International Journal of Horticulture, 2024, Vol.14, No.6, 343-354
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Review and Progress Open Access

The Multipurpose Applications of *Xanthoceras sorbifolium* and Its Prospects in Sustainable Agriculture

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International Journal of Horticulture, 2024, Vol.14, No.6 doi: 10.5376/ijh.2024.14.0035
Received: 02 Oct., 2024
Accepted: 10 Nov., 2024
Published: 26 Nov., 2024

Preferred citation for this article:
Chen H.Y., Zhang D.D., Qi W.H., Hu N.N., Li K., Lin K.A., Wang C., Sun Q.Y., and You L.X., 2024, The multipurpose applications of *Xanthoceras sorbifolium* and its prospects in sustainable agriculture, International Journal of Horticulture, 14(6): 343-354 (doi: 10.5376/ijh.2024.14.0035)

Abstract *Xanthoceras sorbifolium* is a versatile woody oil-bearing plant widely used in the fields of food, health products, bioenergy, and ecological restoration. Its unique botanical characteristics and high adaptability make it an important economic crop for arid and barren lands, with significant ecological value. *X. sorbifolium* plays a key role in desertification control and soil improvement, while also demonstrating great potential in sustainable agriculture. This study explores the multifunctional applications of *X. sorbifolium*, analyzing its economic potential in the food and bioenergy sectors, as well as its value in ecological restoration and sustainable farming. By examining its botanical traits, seed oil composition, ecological functions, and current status in agricultural industries, the study evaluates the importance of *X. sorbifolium* as a sustainable resource for agricultural development. The findings indicate that *X. sorbifolium* holds significant economic and ecological potential across multiple domains, including food, health products, bioenergy, and ecological restoration. Its multifunctional nature offers sustainable raw materials for the food and energy industries while serving as a key crop for ecological rehabilitation and agricultural rotation, contributing to environmental improvement and green agricultural development. This study provides scientific evidence for the promotion and application of *X. sorbifolium* in global agriculture.

Keywords *Xanthoceras sorbifolium*; Oil-bearing crop; Ecological restoration; Desertification control; Sustainable agriculture

1 Introduction

Xanthoceras sorbifolium, commonly known as yellow horn, is a deciduous tree native to Northern and Central China, including regions such as the Loess Plateau. This species has garnered significant attention due to its remarkable adaptability to harsh environmental conditions, including cold and drought, making it a valuable resource for both ecological and economic purposes (Ruan et al., 2017; Bi et al., 2019; Wang et al., 2023). Historically, *X. sorbifolium* has been utilized in traditional Chinese and Mongolian medicine, and modern research has highlighted its potential in various pharmacological applications (Zang et al., 2021). The seeds of yellowhorn are particularly notable for their high oil content, which is rich in unsaturated fatty acids, making them ideal for biodiesel production and other industrial uses (Liu et al., 2013; Ruan et al., 2017).

Xanthoceras sorbifolium is a versatile plant with significant economic potential. The seeds are a rich source of bioactive oils, which are used in food, health products, and biodiesel production (Ruan et al., 2017; Xiao et al., 2023). The oil content of the seeds is high, with selected pure lines averaging up to 34% oil content, which includes valuable fatty acids such as C18:1, C18:2, and C24:11. Additionally, the plant's various parts, including leaves, flowers, and branches, contain numerous chemical compounds with potential medicinal applications, such as anti-inflammatory and anti-tumor properties (Figure 1) (Zang et al., 2021). The development of high-quality genome assemblies and transcriptome analyses has further facilitated the genetic improvement of yellowhorn, enhancing its oil yield and quality (Liu et al., 2013; Bi et al., 2019; Wang et al., 2023).

Ecologically, *Xanthoceras sorbifolium* plays a crucial role in the restoration of arid and semi-arid habitats. Its ability to thrive in desert and xeric environments makes it an excellent candidate for combating desertification and

promoting soil and water conservation (Ruan et al., 2017; Wang et al., 2017; Chen et al., 2021). The plant's robust root system and adaptability to extreme conditions contribute to its effectiveness in ecological restoration projects. Moreover, the species' ornamental value, with its long blooming period and attractive flowers, adds to its utility in urban greening and landscaping (Chen et al., 2021). The integration of *X. sorbifolium* into ecological restoration efforts not only enhances biodiversity but also provides economic benefits through the sustainable production of bioactive oils and other valuable products (Figure 1) (Ruan et al., 2017; Wang et al., 2017; Chen et al., 2021).

This study aims to comprehensively evaluate the multipurpose applications of *Xanthoceras sorbifolium* and its prospects in sustainable agriculture, synthesizing current research findings on its economic and ecological benefits. It focuses on the genetic resources of *Xanthoceras*, its oil biosynthesis pathways, and its potential in biodiesel production, medicinal use, and ecological restoration. Additionally, the study analyzes the ecological benefits of *Xanthoceras* and its potential applications across various industries (Figure 1). This study seeks to fully understand the multifunctional role of *Xanthoceras sorbifolium* and identify future research directions for its sustainable utilization.

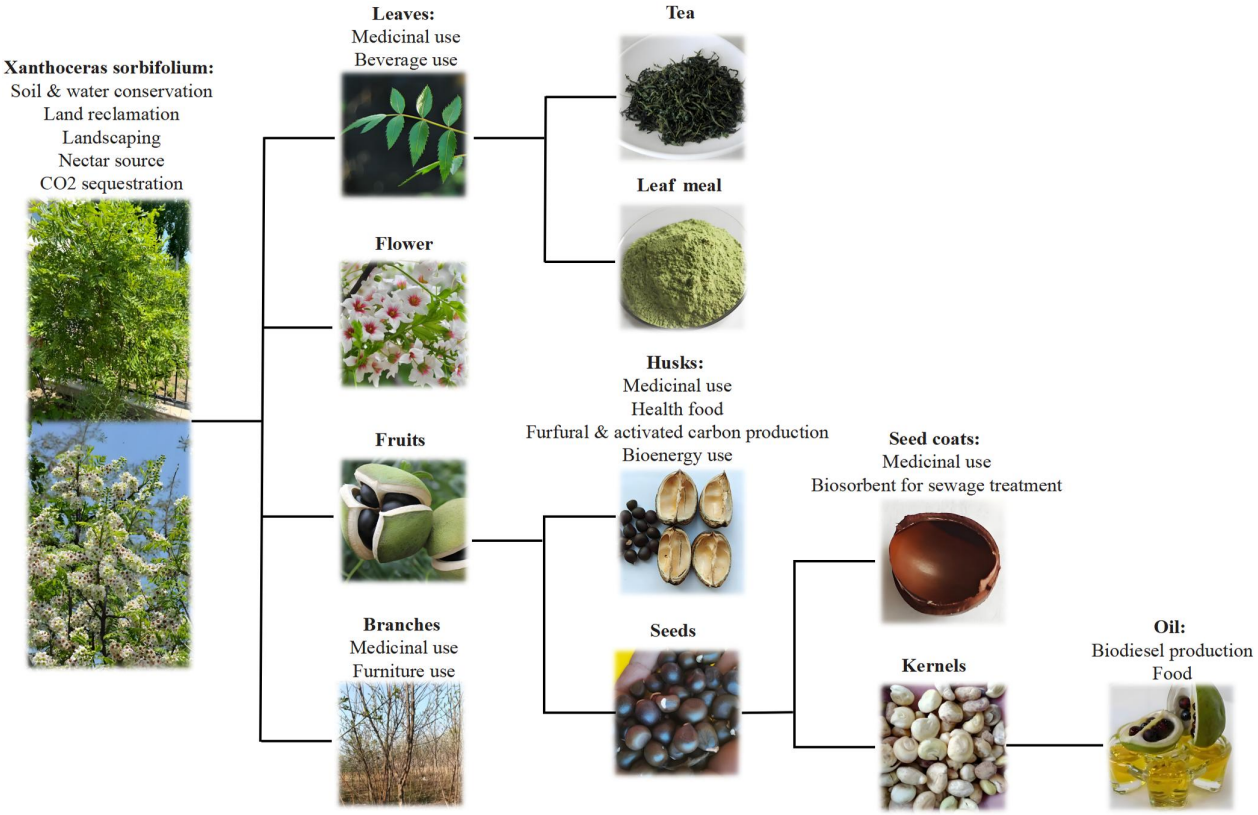

Figure 1 Uses of *Xanthoceras sorbifolium*

2 Botanical Characteristics and Adaptability of *Xanthoceras sorbifolium*

2.1 Morphological structure and adaptability to growing environments

Xanthoceras sorbifolium, commonly known as yellowhorn, is a deciduous tree native to Northern and Central China, including the Loess Plateau. It is characterized by its hardy nature, allowing it to thrive in a variety of growing conditions. The tree can be either a tall arbor with a round or spreading crown or a shrub, depending on the site conditions (Chen et al., 2021; Wang et al., 2023). The root system of yellowhorn is particularly noteworthy for its role in environmental adaptation. The species has a well-developed root cap, which is enriched in gene families associated with root cap development, contributing to its ability to withstand abiotic stress (Wang et al., 2023).

The adaptability of yellowhorn to different environments is further supported by its genetic makeup. Comparative genomics has revealed that yellowhorn has a high degree of genome continuity, with specific gene families under

expansion that are enriched in photosynthesis and root cap development. This genetic foundation enables the tree to tolerate extreme environmental conditions, such as drought and poor soil quality (Liu et al., 2021; Wang et al., 2023). Additionally, the tree's physiological responses to salt and saline-alkali stress have been studied, showing significant changes in various indices, which help it cope with these harsh conditions (Wang et al., 2020).

2.2 Advantages of adaptability in arid and infertile lands

One of the most significant advantages of *Xanthoceras sorbifolium* is its ability to survive and propagate in arid and infertile lands. This adaptability makes it an ideal candidate for ecological restoration and agricultural production in regions with challenging growing conditions. The tree's drought resistance is particularly notable, allowing it to thrive in desert, semi-arid, and arid environments (Lang et al., 2020; Lian et al., 2022). This characteristic is supported by its genetic traits, such as the presence of long-chain acyl-CoA synthetase and ankyrins, which contribute to its defense against abiotic stresses (Liang et al., 2022).

Moreover, yellowhorn's ability to grow in barren and saline environments has been demonstrated through the successful cultivation of various cultivars, such as 'Yan Zi' and 'Yan Xia' (Figure 2). These cultivars are highly adaptable, showing tolerance to cold, drought, and saline conditions, making them suitable for widespread planting in Northern China (Chen et al., 2021; Lian et al., 2022). The tree's resilience in such harsh environments not only supports its use in sustainable agriculture but also highlights its potential for contributing to soil and water conservation, carbon sequestration, and urban greening (Chen et al., 2021). This adaptability, combined with its economic and ecological value, underscores the importance of further research and development to fully exploit the potential of *Xanthoceras sorbifolium* in sustainable agriculture.

Figure 2 Morphological Characteristics of 'Yanxia' (Adapted from Chen et al., 2021)
Image caption: A: 'Yanxia' raceme; B: Pinnateless leaves of 'Yanxia' (Adapted from Chen et al., 2021)

3 Economic Potential of *Xanthoceras sorbifolium* as an Oil Crop

3.1 Composition analysis and nutritional value of *Xanthoceras* seed oil

Xanthoceras sorbifolium seed oil is notable for its high content of unsaturated fatty acids, which are essential for human health. The oil predominantly contains monounsaturated fatty acids, with oleic acid being the most abundant, accounting for approximately 30.73-30.98% of the total fatty acid content. Additionally, the oil is a significant source of nervonic acid, a monounsaturated fatty acid that is crucial for brain health and the development of the nervous system (Zheng et al., 2022). The presence of these fatty acids makes *Xanthoceras* seed oil a valuable nutritional resource.

Moreover, the oil's composition includes a balanced ratio of saturated, monounsaturated, and polyunsaturated fatty acids, which is close to the ideal ratio of 1:1:1, indicating a well-rounded nutritional profile (Wu et al., 2020). This balance is essential for maintaining cardiovascular health and reducing the risk of chronic diseases. The oil also contains high levels of tocopherols and sterols, which contribute to its antioxidant properties and further enhance its health benefits (Zheng et al., 2022). These components help in protecting cells from oxidative damage and support overall health.

3.2 Applications of seed oil in the food industry

The high nutritional value and health benefits of *Xanthoceras sorbifolium* seed oil make it a promising candidate for the food industry. Its high content of unsaturated fatty acids, particularly oleic and linoleic acids, makes it suitable for use as a premium edible oil. The oil's balanced fatty acid profile and antioxidant properties can appeal to health-conscious consumers looking for natural and nutritious cooking oils (Zheng et al., 2022). Additionally, the oil's high stability and resistance to oxidation make it a viable option for various culinary applications.

Furthermore, the oil's rich composition of essential fatty acids and antioxidants positions it well for the health food market. Products such as dietary supplements, fortified foods, and functional foods can benefit from the inclusion of *Xanthoceras* seed oil. The presence of bioactive compounds like tocopherols and sterols enhances the oil's appeal as a health-promoting ingredient (Wu et al., 2020). The potential for developing a range of health food products using *Xanthoceras* seed oil is significant, given the growing consumer demand for natural and functional foods.

3.3 Use of *Xanthoceras* oil in bioenergy

Xanthoceras sorbifolium seed oil also holds promise as a renewable energy source, particularly in the production of biodiesel (Table 1) (Yao et al., 2013). The oil's high content of unsaturated very long-chain fatty acids makes it suitable for biodiesel production, offering a sustainable alternative to fossil fuels (Venegas-Calerón et al., 2017). The use of *Xanthoceras* oil for biodiesel can contribute to reducing greenhouse gas emissions and dependence on non-renewable energy sources.

The oil's physicochemical properties, such as its high oxidation stability and favorable fatty acid composition, enhance its suitability for biodiesel production (Table 2) (Yao et al., 2013). Studies have shown that the oil can be efficiently converted into biodiesel with good performance characteristics. Additionally, the cultivation of *Xanthoceras sorbifolium* on marginal lands, which are not suitable for food crops, provides an environmentally friendly approach to bioenergy production without competing with food resources (Venegas-Calerón et al., 2017). This dual-purpose application of *Xanthoceras* oil in both the food and energy sectors underscores its economic potential and contribution to sustainable agriculture.

Table 1 Fatty acid profile of *Xanthoceras sorbifolium* oil compared with other vegetable oils (Adapted from Yao et al., 2013)

Fatty acid (n:m)[a]	*Xanthoceras sorbifolium*	Palm	Sunflower	Soybean	Jatropha	Cottonseed
Lauric (12:0)	-	0.1	-	-	-	-
Myristic (14:0)	-	0.7	-	-	-	1.2
Palmitic (16:0)	5.2	36.7	6.2	11.3	14.1	29
Palmitoleic (16:1)	-	0.1	0.1	0.1	0.5	0.8
Margaric (17:0)	-	-	-	-	-	0.2
Stearic (18:0)	2.2	6.6	3.7	3.6	6.8	5.9
Oleic (18:1)	28.6	46.1	25.2	24.9	38.6	9.8
Linoleic (18:2)	43.3	8.6	63.1	53	36	50.2
Linolenic (18:3)	0.5	0.3	0.2	6.1	0.2	-
Arachidic (20:0)	0.4	0.4	0.3	0.3	0.2	0.8
Gadoleic (20:1)	6.8	0.2	0.2	0.3	-	0.4
Heneicosanoic (21:0)	0.4	-	-	-	-	-
Behenic (22:0)	0.6	0.1	0.7	-	-	0.5
Erucic (22:1)	8.7	-	0.1	0.3	-	1.1
Tricosanoic (23:0)	-	-	-	-	-	0.1
Lignoceric (24:0)	0.3	0.1	0.2	0.1	3.6	0.2
Nervonic (24:1)	3	-	-	-	-	0.1

Note: [a] n:m=no. of carbon atoms: unsaturated centers

Table 2 Physicochemical properties of *Xanthoceras sorbifolium* seed oil (Adapted from Yao et al., 2013)

Property	Unit	Value
Density at 20 °C	kg/L	0.914
Kinematic viscosity at 40 °C	mm^2/s	38.11
Caloric value	MJ/kg	39.7
Peroxide value	meq O_2/kg	0.16
Acid value	mg KOH/g	0.601
Free fatty acid	%	0.3
Iodine value	g I2/100 g	113
Saponification value	mg KOH/g	176

4 Applications of *Xanthoceras sorbifolium* in Ecological Restoration and Desertification Control

4.1 Ecological role of *Xanthoceras* in windbreaks and sand fixation

Xanthoceras sorbifolium, a small deciduous tree, plays a vital ecological role in mitigating the effects of desertification and providing windbreaks in arid and semi-arid regions. Its deep root system helps anchor soil, reducing erosion caused by strong winds and maintaining soil stability. This makes it an effective species for restoring degraded lands, particularly in northern China, where desertification has severely impacted the environment. Studies have shown that the extensive planting of *Xanthoceras* in desert regions has significantly reduced wind erosion and helped reclaim areas that would otherwise be unsuitable for vegetation growth (Liu, 2012).

Furthermore, *Xanthoceras* serves as a reliable species for ecological restoration due to its high adaptability to poor soil conditions. In areas prone to sand movement and degradation, this species has demonstrated its ability to create stable microenvironments that allow other plant species to establish themselves, thus promoting ecosystem recovery. The use of *Xanthoceras* in windbreaks and sand-fixing belts has proven to be highly beneficial for combating desertification in the Horqin Sandy Lands and other desertified regions (Ruan et al., 2017).

4.2 Role in soil improvement

Beyond its ability to control sand and wind erosion, *Xanthoceras sorbifolium* contributes to soil improvement by enriching infertile soils. This species is known for its ability to fix nitrogen, which helps increase the nutrient content of poor soils, making it more conducive for agriculture and other vegetation. The tree's deep roots improve soil structure by enhancing aeration and promoting water infiltration, which is critical in dry, compacted soils (Table 3). Research has shown that areas planted with *Xanthoceras* experience better water retention and improved organic matter content, which boosts soil fertility over time (Li and Fan, 2010).

Table 3 (113 ° 46 ′ 14.37 ″ E, 32 ° 22 ′ 6.06 ″ N, altitude 120 m) Changes in soil bulk density and porosity under different planting methods

Solum (cm)	Handle	Unit weight (g/cm^3)	Total porosity (%)	Capillary porosity (%)	Ventilation porosity (%)	Soil moisture content (%)
0~20	Convention planting	1.36±0.01[a]	48.74±0.21[b]	31.61± 1.08[a]	19.68±0.88[b]	21.39±0.60[a]
	Ridge culture	1.27±0.02b	52.12±0.89[a]	33.01±0.84[a]	29.08± 1. 18[a]	18.16±0.30[b]
20~40	Convention planting	1.48±0.03[a]	44.03± 1.28[b]	27.34±0.54b	10.92±2.68[b]	22.31±0.45[a]
	Ridge culture	1.41±0.02[b]	46.67±0.63[a]	29.07±0.93a	19.71± 1.92[a]	19.07±0.82[b]

Note: Different lowercase letters in the same soil layer and column indicate significant differences in different planting methods (P<0.05)

In addition to its soil-enhancing properties, *Xanthoceras* contributes to the development of a more resilient ecosystem by creating favorable conditions for microbial activity. This increased biological activity further supports soil health and plant growth. The ability of *Xanthoceras* to improve both the chemical and physical properties of the soil makes it a valuable species in land restoration projects, particularly in marginal lands that have been degraded by desertification and poor land management practices (Figure 3) (Zong et al., 2021).

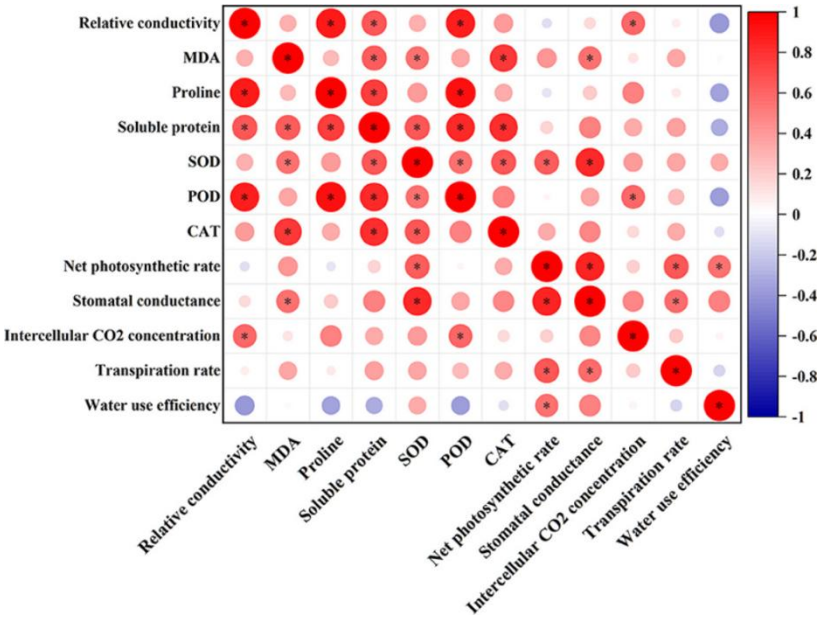

Figure 3 Correlation analysis of physiological, photosynthetic, and antioxidant enzyme activities in *Xanthoceras sorbifolium* seedlings under salt stress (Adapted from Zong et al., 2021)

Image caption: This figure shows the correlations between various physiological indicators, photosynthesis, and antioxidant enzyme activities in *Xanthoceras sorbifolium* seedlings under salt stress. Red indicates positive correlations, blue indicates negative correlations, and the intensity of the color represents the strength of the correlation coefficient. Asterisks indicate significance at the 5% level (Adapted from Zong et al., 2021)

Zong et al. (2021) revealed the physiological adaptation mechanisms of *Xanthoceras sorbifolium* under salt stress conditions. Figure 3 shows that antioxidant enzymes such as SOD, POD, and CAT have significant positive correlations with various physiological indicators, indicating their crucial role in mitigating oxidative damage caused by salt stress. Moreover, the negative correlations between water use efficiency and several physiological indicators suggest a decline in the plant's water regulation ability under salt stress. Combined with the nitrogen-fixing ability and stress resistance of *Xanthoceras sorbifolium*, it holds potential applications in improving saline-alkaline soils. By enhancing soil structure and nutrient cycling, it can contribute to the restoration of saline-alkaline lands and the improvement of agricultural productivity.

4.3 Promotion of biodiversity

Xanthoceras sorbifolium promotes biodiversity by creating a habitat that supports various plant and animal species. By stabilizing the soil and improving microclimatic conditions, *Xanthoceras* facilitates the establishment of other plant species, particularly in degraded areas where vegetation cover is minimal. Over time, this contributes to increased plant diversity, as different species are able to thrive in the protected environment created by *Xanthoceras* windbreaks and sand-fixing belts. Research has shown that species richness and plant diversity are significantly higher in *Xanthoceras*-dominated restoration sites compared to areas without such interventions (Li and Fan, 2010).

Furthermore, the tree provides shelter and food for various wildlife species, including birds and small mammals, which contributes to a balanced ecosystem. Its flowers and fruits serve as a food source, while its dense foliage offers protection from predators and harsh environmental conditions. By supporting a diverse array of organisms,

Xanthoceras plays a crucial role in maintaining ecological balance and promoting the resilience of ecosystems in regions threatened by desertification and land degradation (Ruan et al., 2017).

5 Role of *Xanthoceras sorbifolium* in sustainable agriculture

5.1 Potential for intercropping and crop rotation

Xanthoceras sorbifolium, a versatile tree species, holds significant potential for intercropping and crop rotation, which are essential practices in sustainable agriculture. Intercropping, the practice of growing two or more crops in proximity, can exploit species complementarities to enhance land utilization efficiency. For instance, a meta-analysis on maize and soybean intercropping demonstrated a substantial increase in land equivalent ratio (LER) and fertilizer nitrogen use efficiency (FNER), indicating that intercropping can lead to higher productivity with reduced inputs (Xu et al., 2020; Wang and Li, 2024). Similarly, integrating *Xanthoceras sorbifolium* with other crops could improve land use efficiency by leveraging its unique growth characteristics and nutrient requirements.

Moreover, *Xanthoceras sorbifolium* can be cultivated on marginal lands, making it an excellent candidate for crop rotation systems aimed at restoring soil health and fertility. The tree's ability to thrive in temperate climates and its deep root system can help in breaking pest and disease cycles, improving soil structure, and enhancing nutrient cycling. By incorporating *Xanthoceras sorbifolium* into crop rotation schemes, farmers can achieve a more sustainable and resilient agricultural system that maximizes land productivity while minimizing environmental impacts (Venegas-Calerón et al., 2017).

5.2 Contribution to carbon sequestration and climate change mitigation

Xanthoceras sorbifolium plays a crucial role in carbon sequestration and climate change mitigation, making it a valuable asset in sustainable agriculture. Trees are well-known for their ability to capture atmospheric carbon dioxide and store it in their biomass and soil. *Xanthoceras sorbifolium*, with its substantial biomass production, can significantly contribute to carbon capture, thereby reducing the overall carbon footprint of agricultural practices.

Furthermore, the cultivation of *Xanthoceras sorbifolium* on marginal lands can enhance soil organic carbon levels, which is vital for maintaining soil health and mitigating climate change. The tree's deep root system not only helps in sequestering carbon but also improves soil structure and water retention, making the land more resilient to climate extremes. By integrating *Xanthoceras sorbifolium* into agricultural landscapes, farmers can contribute to global efforts in climate regulation while also benefiting from the tree's various economic and ecological services (Venegas-Calerón et al., 2017).

5.3 Integration of sustainable agriculture with *Xanthoceras* industry development

The integration of sustainable agriculture with the development of the *Xanthoceras* industry can create a circular economy that benefits both the environment and local communities. *Xanthoceras sorbifolium* produces seeds rich in oil, which can be used for biodiesel production, cosmetics, and other industrial applications. The utilization of *Xanthoceras*-derived products not only provides an alternative renewable energy source but also adds economic value to agricultural practices (Venegas-Calerón et al., 2017).

Moreover, the by-products of *Xanthoceras sorbifolium*, such as the extracted meal rich in proteins and essential amino acids, can be used as animal feed or organic fertilizers, further promoting a circular economy. The presence of bioactive compounds like saponins in the seeds also opens up opportunities for pharmaceutical and nutraceutical applications. By developing a robust *Xanthoceras* industry, farmers can diversify their income streams while contributing to sustainable agricultural practices and reducing dependency on non-renewable resources (Venegas-Calerón et al., 2017).

6 Current Status of *Xanthoceras sorbifolium* Cultivation and Industry Development

6.1 Cultivation techniques and management practices

Xanthoceras sorbifolium, commonly known as yellowhorn, is a tree species highly valued for its adaptability and potential as an oil crop. Efficient cultivation techniques are crucial for maximizing its yield and resilience in various environments. High-yield cultivation methods for *Xanthoceras* include selecting high-quality seeds, ensuring optimal planting density, and employing proper pest management practices. In northern China, for example, seed stratification, root cuttings, and seedling planting techniques have proven effective in promoting rapid growth and improving plant survival rates in challenging environments (Feng, 2011). Furthermore, maintaining a well-managed nursery system with adequate watering and fertilization ensures healthy seedlings and reduces mortality rates during the early growth stages.

Pest control is also a vital aspect of *Xanthoceras* cultivation. Various pests such as aphids and caterpillars can damage the trees, particularly in young plantations. Effective pest management practices include monitoring pest populations, using biological control agents, and applying insecticides when necessary. Integrated pest management (IPM) strategies, combining biological and chemical controls, have been successfully implemented to reduce the reliance on pesticides and minimize environmental impact (Chun, 2012). These practices not only improve crop productivity but also contribute to the sustainable cultivation of *Xanthoceras*.

6.2 Current status of the *Xanthoceras* industry in china and abroad

The *Xanthoceras* industry in China is rapidly expanding, particularly in northern regions such as Heilongjiang, Inner Mongolia, and Shaanxi, where the species thrives in arid and semi-arid climates. These regions have become the primary production areas for *Xanthoceras* due to its resilience in poor soil conditions and its ability to tolerate drought and cold. The demand for *Xanthoceras* oil, both for edible purposes and as a biodiesel feedstock, has spurred the growth of the industry, with many farmers transitioning from traditional crops to this more lucrative option (Li and Liu, 2013).

Internationally, *Xanthoceras* is gaining attention as an alternative bioenergy crop. Its potential to produce high-quality oil with relatively low input costs has attracted interest from biofuel industries in countries with similar environmental conditions. Despite its current limited cultivation outside China, there is growing interest in regions with arid climates, such as parts of the United States and Africa. The global market for *Xanthoceras* products, including edible oil and biofuels, is expected to expand as research into its applications progresses, presenting significant opportunities for market growth (Zang et al., 2021).

6.3 Challenges and opportunities for the *Xanthoceras* industry

The development of the *Xanthoceras* industry faces several challenges, particularly in terms of policy support and technology dissemination. One of the main barriers to large-scale adoption is the lack of comprehensive agricultural policies that promote the cultivation of non-traditional crops like *Xanthoceras*. Although the tree has great potential as a biofuel and edible oil source, limited government subsidies and research funding have hindered its broader adoption. Furthermore, the dissemination of advanced cultivation technologies, such as improved pest management and optimized planting techniques, is often restricted to larger commercial growers, leaving small-scale farmers at a disadvantage (Feng, 2011).

Despite these challenges, there are significant opportunities for growth in the *Xanthoceras* industry. As the demand for renewable energy sources and sustainable agricultural practices increases, *Xanthoceras* presents a promising solution for both environmental and economic challenges. The tree's adaptability to marginal lands and its ability to improve soil fertility make it an ideal candidate for large-scale cultivation in regions affected by desertification. With increased policy support and investment in research, the *Xanthoceras* industry could expand rapidly, providing both sustainable agricultural solutions and economic opportunities for rural communities (Zang et al., 2021; Huang, 2024).

7 Future Prospects of *Xanthoceras sorbifolium* Industry and Sustainable Development Potential

7.1 Strategic importance of *Xanthoceras* in China's ecological agriculture

Xanthoceras sorbifolium, a native Chinese plant, holds significant strategic importance in China's ecological agriculture due to its dual ecological and economic benefits. The plant is well-suited for cultivation in marginal lands, which makes it an excellent candidate for sustainable agricultural practices. Its ability to thrive in temperate climates and its high oil content make it a valuable resource for biodiesel production, thus contributing to renewable energy initiatives (Venegas-Calerón et al., 2017; Ma et al., 2020; Xiao et al., 2023). Additionally, the plant's various bioactive compounds have been traditionally used in Chinese medicine, offering potential economic benefits through the development of pharmaceuticals and health products (Chen et al., 2021; Zang et al., 2021). The comprehensive utilization of *X. sorbifolium*, from biodiesel to medicinal applications, underscores its role as a green industry that supports both ecological sustainability and economic growth.

7.2 Global prospects for desertification control using *Xanthoceras*

Globally, *Xanthoceras sorbifolium* presents promising prospects for desertification control and ecological restoration. The plant's adaptability to harsh environmental conditions, such as those found in desertified areas, makes it a valuable tool for combating land degradation. Its deep root system helps stabilize soil, reduce erosion, and improve soil fertility, thereby facilitating the restoration of degraded lands (Figure 4) (Wu et al., 2021). Moreover, the plant's ability to sequester carbon and its role in producing biodiesel contribute to mitigating climate change, further enhancing its ecological restoration potential on a global scale (Zhou et al., 2015; Ma et al., 2020). The expansion of *X. sorbifolium* cultivation in regions prone to desertification could thus play a crucial role in global ecological restoration efforts.

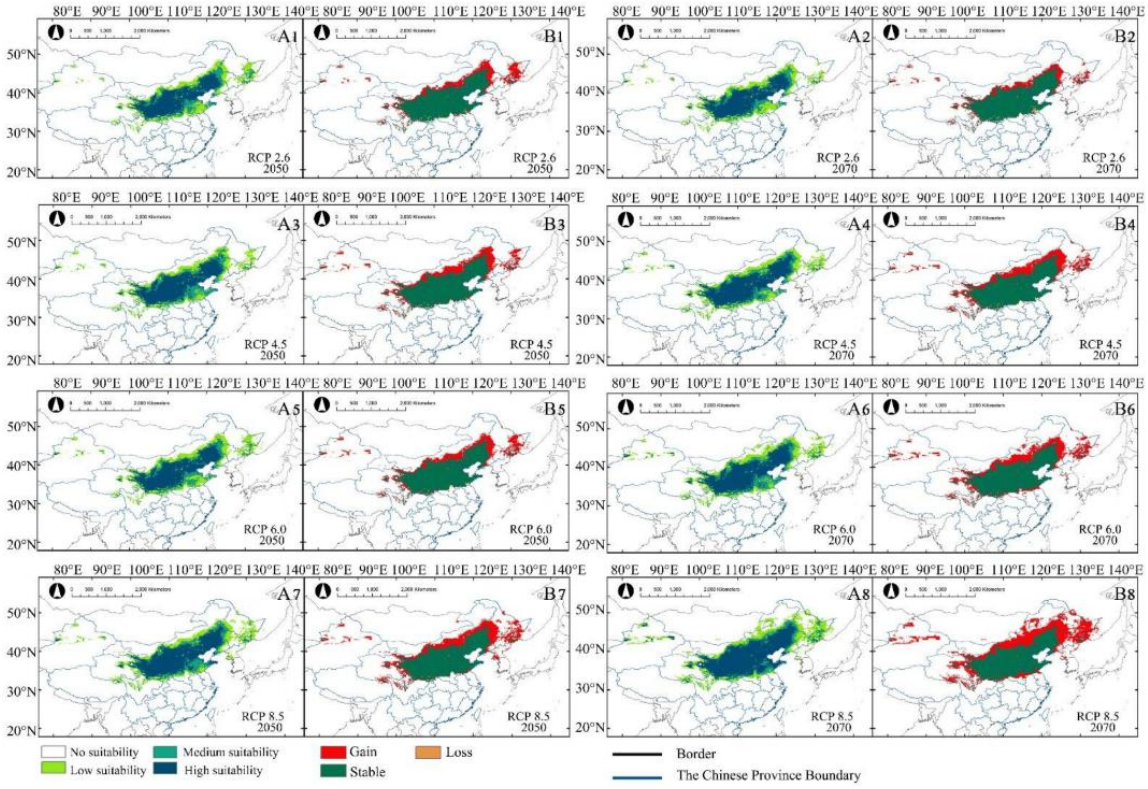

Figure 4 Potential suitable distribution and changes in suitability zones for *Xanthoceras sorbifolium* under different climate change scenarios (2050 and 2070) (Adapted from Wu et al., 2021)

Image caption: A1-A8: Potential suitable distribution of *Xanthoceras sorbifolium* under future climate change scenarios, classified into high, medium, low, and non-suitable areas; B1-B8: Changes in the suitable areas for *Xanthoceras sorbifolium* under future climate conditions, with area gains, losses, and stable regions compared to the current climate scenario represented by different colors. The study covers different climate models (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5) (Adapted from Wu et al., 2021)

In the study by Wu et al. (2021), climate change has a significant impact on the suitable habitat for *Xanthoceras sorbifolium*. By 2050 and 2070, highly suitable areas are projected to expand towards the northeast, while suitability in southern regions is expected to decrease. As global warming progresses, *Xanthoceras sorbifolium* may experience an expanded suitable range in northern China, especially in areas severely affected by desertification. Due to its strong resilience and ability to adapt to arid environments, *Xanthoceras sorbifolium* holds great potential for global desertification control, with its expanded suitable zones aiding in the restoration and sustainable use of desertified lands.

7.3 Future trends in *Xanthoceras* industry development

The future development of the *Xanthoceras sorbifolium* industry is poised to benefit from several key trends, including technological innovation, increasing market demand, and supportive policies. Advances in biotechnology and agricultural practices are expected to enhance the yield and quality of *X. sorbifolium* products, making them more competitive in the market (Zhou et al., 2015; Zhang et al., 2020). The growing demand for renewable energy sources and natural health products is likely to drive market expansion for *X. sorbifolium*-based biodiesel and pharmaceuticals (Chen et al., 2021; Xiao et al., 2023). Additionally, government policies promoting sustainable agriculture and renewable energy are anticipated to provide significant support for the industry's growth (Wu et al., 2021; Zang et al., 2021). These trends suggest a bright future for the *X. sorbifolium* industry, with substantial potential for contributing to sustainable development.

By leveraging its ecological benefits, global restoration potential, and the support of technological and policy advancements, the *Xanthoceras sorbifolium* industry is well-positioned to play a pivotal role in sustainable agriculture and environmental conservation.

8 Concluding Remarks

Xanthoceras sorbifolium, a versatile oilseed tree, has garnered significant attention due to its diverse applications across various industries. The seeds of *Xanthoceras* are rich in oil, particularly unsaturated very long chain fatty acids, which are valuable in the production of cosmetics and biodiesel. Additionally, the seeds contain high levels of proteins and essential amino acids, making them a potential source of nutritional supplements. The presence of saponins, particularly triterpenic saponins, further enhances the medicinal value of *Xanthoceras*, as these compounds are known for their bioactive properties. Beyond its nutritional and medicinal uses, *Xanthoceras* has been traditionally utilized in Chinese medicine for its various health benefits, including improving cognitive functions, stabilizing capillaries, and lowering cholesterol.

Xanthoceras sorbifolium holds significant promise for sustainable agriculture due to its ability to thrive on marginal lands in temperate climates, thus not competing with food crops for prime agricultural land. Its cultivation can contribute to ecological sustainability by preventing soil erosion and promoting biodiversity. Economically, *Xanthoceras* offers multiple revenue streams through its diverse applications. The oil extracted from its seeds can be used in biodiesel production, providing a renewable energy source that can reduce dependence on fossil fuels. The nutritional and medicinal products derived from *Xanthoceras* can cater to the growing demand for health supplements and natural remedies, thereby boosting the economic value of this crop. Furthermore, the variation in seed traits across different geographical regions allows for targeted cultivation strategies to optimize yield and quality for specific applications, enhancing the overall economic viability of *Xanthoceras* cultivation.

In conclusion, *Xanthoceras sorbifolium* is a multipurpose plant with significant potential in sustainable agriculture. Its diverse applications in nutrition, medicine, and renewable energy, coupled with its ability to grow on marginal lands, make it a valuable crop for ecological and economic development. The continued research and development of *Xanthoceras*-based products can further enhance its contributions to a sustainable and prosperous future.

Funding

This study was supported by the 2024 Youth Fund Project of Changchun Sci-Tech University (No.2024C104-01).

Acknowledgments

We thank the anonymous reviewers for their insightful comments and suggestions for the manuscript.

Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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