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Review

Chemical composition, health effects, and uses of water caltrop

Fan Zhu

School of Chemical Sciences, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand

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ABSTRACT

Background: Water caltrop (*Trapa* spp.) has been cultivated for food and traditional medicine in Asia for thousands of years. It is, however, considered as a pest in North America due to the adverse effects on ecological systems. Thus, a better understanding of the chemistry and potential applications of water caltrop may suggest strategies to utilize this aquatic plant.

Scope and approach: This review summarizes the chemical composition, nutritional benefits, processing, and food and industrial uses of different parts of water caltrop from diverse species. The relationships between the components and potential uses of water caltrop are discussed.

Key findings and conclusions: Peels and kernels of water caltrop are rich in starch, dietary fiber, essential amino acids, and certain types of phenolics and minerals, and showed a range of bioactivities such as anti-cancer and antioxidant capacities. Water caltrop has been utilized in diverse food and non-food sectors. There is great potential of water caltrop for various applications due to the unique chemical composition and abundance of supply.

1. Introduction

Water caltrop is a group of annual, floating-leaved aquatic plants belonging to the genus of *Trapa* in the family Lythraceae (Hummel & Kiviat, 2004). Water caltrop is commonly found in freshwater wetlands, lakes, ponds, sluggish reaches of rivers in tropical, and subtropical, and temperate regions (Adkar, Dongare, Ambavade, & Bhaskar, 2014; Hummel & Kiviat, 2004). The floating leaves are usually rhomboid/ovate in shape with a diameter of 2–6.5 cm, dark green above and reddish purple beneath (Adkar et al., 2014). The submerged stems anchor into the mud through branched roots, and can be 1–5 m long (Adkar et al., 2014; Hummel & Kiviat, 2004). It bores starchy fruits with hard peels and horns (Fig. 1).

Trapa genus is sometimes placed in the family Trapaceae (Hummel & Kiviat, 2004). The commonly reported species include *Trapa acornis*, *Trapa bispinosa*, *Trapa incisa*, *Trapa japonica*, *Trapa manshurica*, *Trapa natans*, *Trapa quadrispinosa*, and *Trapa taiwanensis* (Chiang, Li, Huang, & Wang, 2009; Lin, Shen, Ning, Shen, & Das, 2013; Suriyagoda, Arima, Suzuki, & Hoque, 2007). *Trapa* has been categorized into various species by the difference in fruit morphology (e.g., number of horns in the fruit), and some of them may be synonymous (Hummel & Kiviat, 2004; Lin et al., 2013). There is a great variation in vegetative growth, fruit morphology, and yield among diverse *Trapa* species (Suriyagoda et al., 2007). Further efforts from plant biologists are required to address the discrepancy in the taxonomy of water caltrop. Water caltrop is also commonly known as water chestnut or water-nut. It should not be confused with the Chinese water chestnut (*Eleocharis dulcis*), a grass-like sedge in the family Cyperaceae, which is also commonly known as water chestnut (Hummel & Kiviat, 2004). Thus, water caltrop is suggested as the common name of *Trapa* spp. for scientific research in order to avoid any confusion.

The fruit of water caltrop contains diverse nutrients including starch and protein. It has been used as food and medicinal materials in China and India since ancient times. The Rites of Zhou (a book appeared in the 2nd century BC in China) recorded that "a worshipper should use a bamboo basket containing dried water caltrops" (Adkar et al., 2014). Ancient Chinese medicinal books suggested that the peels of water caltrop can help to combat a range of diseases such as diarrhea and alcohol-poisoning (Sheng, Sun, & Shan, 2006). Water caltrop is also a useful plant in the Indian Ayurvedic system of medicine, and an important food item known as "singhara" (Adkar et al., 2014). The nutritional and pharmacological properties of *T. bispinosa* have been reviewed (Adkar et al., 2014). Despite these uses, upon the introduction to North America in the 1800s, water caltrop becomes a nuisance. It is also classified as a noxious weed in Australia. Water caltrop displaces other submergent aquatic plants, interferes with boating, fishing, and swimming, and depletes dissolved oxygen which adversely

E-mail address: fzhu5@yahoo.com.

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Fig. 1. *T. bispinosa* fruit (above) and kernel (below) (Tulyathan et al., 2005).

influences fish communities (Hummel & Kiviat, 2004). For example, high density growth of water caltrop can lead to the interception of 95% of incident sunlight. This causes the destruction of other submerged vascular plants and their associated fauna and flora (Hummel & Kiviat, 2004). Review of world literature suggested that water caltrop can be utilized for diverse food and energy applications, as well as for fish habitat and recreation even in North America (Hummel & Kiviat, 2004). Indeed, there is growing interest in developing and utilizing water caltrop for food applications in Asia (Hoque, Davey, & Arima, 2009; Sheng et al., 2006). Diverse food products (e.g., jam, biscuit, and beverage) with water caltrop as a major ingredient can be found in niche market in China (Sheng et al., 2006). Machinery for removing the peels from the kernels is commercially available there. Water caltrop can also play a significant role in food security, especially in regions (e.g., Bangladesh) regularly affected by flood (Hoque et al., 2009). Therefore, exploring the potential applications of this aquatic plant, especially the peels which are considered a waste, can provide an economically viable source of food, medicine, and energy (Chiang & Ciou, 2010; Hummel & Kiviat, 2004).

This review summarizes the chemical composition, nutritional properties, processing, and food and nonfood applications of water caltrop from diverse species, with an aim to provide a basis to comprehensively utilize this crop.

2. Chemical composition

2.1. Starch

Starch, the major component of water caltrop (Gani, Haq, Masoodi, Broadway, & Gani, 2010; Hizukuri et al., 1988; Shafee & Sarin, 1937; Murty, Choudhury, & Bagchi, 1962; Tulyathan, Boondee, & Mahawanich, 2005), may amount over 80% of the kernel's dry weight (Chiang et al., 2009). The starch isolation methods from different reports are rather similar. Briefly, the peel and pericarp of water caltrop are removed, and the kernels are cut into small pieces. The resulting pieces in aqueous solution containing alkaline (e.g., 0.2%) or potassium metabisulphite (e.g., 0.1%) are ground in a blender. The slurry is filtered and centrifuged. The washing steps are repeated and the resulting samples are dried to obtain the purified starch.

Diversity in granule morphology and crystallinity, amylose content, functional properties, and enzyme and acid susceptibility has been observed among different species (Chiang, Li, Huang, & Wang, 2007; Gao et al., 2014; Tran, Lee, & Park, 2013). Starch contents of *T. quadrispinosa* and *T. taiwanensis* kept increasing during a 49 day growth period (from 19.2 to 79.4% for the former and 12.3–74.8% for the latter) (Chiang et al., 2009). The amylose contents from diverse studies ranged from 19.5% (*T. natans*, measured by amperometric titration-based method) (Lertphanich et al., 2013) to 47.1% (*T. bispinosa*, measured by iodine-binding spectrophotometry-based method) (Tran et al., 2013). The amylose contents of *T. quadrispinosa* and *T. taiwanensis* increased during a 49 day growth period (from 26.8 to 38.4% for the former and 25.9–40.2% for the latter) (Chiang et al., 2009).

Starch granules from *T. natans* appeared oval with an average size of 22 μm (Lertphanich et al., 2013) (Fig. 2a). The size increased from 1–3 μm to 15–30 μm during a 49 day period of growth (Chiang et al., 2009). The polymorphism of granules, revealed by wide-angle X-ray diffraction, was A-type (*T. taiwanensis* and *T. quadrispinosa*) (Chiang et al., 2007; Wang, Chiang, Li, & Huang, 2008), or C_A-type (*T. quadrispinosa*, *T. bispinosa*, and *T. pseudoinisa*) (Gao et al., 2014). During growth, the starch polymorphism remained the same (Chiang et al., 2007; Wang et al., 2008). Unit chain length distribution of amylopectin from *T. natans* was analyzed by high-performance anion-exchange chromatography, and was compared with that of cassava, taro, yam bean, ensete, mungbean, and chickpea starches (Lertphanich et al., 2013). *T. natans* amylopectin had a relatively low amount of chains with DP 6–12 and a high amount of chains with DP 13–24.

Physicochemical properties of water caltrop starch have been compared with other types of starches (Chiang et al., 2007; Wang et al., 2008). Starch of *T. natans* had higher breakdown and setback of pasting and lower enthalpy change (ΔH) of gelatinization, than maize and potato starches (Singh, Bawa, Riar, & Saxena, 2009; Singh, Bawa, Singh, & Saxena, 2009). Pasting, rheological, and thermal analysis showed *T. natans* starch had relatively high pasting and gelatinization temperatures, compared with cassava, taro, yam bean, ensete, mungbean, and chickpea starches (Fig. 2b). Starch from a high-amylose variety of *T. bispinosa* from Vietnam (amylose content: 47.1%) had two endothermic peaks at 73.6 and 80.7 °C in the thermogram of differential scanning calorimetry (DSC) (starch to water ratio at 1:3) (Tran et al., 2013). This starch had a strong gel forming capacity, a high storage modulus (G') of rheological analysis, and high final viscosity of pasting, due to the high amylose content (Tran et al., 2013). The properties of water caltrop were also affected by the growing period. Swelling power, solubility, temperature, peak viscosity, final and setback viscosity of pasting, temperatures and ΔH of gelatinization (DSC) of starch increased during growth (Chiang et al., 2007; Wang et al., 2008).

The potential abundant supply and the unique properties and structures of water caltrop starch suggest an alternative source for specialty starch. As the starch is a major component of water caltrop food products, the properties and structures of starch should be better understood. Potential topics such as structure–property relationships and digestion of starch can be explored.

2.2. Dietary fiber

Dietary fiber has protective effects against coronary heart disease, stroke, hypertension, obesity, diabetes, and certain gastrointestinal diseases (Anderson et al., 2009). Water caltrop peel is considered a source of dietary fiber, which amounted over 70% of the peels of *T. taiwanensis* (dry basis) (Chiang & Ciou, 2010). Lignin is dominant, followed by hemi-cellulose and cellulose (Chiang &