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Review

Biological properties and pharmacological potential of plant exudates

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ABSTRACT

Exudates released from plants, consist of complex mixtures of organic and inorganic molecules that have been used in traditional medicine from several years. They may vary among genera, species or within a genus and mainly include latex, sap, gums, resins, seed or root exudates. Plant exudates are known to possess several biological activities including, antimicrobial, anti-inflammatory, antioxidant, wound healing and anti-nociceptive. Exudates oozed out from plants have also been used as ingredients in medicines, food, perfumes and cosmetics. The present review provides brief overview about the exudates released from plants, their biological properties and beneficial effects for human beings. Due to the presence of various compounds, different methodologies and procedures have been employed for their collection and analyses. Literature studies suggest that plant exudates have extensive therapeutic potential for curing diseases with minimal toxic effects. This aspect could be taken into account in prospective studies regarding the search of new products derived from plant exudates with pharmaceutical value.

1. Introduction

Traditional medicines derived from various plants species have been frequently used in daily health care system in developing countries since a long time (Breitbach, Niehues, Lopes, Faria, & Brandao, 2013; Ferreira et al., 2014; Júnior & Pinto, 2005). Knowledge obtained from ethnopharmacological studies have been employed to cure several diseases in traditional system of medicine and also known as the efficient means for drug discovery. The resurgence of public interest for plant based natural compounds due to their lesser side effects and better compatibility with the human body has resulted in finding out alternative ways to obtain bioactive compounds, which could be effective and safe as compared to synthetic drugs (Malik et al., 2011; Malik, Mirjalili, Fett-Neto, Mazzafera, & Bonfill, 2013; Malik, Bhushan, Sharma, & Ahuja, 2014; Malik, Biba, Gruz, Arroo, & Strnad, 2014; Gallego et al., 2017). The widespread use of synthetic drugs has resulted in development of resistance against the pathogens. It has become one of the world's most serious public health problems (Gumz, Schoneweg, & Arcanjo, 2015; Varaldo, 2002; Wise, 2003). It is difficult to eradicate some pathogenic bacteria and in several cases, use of more than one antibiotic is required, which may leads to side effects and other problems (Golkar, Bagasra, & Pace, 2014; Gould & Ball, 2013; Malfertheiner et al., 2007).

Natural products, mainly from plants represent potential alternative to treat various diseases caused by micro-organisms. The use of plants for therapeutic purposes is based on popular and scientific knowledge. These are also acts as suppliers of isolated active substances, such as total or purified extracts (Atanasov et al., 2015; Carmona & Pereira, 2013). Phytotherapeutic remedies are cost-effective with minimal toxicity and reduced health risks. These are also readily available in the market as compared to synthetic drugs (Khandaker, Sajan Das, Akhter, & Shahriar, 2016).

Among various plant- derived natural bioactive compounds, exudates employed routinely for primary health care in developing countries (Joy, Thomas, Mathew, & Skaria, 1998). These are the complex mixtures of large and small molecules, including carbohydrates, proteins, amino-acids, volatile compounds or inorganic ions released from healthy plants during the process of exudation (Mirhosseini & Amid, 2012; Neumann & Römheld, 2007; Uren, 2007). Exudates are known to possess several medicinal properties and have also been used as ingredients in medicines, food, perfumes and cosmetics (Iqbal & Fry, 2012). They may vary greatly among genera, between species or within a genus, and their function in plants is not fully understood (Boer & Ella, 2000). Certain legumes exude specific flavonoids and isoflavonoids, which activate genes responsible for nodulation and promote chemotaxis (Bais, Weir, Perry, Gilroy, & Vivanco, 2006; Hassan & Mathesius, 2012). Other members of family *Poaceae* exude carbohydrates and amino acids that are energy sources and nutrients for

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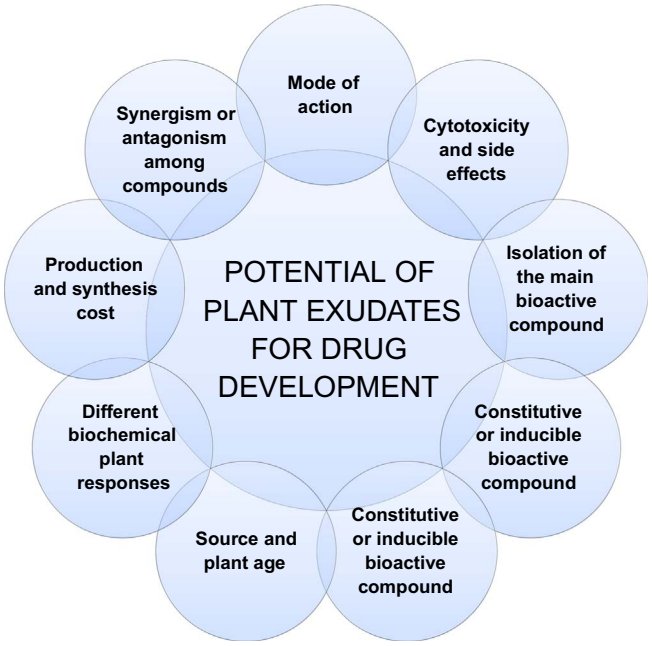

Fig. 1. Various factors to be taken into account in assessing the potential of plant exudates for drug development.

microorganisms thus increasing the population of plant growth promoting bacteria in rhizosphere (Gray & Smith, 2005; Souza, Ambrosini, & Passaglia, 2015). Weert et al. (2002) found that exudation of some organic acids, such as malic, pyroglutamic, succinic and fumaric acid and amino acids including; L-aspartic acid, L-glutamic acid, L-isoleucine, L-leucine and L-lysine by tomato plants influence flagellar motility of *Pseudomonas fluorescens*. The substances released during exudation may exert a chemo-attractant effect on microorganisms present in soil or even prevent the seed from being colonized by phyto-pathogens (Lugtenberg, Rozen, & Kamilova, 2017; Ma, Oliveira, Freitas, & Zhang, 2016; Nóbrega, Santos, Cunha, Carvalho, & Gomes, 2005; Okubara & Paulitz, 2005). We are not describing here this subject in detail since there are number of excellent reviews published during the last decade on interaction between plant exudates and microbes (Baetz & Martinoia, 2014; Huang, Chaparro, Reardon, & Zhang, 2014; Walker, Bais, Halligan, Stermitz, & Vivanco, 2003).

Ethnopharmacological studies have indicated the use of plant exudates in traditional medicines but there are only a few scientific records or merits of these products. Fig. 1 depicts the various factors need to take into account in order to use plant exudates for drug development. Root exudates are the most studied compounds but in relation to understand the interactions between plants and microbial communities in the rhizosphere or for molecular mechanisms (Badri & Vivanco, 2009; Deshpande, Pontaroli, Chaluvadi, Lu, & Bennetzen, 2011; Doornbos, Van Loon, & Bakker, 2012; Huang et al., 2014; Semchenko, Saar, & Lepik, 2014; Walker et al., 2003). Although, there are scientific reports discussing about the therapeutic potential of exudates released from plants but there is no any detailed review focusing on the medicinal uses of plant exudates. Therefore, the aim of present paper is to assess the various biological activities and pharmacological potential of plant exudates. Different types of exudates released from plants, their method of collection and analyses are described. All the available reports on various activities of plant exudates including; antimicrobial, anti-inflammatory, antioxidant, wound healing, anti-nociceptive will be discussed in detail. Future prospects of these plant exudates for drug discovery and various factors concerning them are highlighted.

1.1. Different types of exudates released from plants

Depending on the physical and chemical characteristics, exudates are generally classified as resins, sap, latex or gums (Coppen, 1995; Langenheim, 2004). Additionally, there are other plant exudates such as seed exudates and root exudates. Latex, also known as milk sap is a cytoplasmic exudate of specialized cells, called laticiferals (Konno, 2011; Rudall, 1987). The chemical composition of latex acts as a defense to fight against fungi and viruses through its constituents (Pereira, Valdirene, Fernandes, Maurício, & Xavier-Filho, 1999). More than 20,000 plant species from over 40 families exude latex, which accounts for about 8.9% of all angiosperm plants (Lewinsohn, 1991). The best-known example is latex obtained from rubber, which has solids content over 50% of the weight of latex. Latex contains a variety of chemicals, such as terpenoids, alkaloids, rubber, cardenolides as well as various proteins and enzymes; such as proteases, chitinases, and glucosidases (Konno, 2011). Some chemical compounds in latex, such as morphine (an alkaloid from poppy latex) and cardenolides (from milkweed latex) show apparent toxicity against animals, including insects (Konno et al., 2004, 2006; Ramos et al., 2007, 2010; Wasano et al., 2009). Such toxic chemicals are suggested to have defense roles (Farrell, Dussourd, & Mitter, 1991). Some of the species that produce latex include: *Asclepias syriaca* L. (milkweed), *Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg. (rubber tree) and *Lactuca sativa* L. (Dussourd, 1995; Dussourd & Eisner, 1987).

The resins are solid or semisolid amorphous materials, generally comprising a complex blend of organic compounds called terpenes. They are insoluble in water but soluble in certain organic solvents (Lambert, Heckenbach, Wu, & Santiago-Blay, 2010; Langenheim, 2004; Paparozzi, 2005). They can occur in almost any organ or tissue of the plant species (Rikkinen et al., 2016). Important families that produce resins are: *Burseraceae*, *Dipterocarpaceae*, *Leguminosae* (mainly, *Caesalpinioideae*), *Styracaceae* and two families of conifers, each with an important resin producing genus, *viz*. *Araucariaceae* (*Agathis*) and *Pinaceae* (Lambert et al., 2010).

Vegetable gums are solids consisting of mixtures of polysaccharides, which are water soluble or absorb water and swell to form a gel or gelatin, when placed in water (Bhosale & Osmani, 2014; Yang & Zhang, 2009). They are translucent and amorphous substances often produced by plants as a protection after an aggression (Buckeridge, Tiné, Santos, & Lima, 2000). Many plants growing in semi-arid conditions produce gummy exudates in large quantities, when cortex is assaulted. This is to seal cutting and prevent dehydration (Buckeridge et al., 2000). Gums can be obtained from the shells, or even from seeds, such as guar gum of *Cyamopsis tetragonoloba* (L.) Taub. and carob gum (or carob tree) of *Ceratonia siliqua* L., both obtained from the seed endosperm. Other natural gums are mucilages produced by algae (*e.g.* alginates, agar, carrageenan) and bacteria (dextran, xanthan) (Bhosale & Osmani, 2014).

Sap is a fluid transported in xylem cells (vessel elements) or phloem sieve tube elements of the plant (Robert & Shmuel, 2009). These cells transport water and nutrients throughout the plant. Sap should not be confused with latex, resin or cell sap; it is a different substance, produced separately and possesses different components and functions (Douglas, 2006). Xylem sap consists primarily of a watery solution of hormones, mineral elements and other nutrients. Transport of sap in xylem is characterized by its movement from roots towards leaves (Douglas, 2006). Phloem sap consists primarily of sugars, hormones, and mineral elements dissolved in water (Douglas, 2006).

2. Methodology

Scientific publications from various recognized databases including Scopus, Google Scholar, ACS, PubMed, Wiley, Scielo and Web of Science were surveyed and analyzed. Anthelmintic, nematicide, antifungal, fungicide, antimicrobial, antioxidant, anti-ulcerogenic, wound