free radicals, inhibiting lipid peroxidation reactions, and activating antioxidant systems [13]. The nutritional and bioactive content of *Sea buckthorn* fruit influences its health value [14].

4.1.1. Flavonoids

Flavonoid compounds may have potential roles in preventing chronic diseases such as diabetes, cardiovascular diseases, and cancer [15]. Guo et al. [15] found that total phenols and flavonoid alcohols in *Sea buckthorn* extracts exhibited antioxidant and anti-proliferative activities. To date, 95 flavonoid compounds have been identified in *Sea buckthorn*, including 75 flavonol alcohols, 2 dihydroflavonols, 6 catechins, 1 resveratrol, 9 anthocyanins, 1 proanthocyanidin, and 1 flavone [16]. Resveratrol is a phenolic phytoalexin exhibiting antifungal properties within the realm of plant secondary metabolites. The research has indicated its beneficial impact on human health, in conjunction with other categorized compounds. Investigations highlight that diverse technical approaches during the processing of plant materials can exert an influence on the presence of these phenolic compounds in the ultimate product. The conclusions drawn from the research report authored by Aleksander V. et al. [17] underscore that the initial processing and brewing methodology can impact and augment the resveratrol content. The concentration of resveratrol tends to escalate with prolonged soaking and fermentation times. Notably, red grape wine manifests a higher resveratrol content compared to white grape wine. The thermal vinification process, involving heating to 60 °C with a 1-h incubation, proves to be more efficacious in extracting phenolic substances than traditional methods

4.1.2. Phenolic Acid Compounds

Polyphenols are the main compounds in *Sea buckthorn* responsible for its antioxidant activity. They are a class of compounds with multiple phenolic ring structures, including flavonoids, flavonols, and phenolic acids. Polyphenols possess strong antioxidant properties, neutralizing and stabilizing free radicals and reducing cell damage induced by oxidative stress. The reported polyphenol content in *Sea buckthorn* fruit ranges from 12.36 to 34.6 milligrams of gallic acid equivalents (GAEs) per gram, which is higher than that in oranges (1.27 mg GAE/g), citrus fruits (1.16 mg GAE/g), blueberries (2.19 mg GAE/g), sour cherries (2.56 mg GAE/g), and strawberries (1.12 mg GAE/g) [18] [19].

4.1.3. Vitamins

The quality of *Sea buckthorn* fruit is often evaluated based on its abundant nutritional value [18]. *Sea buckthorn* is renowned as a “natural treasure trove of vitamins” due to its high vitamin content. The vitamin C content in *Sea buckthorn* fruits varies between 52.86 mg and 896 mg per 100 g [14][18]. The vitamin C content in 100 g of *Sea buckthorn* berries can reach as high as 275 mg, far surpassing the same quantity of other fruits, such as mangoes (27.7 mg), apricots (10 mg), bananas (8.7 mg), oranges (50 mg), and peaches (6.6 mg). Hence, owing to its elevated vitamin C content, *Sea buckthorn* products are capable of retaining substantial vitamin C levels even post-processing. This is crucial, as many products encounter challenges in preserving adequate vitamin C levels throughout processing. Nevertheless, certain studies indicate that subjecting *Sea buckthorn* to high-temperature processing may result in a reduction in vitamin C content. This juice can be effectively harnessed for the production of nutritionally rich fruit juice powder through the utilization of the spray drying process. Alterations in spray drying conditions, such as the inlet air temperature, are observed to impact the vitamin C content of the fruit juice powder. It was noted that a significant increase in the vitamin C content of the juice powder could be achieved by adjusting the spray drying conditions, specifically by reducing the inlet air temperature [20].

4.2. Commercial Values and Valorization of Sea Buckthorn

4.2.1. Development of *Sea buckthorn* Functional Foods

Sea buckthorn has significant importance in the food industry, particularly as a raw material for functional foods or dietary supplements. While all parts of the *Sea buckthorn* plant have diverse applications, the fruit, especially the pulp (used for making *Sea buckthorn* juice) and the fruit seeds (used for oil extraction), are the most valuable components [21][22]. Various products derived from *Sea buckthorn* fruit have been developed, similar to common products obtained from other fruits, and there were over 200 different products derived from *Sea buckthorn* species in 2018 [23]. *Sea buckthorn* low-temperature freeze-dried powder, prepared through low-temperature freeze-drying technology, can actively impact the composition and structure of the gut microbiota and help combat high-fat diet-induced obesity [24]. Adding 3% *Sea buckthorn* fruit juice extract to pork sausages effectively inhibited lipid oxidation and reduced the total bacterial count by approximately 7 times, thereby enhancing the microbial content of the sausages [25]. In Finland, *Sea buckthorn* is used as a functional ingredient in baby food products [26].

4.2.2. Extraction of *Sea buckthorn* Oil

Sea buckthorn oil can be categorized into fruit oil, seed oil, and blended oil. Product types include capsules, oral liquid, and bottled oil, among others. In the food market, *Sea buckthorn* products containing added *Sea buckthorn* oil hold an important and distinct position. *Sea buckthorn* oil can be found as an ingredient in certain dietary supplements, such as those aimed at improving mucous membrane conditions. These supplements are highly appealing to consumers because they are sourced naturally and offer health benefits [27] *Sea buckthorn* fruits contain two different oil components: one obtained from the seeds and the other retained in the pulp. The primary compounds in these oil fractions are unsaturated fatty acids and tocopherols, but their concentrations vary significantly. Seed oil contains higher concentrations of tocopherols and α-linolenic acid, while pulp oil has higher concentrations of palmitoleic acid.

Considering the known positive effects of *Sea buckthorn* oil on the skin and mucous membranes, researchers have investigated its potential impact on dry eye syndrome. A group of men and women suffering from dry eye syndrome orally consumed *Sea buckthorn* oil for three months during the autumn and winter. *Sea buckthorn* oil reduced the increase in tear film osmolarity during the cold season and had a positive effect on dry eye symptoms [28]. Despite the long history of *Sea buckthorn*'s nutritional and medicinal use, information regarding its toxicity and safety remains relatively limited.

4.2.3. Making *Sea buckthorn* Juice Beverages

Sea buckthorn has a wide range of applications in food, providing not only a delicious taste and color to dishes but also a rich nutritional content and antioxidants for the human body. These applications not only enrich food choices but also contribute to promoting health and creating delicious meals. Some of the most popular and ancient *Sea buckthorn* products are juices and refreshing beverages. These nutrient-rich drinks are abundant in vitamin C and carotenoids and are highly popular in China, Germany, the Scandinavian Peninsula, and other Nordic countries. *Sea buckthorn* beverages served as the official drink for Chinese athletes during the 1988 Seoul Olympics [29]. They are also used in the diets of Indian soldiers working in extremely cold conditions [30]. Furthermore, *Sea buckthorn* berries, despite their tartness, are used for making jams and jellies. Their rich aroma can be balanced by blending *Sea buckthorn* juice or sauce with other milder-flavored fruits in various proportions [31]. The research indicates that *Sea buckthorn* fruits are valuable for jam production due to their high content of bioactive compounds. In a study by Rafalska et al. [32], various jams with different flavors and colors were prepared by mixing *Sea buckthorn* fruit with other fruits, such as apples, currants, raspberries, and strawberries.

5. Conclusions

Sea buckthorn offers rich nutritional value; however, there is still room for ongoing improvements in various aspects, including genetic enhancement and adaptability to diverse environments. As a nutrient-rich fruit, *Sea buckthorn* has a wide range of applications and prospects, but future development should encompass factors such as variety improvement, agricultural practices, food safety, market promotion, sustainable production, clinical research, and international cooperation. Through continued research and ongoing improvement in practices, *Sea buckthorn* is poised to become an integral component of healthy food and sustainable agriculture.

- Breeding of New Varieties: *Sea buckthorn* has multiple varieties, and variations in nutritional content and taste may exist among different varieties. The future research should focus on breeding *Sea buckthorn* varieties with higher yields, drought resistance, and enhanced nutritional value to meet market demands. This will contribute to improving the sustainable production and commercial potential of *Sea buckthorn.*

- Genetic Enhancement of *Sea buckthorn*: While *Sea buckthorn* exhibits strong adaptability to the environment, the regions suitable for its growth may change with climate change and rising temperatures. The research indicates that global warming in recent decades has led to changes in the distribution range of *Sea buckthorn*. For instance, the population of *Sea buckthorn* in some high-latitude areas has decreased, while *Sea buckthorn*

in some low-latitude regions is gradually expanding northward. Furthermore, climate change may also affect the quality and yield of *Sea buckthorn* berries. As *Sea buckthorn* has high requirements for sunlight and water, climate change may lead to drought and excessively high temperatures, affecting *Sea buckthorn* growth and fruit yield.

- Agricultural Practices and Sustainability: The cultivation and management techniques for *Sea buckthorn* need continuous improvement to enhance yield and quality while ensuring sustainable agricultural practices. Farmers need training to understand how to maximize the potential of this plant. *Sea buckthorn* is a highly adaptable and drought-resistant plant suitable for growth under various climatic conditions. Therefore, it has the potential to become a promising agricultural crop that can improve rural economies and increase farmers' income. Additionally, the root system of *Sea buckthorn* can be used to prevent soil erosion, contributing to sustainable land management. Sustainable methods of *Sea buckthorn* production and harvesting need to be considered to ensure that they do not harm the ecosystem. Planting and harvesting practices should take into account their environmental impact and resource management.

- Food Safety and Innovation: As the production and consumption of *Sea buckthorn* products increase, ensuring food safety is crucial. The research should focus on hygiene standards and food preservation techniques during the production process to prevent foodborne illnesses. There is still significant room for the use of *Sea buckthorn* in the food industry. Food producers can continue to develop a variety of new products, such as *Sea buckthorn* jams, cookies, ice creams, beverages, and dietary supplements, to meet consumer demands for natural and nutrient-rich foods.

- Clinical Research: The potential medicinal value of *Sea buckthorn* has yet to be thoroughly explored. Clinical trials can investigate its role in the treatment of chronic diseases, promoting skin health, improving eye health, and its potential applications in drug development.

- International Cooperation: With increasing global demand for *Sea buckthorn* products, international trade will become a vital area of growth. Simultaneously, there is substantial potential for international trade and cooperation involving *Sea buckthorn*. Countries can collaborate to conduct research, share best practices, and promote international trade of *Sea buckthorn* products, fostering sustainable growth of the global *Sea buckthorn* industry and advancing the international trade of *Sea buckthorn* and its products, promoting agricultural cooperation and economic development.

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