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Totora (*Schoenoplectus californicus* (C.A. Mey.) Soják) and its potential as a construction material

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ABSTRACT

Totora is an emergent macrophyte with properties and historical uses supporting its potential use in contemporary construction and for reducing pressure on conventional forest plantations by diversifying the sources of biomass-based materials. Recent advances in the wood construction field have demonstrated the feasibility and advantages of using wood-based materials in tall building structures and other massive constructive uses, which could lead to a net reduction in CO_2eq emissions from the construction sector by replacing high-energy consuming materials such as concrete or steel with wood and biomass-based materials. Among these biomass-based materials are non-timber forest products. This category includes plants that can provide important contributions to the construction sector by diversifying the sources of biomass-based materials. One of these plants is totora (*Schoenoplectus californicus* (C.A. Mey.) Soják). Totora is a bulrush that grows in lakes and marshes in the Americas, from California to Chile, and some of the Pacific islands. This bulrush has been used by many cultures as medicine, food, forage, and material for building houses, boats, and different handicrafts. Although several people still use totora to make their handicrafts and rafts, the most important current examples of the use of totora are the floating islands of the Uros in Lake Titicaca. The Uros people have developed traditional techniques for building their homes, boats, and even the artificial islands where they live, with methods based almost exclusively on the totora culms. The studies and experimentation conducted on this plant have underscored its fast growth capacity, high yield values, anatomical and physical properties, and potential environmental benefits. This review aims to analyze the available data on this material regarding its potential for construction, which is intended to foster its research and development as an alternative source of a biomass-based building material.

1. Introduction

The increasing number of massive wood building projects has raised discussions on how environmentally friendly and how feasible is to replace materials such as concrete or steel with engineered wood and wood-based materials in the long term (Green and Karsh, 2012; Intergovernmental Panel on Climate Change, 2014). Studies have shown that some engineered wood elements can perform as well as concrete or steel in tall buildings (Podesto and Breneman, 2014; Popovski and Gavric, 2016; Ramage et al., 2017). Although wood construction has been demonstrated to be environmentally beneficial in comparison with concrete or steel, the demand for wood products is expected to rise threefold by 2050, which is expected to increase pressure on land and water resources that must concurrently provide the growing human population with food, urban area and other resources (FAO, 2015; García-Navarro et al., 2013; Intergovernmental Panel on Climate Change, 2014; World Wildlife Fund, 2012).

In this scenario, non-timber forest products, which include palms, herbaceous plants, bulrushes and reeds, among others, are an important source of biomass-based materials that can be studied to diversify the assortment of low-energy and biomass-based construction materials. Several studies have been conducted to examine these types of plants, assessing their feasibility for sue in the construction field and their environmental benefits (Bajwa et al., 2015; Flores et al., 2011; Hidalgo C., 2016; Wichmann and Köbbing, 2015). The non-timber-forest-products category includes totora (*Schoenoplectus californicus* (C.A. Mey.) Soják), which is a bulrush from the *Cyperaceae* family that grows in the Americas, from California (37°N, 120°W) to Tierra del Fuego (54°S, 70°W), and some of the Pacific islands such as the Cook Islands (21.23°S, 159.77°W), Eastern Island (27.11°S, 109.28°W), New Zealand (37.39°S, 174.72°E), and Hawaii (19.77°N, 155.57°W) (de Lange et al., 2008; Heiser, 1978; López et al., 2016). The taxonomy of totora has

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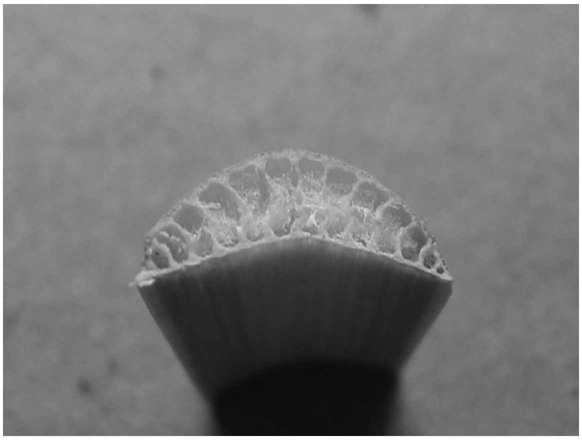

Fig. 1. *Typha latifolia* leaf section (Hidalgo-Cordero).

been studied to define if there are differences between individuals from different locations. The observations of different chromosome numbers and physical differences may support the existence of subspecies or varieties (Barros, 1942; Beetle, 1941; Heiser, 1974; Koyama, 1963). In the available literature, totora has been identified under different taxa names, e.g., *Scirpus californicus var. tatora* (Kunth) Barros, *S. californicus subsp. Tatora* (Kunth) T. Koyama, and *Schoenoplectus tatora* (Kunth) Palla. However, in the database of the Word Checklist of Selected Plant Families (WCSP), to date, these other names are considered synonymous to *Schoenoplectus californicus* (C.A. Mey.) Soják, (Heiser, 1978; WCSP, 2017). In some cases, the term totora has been used to designate some plants of the *Typha* species, another emergent macrophyte species with similar leaves to the culms of *Schoenoplectus californicus* (C.A. Mey.) Soják (Heiser, 1978; Heredia, 2014). Although in some cases, these two species have been used in similar ways, the differences are notorious. *Typha* leaves are thinner, and their sections are semi-circular (Fig. 1).

In contrast, *Schoenoplectus californicus* (C.A. Mey.) Soják is bigger, stronger, and has a round-to-triangular-shaped culm (Fig. 2). Different local names are used to refer to this plant, such as the term "tule" in California, Mexico, and some parts of Central America; or the term "piri" in Brazil (Dick et al., 2016; Heiser, 1978). In this review, the term "totora" will refer to the *Schoenoplectus californicus* (C.A. Mey.) Soják species.

In Lake Titicaca, where totora is an important part of the ecosystem, besides its social and economic importance for the local communities, institutions of Peru and Bolivia, the Autoridad Binacional del Lago Titicaca (ALT), and the United Nations Program for Development (PNUD) have worked on the development of projects aimed to research and improve the local management of this resource. The most relevant projects and institutions in this sense are the Proyecto Especial Binacional del Lago Titicaca (PELT), Fundación Medio Ambiente, Minería e Industria (MEDMIN), Asociación para el Desarrollo Sustentable (ADESU), Asociación Boliviana de Teledetección para el Medio Ambiente (ABTEMA), and Unidad Operativa Boliviana (UOB).

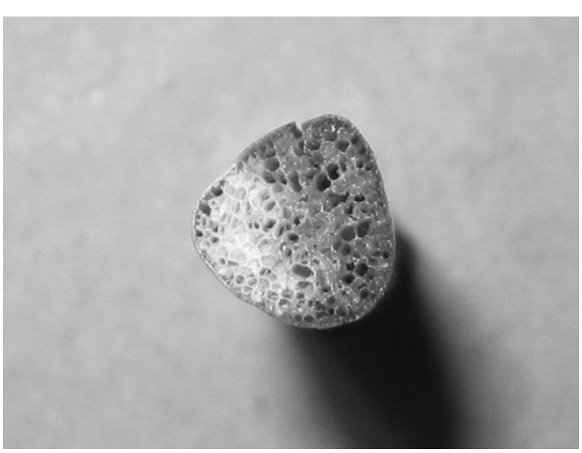

Fig. 2. *Schoenoplectus californicus* (C.A. Mey.) Soják culm section (Hidalgo-Cordero).

Typha species, which are broadly distributed worldwide, have been more extensively researched and studied for applications in the construction field (Kim et al., 2016; Wuzella et al., 2011). The procedures used in these studies could be a guide to develop and evaluate methodology that is applicable to totora and extend the results to other similar species.

Totora grows in lakes and marshes and achieves its best development in depths of 30–70 cm. However, in Lake Titicaca, it can grow in water depths up to 5 m (Collot, 1980; Gilson, 1937; Iltis and Dejoux, 1991). It can yield up to 57.90 t/ha/year of dry matter, depending on the substrate nutrients, location, and climate, as shown in Table 1 (Collot et al., 1983; de Lange et al., 2008; Heiser, 1978; Neill, 2007; Pratolongo et al., 2008).

This maximum yield capacity is high compared with the data obtained for the maximum over-bark yield of conventional planted forests from the Food and Agriculture Organization of the United Nations (FAO) report on Global Planted Forests (FAO, 2006), as shown in Fig. 3. Totora's fast growth makes it possible to harvest it twice a year for use in construction, guaranteeing a constant source of material supply from a relatively small plantation area (ABTEMA and UOB, 2000; Collot et al., 1983; Mardorf, 1985; PELT, 2000a; PELT and ADESU, 2003; Rodriguez, 2010). The sun-dried totora, when kept dry, is not prone to attack by biological agents, which can be observed on dry totora stalks or on traditional objects such as esteras that can last for decades when they are protected from extreme moisture (Hidalgo-Cordero and García-Navarro, 2017; PELT, 2000a; Simbaña, 2003).

These features stimulated several ancient cultures to use totora as food, forage, medicine, and for making a wide range of objects from rugs to huts (Hall, 2009; Heiser, 1978; Margolin, 1978). Nevertheless, the most important example of current use of totora is presented by the complex of the Uros Islands in Lake Titicaca (15.81°S, 69.96°W). The Uros' constructive practices depend almost exclusively on the totora culms, which are virtually the only material available in abundance in the lake. Uros people use the totora bundled, weaved, or braided to build their houses, boats and artificial floating islands where they have lived for more than 500 years (Banack et al., 2004; Macía and Balslev, 2000). Despite the intensive use of totora by some communities, the available data on its constructive applications are still scarce and widely scattered. This review includes information obtained from books, primary sources, direct observation, peer-reviewed sources, gray literature, videos, and web sources.

This review is intended to provide a background for assessing the potential of totora as an alternative biomass-based source of material that could be used in the contemporary construction industry, and the potential environmental benefits or impacts of its usage in each context.

2. Anatomy

Totora is an emergent wetland macrophyte that has roughly three identifiable parts with different characteristics as follows: the roots, submerged culm and aerial culm (Corsino et al., 2013).

The root system consists of rhizomes that grow parallel to the substrate. The rhizome has nodes every 2–6 cm, from which the culms grow vertically. The roots system develops as a net-like structure that stores nutrients and helps the plant survive during dry seasons and adverse conditions (Honaine et al., 2013; PELT and ADESU, 2003). This netlike structure can be 0.50–3-m thick depending on the plant age and is intended to provide the plant with a stable support for growth (PELT and ADESU, 2003). When the water level of the lakes increases, these root blocks, which often contain air bubbles because of the aeration