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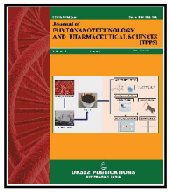

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Breeding of water spinach (*Ipomoea aquatica* Forsk.) for enhanced pharmaceutical properties of leaves: A review

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Abstract

Water spinach (*Ipomoea aquatica* Forsk.) is a highly nutritious leafy vegetable widely cultivated in tropical and subtropical regions. This abstract explores the breeding techniques and pharmaceutical properties of water spinach, highlighting its potential benefits in agriculture and medicine.The breeding of water spinach involves both traditional and modern approaches. Traditional methods focus on selecting high-yielding and disease-resistant varieties, while modern techniques incorporate molecular breeding and biotechnology. Techniques such as micropropagation and tissue culture are employed to rapidly produce elite plantlets and maintain genetic purity. The integration of bioinformatics and genomics aids in identifying key genes responsible for desirable traits, leading to the development of superior cultivars. Water spinach is renowned for its rich phytochemical composition, including phenolic compounds, flavonoids, alkaloids, and terpenoids. These compounds exhibit potent antioxidant, anti-inflammatory, and hepatoprotective properties. The plant is traditionally used to treat various ailments such as diabetes, constipation, liver diseases, and heavy metal toxicity. Recent studies have validated its therapeutic potential, demonstrating its efficacy in reducing oxidative stress and inhibiting cancer cell proliferation. The breeding of water spinach and its pharmaceutical properties offer promising avenues for enhancing agricultural productivity and developing natural remedies for health conditions. Further research and development are essential to fully harness the benefits of this versatile plant.

1. Introduction

Water spinach (*Ipomoea aquatica* Forsk.), commonly known as kangkong, swamp cabbage, or Chinese spinach, is a highly nutritious leafy vegetable that thrives in tropical and subtropical regions. This plant is widely cultivated in countries like China, India, the Philippines, Thailand, and Indonesia due to its ease of growth and versatility in culinary applications (Daniel and Arizona-Sonora, 2021). Water spinach is characterized by its long, hollow stems and tender, broad leaves. It grows quickly and can be cultivated in both aquatic and moist soil environments, making it an excellent crop for various farming systems.This versatile vegetable is widely cultivated in tropical and subtropical regions around the world, especially in countries such as China, India, the Philippines, Thailand, and Indonesia.Its exact origins are somewhat unclear, but it has been a staple in Asian cuisine for centuries, prized for its tender leaves and hollow stems. Whether stir-fried, steamed, or used in soups, water spinach adds a delightful crunch and nutrition to many dishes.

Figure 1: Water spinach plant grown as leafy vegetable.

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Water spinach is a powerhouse of nutrients, providing essential vitamins and minerals. Here are some key components: Rich in vitamin A (important for vision and immune health) and vitamin C (an antioxidant that supports skin health and immune function). Contains significant amounts of iron (vital for blood health), calcium (important for bones), and potassium (crucial for muscle function and heart health). High in phenolic compounds and flavonoids, which help combat oxidative stress. A good source of dietary fiber, aiding in digestion and promoting gut health (Khwankaew *et al*., 2018).

Water spinach is a staple in many Asian dishes and can be prepared in various ways. It is often cooked with garlic, chili, and a splash of soy sauce for a quick and flavorful dish. It adds nutrition and texture to broths and stews.The rich nutritional and phytochemical profile of water spinach offers numerous health benefits such as it helps reduce the risk of chronic diseases by neutralizing free radicals. It can help in managing inflammation and related conditions and promotes regular bowel movements and prevents constipation due to its high fiber content. It also assists in detoxifying the body, supporting liver health and overall wellness. Water spinach is not only a delicious and versatile addition to meals but also a valuable source of nutrition and health benefits. Its rapid growth and adaptability make it a favored crop for small-scale and commercial farming.

2. Origin and genetics

Water spinach has been the subject of various genetic studies to understand its traits and improve its cultivation. Water spinach exhibits significant genetic variability, which is crucial for breeding programs. Traits such as leaf length, leaf width, foliage yield, and dry matter content show high heritability, meaning these traits can be reliably passed on to offspring (Hina *et al*., 2017). Researchers use molecular markers to assess genetic diversity and identify desirable traits. Techniques like random amplified polymorphic DNA (RAPD) markers help in evaluating genetic diversity among different accessions of water spinach. Studies have explored the creation of autotetraploid water spinach (having four sets of chromosomes) using colchicine treatment. This process results in morphological changes such as wider leaves, thicker petioles, and longer stomas. Research has shown that genome doubling in water spinach leads to changes in DNA methylation patterns, which can affect gene expression and plant traits. These genetic studies are essential for developing improved varieties of water spinach with better yield, nutritional value, and resistance to diseases.

Water spinach has an interesting floral biology. The flowers of water spinach are trumpet-shaped, usually white with a mauve center, and about 3-5 cm in diameter. They grow on long, hollow stems that can reach up to 3 meters in length. Water spinach can reproduce both sexually through seeds and asexually through stem cuttings. The seeds are produced in pods that develop after flowering. Water spinach is sensitive to photoperiod, meaning the length of day and night affects its flowering time. It typically flowers under short-day conditions, which can reduce the yield of vegetative tissues. Studies have shown that genes like IaCCA1, IaLHY, and IaTOC1 play roles in the plant's circadian rhythm and photoperiod-dependent flowering. The gene IaFT1 is particularly important for flowering under long-day conditions.

There are two main types of water spinach. Green stem water spinach (Ching quat) has narrow leaves and white flowers. It is usually grown in moist soils. White stem water spinach (Pak quat) has arrow-shaped leaves and pink flowers. It is typically grown in aquatic conditions, similar to rice. Both types are popular in various Asian cuisines and are appreciated for their tender shoots and leaves.

Water spinach flowers come in a few distinct colors, primarily depending on the variety. White is the most common flower color for water spinach, often with a purple or mauve center. Some varieties, especially those with white stems, have pink flowers. Occasionally, flowers can appear more mauve or purple, usually in the center. These flowers are not just beautiful, but also add to the diversity of this versatile plant.

3. Breeding

Water spinach breeding involves several techniques to improve its yield, nutritional value, and resistance to diseases (Gangopadhyay *et al*., 2021). This involves selecting plants with desirable traits such as high yield, disease resistance, and good nutritional quality, and cross-breeding them to produce improved varieties. This method uses genetic markers to identify and select plants with desirable traits more accurately and quickly. It helps in developing high-quality varieties by exploring major genes. This technique involves growing plants in a controlled environment using small tissue samples. It allows for rapid micropropagation and the conservation of elite plant lines. This method is used to screen plants for contaminants and ensure they are safe for consumption. Combining different plant varieties to create hybrids with improved traits, such as thicker stems and longer leaves is reported. These approaches help in identifying genes responsible for desirable traits and using this information to develop better varieties.

4. Nutritional profile

Water spinachis not only versatile in the kitchen, but also packed with nutrients (Table 1).

Table 1: Water spinach nutritional profile per 100 g

Nutrient	per 100 g
Calories	About 20
Carbohydrates	3.1 g
Protein	2.5 g
Fat	0.2 g
Fiber	2.1 g
Potassium	5,458.33 mg
Iron	210.30 mg
Calcium	416.70 mg
Magnesium	301.64 mg
Phosphorus	109.29 mg

Source: Umar *et al*. (2007).

Water spinach is rich in essential vitamins and minerals (Table 2), includingvitamin A, which is crucial for eye health and immune function and vitamin C, an antioxidant that helps in skin health and immune defence. It also contains iron, is vital for blood production

and oxygen transport along with calcium which supports bone health and muscle function and potassium, which helps in maintaining fluid balance and proper muscle contractions. Additionally, water spinach contains antioxidants such as beta-carotene and lutein, which are beneficial for overall health and help in reducing the risk of chronic diseases.

Table 2: Proximate analysis of water spinach

Component	Percentage (%)
Moisture	72.83
Ash	10.83
Crude lipid	11.00
Crude fiber	17.67
Available carbohydrate	54.20
Crude protein	6.30
Energy value (kcal/100 g)	300.94

Source: Adedokun *et al.* (2019).

4.1 Chemical constituents

Water spinach contains a variety of chemical constituents that contribute to its nutritional and medicinal properties. Water spinach is rich in phenolic compounds, which have strong antioxidant properties. These compounds help in neutralizing harmful free radicals in the body (Umar *et al*., 2007). The plant contains flavonoids, which are known for their antioxidant and anti-inflammatory properties. These compounds help in reducing inflammation and improving overall health. Water spinach contains alkaloids, which have various medicinal properties, including antimicrobial and antiproliferative effects. Terpenoidscompounds are known for their anti-inflammatory, antiviral, and anticancer properties. The plant contains essential unsaturated fatty acids like á-linolenic acid, which are beneficial for heart health. Water spinach also contains various amino acids and sugars, which contribute to its nutritional value (Saikia *et al*., 2013) (Table 3).

Table 3: Chemical constituents of water spinach

Chemical constituent	Description
Phenolic compounds	Strong antioxidants that help neutralize free radicals
Flavonoids	Known for their antioxidant and anti-inflammatory properties
Alkaloids	Have antimicrobial and antiproliferative effects
Terpenoids	Possess anti-inflammatory, antiviral, and anticancer properties
Fatty acids	Includes essential unsaturated fatty acids like α-linolenic acid
Amino acids	Contribute to the nutritional value of the plant
Sugars	Provide energy and contribute to the plant's sweetness
Organic acids	Involved in various metabolic processes

Source: Umar *et al.* (2007).

5. Pharmaceutical properties

Water spinach has several pharmaceutical properties and has been traditionally used in various medicinal systems.

5.1 Antioxidant properties

Water spinach contains high levels of antioxidants, including flavonoids and phenolic compounds, which help in neutralizing harmful free radicals in the body. This can help in preventing diseases like cancer, heart disease, and neurodegenerative disorders (Ribo *et al*., 2014).

5.1.1 Phenolic compounds

Water spinach contains significant amounts of phenolic compounds, which are strong antioxidants. These compounds help protect cells from damage caused by environmental pollutants and toxins (Huang *et al*., 2005).

5.1.2 Flavonoids

The plant is rich in flavonoids, which have both antioxidant and anti-inflammatory properties. These compounds help reduce inflammation and improve overall health.

5.1.3 Free radical scavenging

Studies have shown that water spinach extracts exhibit strong free radical scavenging activity. This means they can neutralize harmful free radicals in the body, reducing oxidative stress and potentially lowering the risk of chronic diseases.

5.1.4 Antioxidant activity

Research has demonstrated that both the leaves and stems of water spinach have antioxidant activity, with the stem extract showing higher antioxidant activity compared to the leaf extract.

5.2 Anti-inflammatory effects

The plant has been used traditionally to treat inflammation, fever, and liver malfunctions. Its anti-inflammatory properties can help in reducing swelling and pain.

5.2.1 Phytochemicals

Water spinach contains various phytochemicals, including flavonoids and phenolic compounds, which are known for their anti-inflammatory effects.

5.2.2 Traditional uses

In traditional medicine, water spinach has been used to treat inflammation, fever, and liver malfunctions. Its extracts are believed to help reduce swelling and pain.

5.2.3 Research studies

Studies have demonstrated that hydroalcoholic extracts of water spinach leaves exhibit potent anti-inflammatory activity. These extracts can inhibit the production of inflammatory markers, making them useful in managing conditions like arthritis and other inflammatory diseases.

5.3 Digestive health

Water spinach is known for its laxative properties and is used to treat constipation and piles. It helps in improving digestion and relieving gastrointestinal issues. Water spinach is highly beneficial for digestive health due to its rich nutrient profile and fiber content.

5.3.1 High fibercontent

Water spinach is rich in dietary fiber, which aids in digestion and helps prevent constipation. Fiber adds bulk to the stool, making it easier to pass and promoting regular bowel movements1.

5.3.2 Laxative properties

The mild laxative properties of water spinach help in relieving constipation and other digestive issues. It can be a natural remedy for those suffering from indigestion and piles.

5.3.3 Nutrient rich

Water spinach contains essential vitamins and minerals such as vitamin A, vitamin C, calcium, magnesium, and iron, which contribute to overall digestive health.

5.3.4 Hydration

Being a water-rich vegetable, water spinach helps in maintaining hydration, which is crucial for proper digestion and preventing digestive discomfort.

5.4 Detoxification

The plant is used to treat heavy metal toxicity and opium poisoning. It helps in detoxifying the body and removing harmful substances.

5.4.1 Heavy metal detoxification

Water spinach is traditionally used to treat heavy metal toxicity, such as lead and arsenic poisoning. Its phytochemicals, including flavonoids and phenolic compounds, help in chelating and eliminating these toxic metals from the body.

5.4.2 Liver protection

The plant's antioxidant properties help protect the liver from chemical-induced damage. It modulates detoxification enzymes and scavenges free radicals, promoting liver health.

5.4.3 Jaundice treatment

Water spinach is used in traditional medicine to treat jaundice by supporting liver function and aiding in the removal of toxins from the body.

5.4.4 General detoxification

The high fiber content and nutrient profile of water spinach contribute to overall detoxification, helping to cleanse the digestive system and improve overall health.

5.5 Hepatoprotective effects

Water spinach has been shown to protect the liver and improve its function. It is used in traditional medicine to treat jaundice and other liver-related conditions (Mokhtari *et al*., 2021).

5.5.1 Antioxidant activity

Water spinach contains antioxidants like flavonoids and phenolic compounds, which help neutralize harmful free radicals and reduce oxidative stress in the liver.

5.5.2 Drug-Induced liver damage

Studies have shown that water spinach extracts can protect against liver damage caused by drugs like acetaminophen. The extracts help in reducing liver enzyme levels and preventing liver cell damage.

5.5.3 Traditional uses

In traditional medicine, water spinach has been used to treat jaundice and liver diseases. Its hepatoprotective effects are attributed to its ability to support liver function and detoxification.

5.5.4 Research findings

A study on Wistar albino rats demonstrated that the ethanolic extract of water spinach had significant hepatoprotective activity against carbon tetrachloride-induced liver damage.

5.6 Antiproliferative activity

Studies have shown that extracts from water spinach can inhibit the proliferation of cancer cells, making it a potential candidate for cancer treatment research.

5.6.1 Ethanol extracts

Studies have demonstrated that ethanol extracts of water spinach, particularly from the stems, exhibit significant antiproliferative activity against human lymphoma NB4 cells. The stem extract had the highest activity with an EC50 (effective concentration for 50% inhibition) of 661.40 ± 3.36 $\mu g/ml^{-1}$.

5.6.2 Phenolic compounds

The presence of phenolic compounds in water spinach is believed to contribute to its antiproliferative effects. These compounds have strong antioxidant properties, which help in neutralizing free radicals and preventing cellular damage.

5.6.3 Flavonoids

Water spinach is rich in flavonoids, which are known for their antiproliferative and anti-inflammatory properties. These compounds help in reducing inflammation and inhibiting the growth of cancer cells (Ribo *et al*., 2014).

6. Conclusion

Water spinach (*Ipomoea aquatica* Forsk.) stands out as a valuable crop due to its nutritional and medicinal benefits. Breeding efforts have made significant strides in improving yield, disease resistance, and nutritional quality through both traditional and modern techniques, including molecular breeding and biotechnology. These advances have led to the development of superior water spinach varieties that can cater to the increasing demand for this versatile vegetable. On the pharmaceutical front, water spinach's rich

composition of phenolic compounds, flavonoids, alkaloids, and terpenoids endows it with powerful antioxidant, anti-inflammatory, and hepatoprotective properties. Its traditional uses in treating various ailments, alongside modern scientific validation, highlight its potential as a natural remedy for health conditions such as oxidative stress, inflammation, liver diseases, and even cancer. The combined progress in breeding techniques and the recognition of water spinach's pharmaceutical properties underscore its significance in both agriculture and medicine. Continued research and development are essential to fully exploit the benefits of this remarkable plant, ensuring its contribution to sustainable agriculture and natural health solutions.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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