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Review

An overview of odoriferous marine seaweeds of the *Dictyopteris* genus: insights into their chemical diversity, biological potential and ecological roles

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ABSTRACT

Since the middle of the twentieth century the marine algae have attracted attention as a source of new drugs. *Dictyopteris* is an important group of marine seaweeds and is widely distributed in tropical, subtropical and temperate regions. This genus is known by its characteristic "ocean smell". Some species show a distinct phytochemistry, with specific secondary metabolites, including C_{11}-hydrocarbons, sulfur compounds and quinone derivatives, not usually found in marine seaweeds and described for the first time in the literature. Furthermore, several terpenes, steroids and halogenated compounds have been described. This chemical diversity gives it interesting biological properties, including cytotoxic, antimicrobial, antioxidant, anti-inflammatory and anti-herbivory activities. These findings highlight the importance to continue investigations on this genus and the need to compile the data available so far, since the species are quite heterogeneous, notably in relation to the chemical constitution. This paper reviews the literature on the *Dictyopteris* genus, focusing on its secondary metabolites and biological activities, in order to build the base for further studies.

Introduction

More than 70% of the earth's surface is covered by ocean, an enormous ecosystem that is a source of novel opportunities in the field of biotechnology. Marine secondary metabolites have demonstrated outstanding structural and functional diversity related to their different metabolic pathways (Shanura Fernando et al., 2016). Some current applications for high-value marine-derived products are in drug discovery, antifoulants, biofilm inhibitors, bioremediation, human and animal tissue repair, nutraceuticals, and personal care products (Allen and Jaspars, 2009).

While the fragrances of terrestrial plants have attracted the attention of man since antiquity, these odors being associated with monoterpenes, phenols, and simple aliphatic esters, the fragrance of marine plants is much less familiar, and relatively few marine plants possess odor (Moore, 1977). A typical "sea-breeze" fragrance has interesting nuances for perfumery, eliciting a sense of peace, well-being and lightness. The trend in marine fragrances is relatively recent compared to other scents used in traditional perfumery (Oigman et al., 2015), such as amber and musk, which are perhaps the oldest fragrances, and have been used since ancient times, in religious traditions, cultures, cuisine, and beautification. The chemistry of marine fragrance is mainly associated with four groups of organic compounds of natural or synthetic origin: cyclic and alicyclic C_{11}-hydrocarbons (which act as pheromones); polyunsaturated aldehydes from the degradation of fatty acids; synthetic benzodioxepanes (such as Calone 1951®, an unusual structure that was patented by Pfizer in 1969); and halogenated phenols, which is believed to be the main component in the flavor of several seafoods (Oigman et al., 2015).

Marine macroalgae (seaweeds) are multicellular photosynthetic organisms, belonging to the lower plants category. These organisms are thallophytes, which means that they are constituted by leaf-like thallus instead of roots, stems, and leaves. According to the specific combination of photosynthetic pigments, they can be classified into three groups: green (Chlorophyta, mainly chlorophyll *a* and *b*), brown (Phaeophyceae, mainly chlorophyll *a* and *c*, β-carotene and xanthophylls) and red algae (Rhodophyta, mainly chlorophyll *a*, phycoerythrin and phycocyanin) (Reviers, 2006).

The brown algae of the genus *Dictyopteris* are among the few odoriferous types of seaweed (Pettus Jr. and Moore, 1971). These

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species contain C_{11}-hydrocarbons, which are structurally similar to sexual attractants and act as odoriferous compounds. In this context, due to its spicy taste and agreeable odor, *D. plagiogramma* (known as "limu lipoa") has been used by Hawaiians instead of pepper and sage, as a condiment with raw fish and other foods (Pettus Jr., 1971; Moore, 1977). Some patents have also been registered for formulations containing its odoriferous compounds (Chapuis, 1992; Gaudin and Morel, 1992; Kajiwara et al., 2003).

The genus *Dictyopteris* J.V. Lamouroux (from Greek *Dictyon* = network, and *Pteris* = fern) was first proposed by Lamouroux in 1809 (Nizamuddin and Saifullah, 1966) and belongs to the Dictyotales order (Silberfeld et al., 2014). It includes species with flattened, generally dichotomously branched thalli with a distinct central midrib. Thalli are attached by a matted rhizoidal holdfast, up to 60 cm long, subdichotomously to laterally branched, branches 0.5–25 mm broad. Growth is via a row of meristematic cells that lie in a shallow depression on the branch apex. The genus comprises 35 species and considerable morphological and anatomical variation may occur between the small and the larger robust species (Phillips and Huisman, 1998; Guiry and Guiry, 2018).

The species are widely distributed in oceans of tropical, subtropical and temperate regions (Nizamuddin and Saifullah, 1966; Guiry and Guiry, 2016). Fig. 1 shows the geographic distribution of eighteen *Dictyopteris* species, which have already been studied for their chemical and biological properties. Fig. 2 shows two *Dictyopteris* species (*D. plagiogramma* and *D. jolyana*).

The review is organized into three main sections. The first section covers its chemical diversity (focusing on C_{11}-hydrocarbons, sulfur compounds, terpenes, meroditerpenes, halogenated compounds and sterols), followed by the first reports and context of its discovery. The subsequent section covers further chemical and biological reports by species.

Methods

A literature search was conducted covering the period from January 1951 to December 2017, using the keywords "Dictyopteris" and all the names of the individual species, including synonyms. Searches were conducted on the electronic databases Web of Science, Scopus, Springer, Science Direct, Pub Med and Google Scholar. Reference lists of the identified papers were also searched, and additional research traced online. Inclusion criteria were papers reporting the isolation or identification of compounds and biological activities related to the *Dictyopteris* genus.

Chemical diversity

A number of investigations have demonstrated a wide chemical diversity for the species of the *Dictyopteris* genus that showed interesting biological activities, which are presented in Box 1. Isolated metabolites from the genus include C_{11}-hydrocarbons and their derivatives, terpenes, meroditerpenes, sulfur compounds,

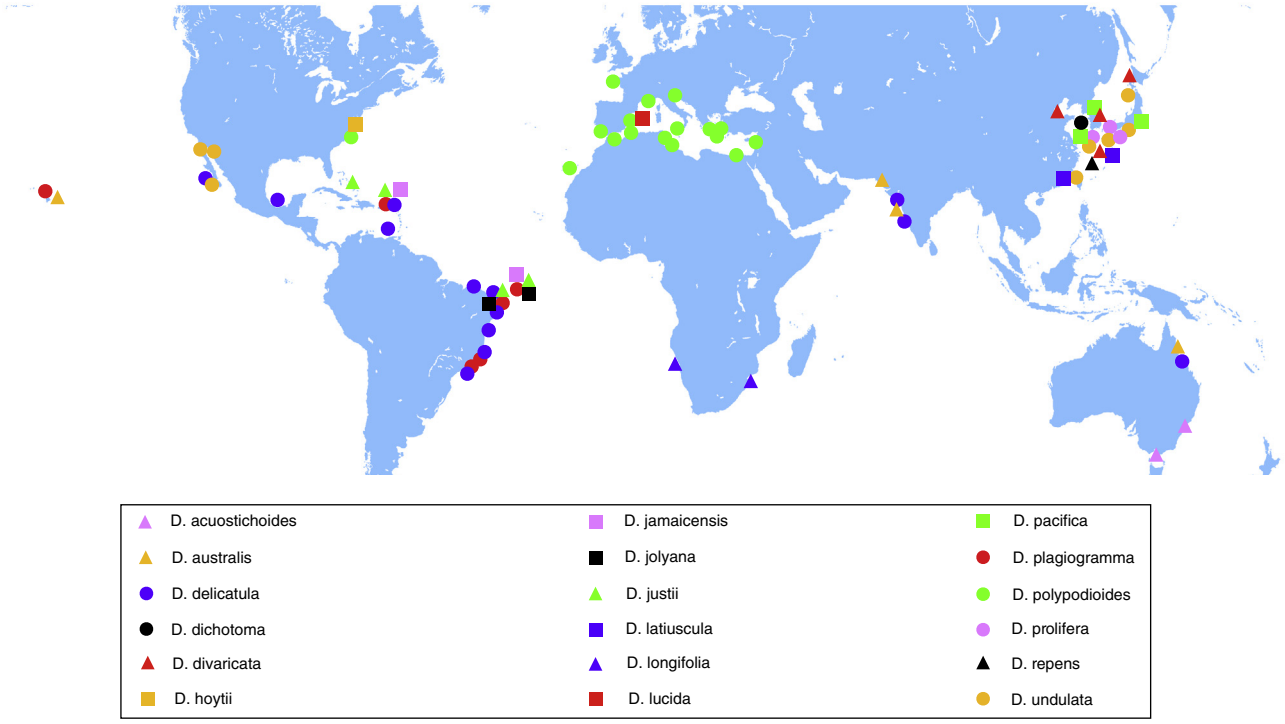

Fig. 1. Geographic distribution of *Dictyopteris* species which have already been studied for their chemical and biological properties.

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