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Control of insect pests in crop plants and stored food grains using plant saponins: A review

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ABSTRACT

Insect pests inflict damage to crop plants and deteriorate the quality of food grains and food products. The present review provides collective information of studies suggesting use of plant saponins in crop plants and stored food grains to control insect pests. Saponins are a class of high molecular weight surface active compounds characterized by the presence of non-polar aglycone moiety coupled with polar sugar molecules. They are present in many wild and cultivated plants and are known for a diverse range of biological activities. Saponins have received attention as insecticidal compounds due to their toxic nature to many serious insect pests of crops and stored grains. Studies have evidenced that saponins possess repellent or deterrent activity and provoke insect moulting defects or cause cellular toxicity in insect pests. The observed effects of saponins on insect pest are reduced food intake, indigestion, weight reduction, developmental retardation, decrease in the rate of reproduction, and mortality.

1. Introduction

Insect infestation has a direct impact on agricultural food production and stored products as they may account for 20–30% production loss and in severe cases, they cause total loss (De Geyter, Lambert, Geelen, & Smagghe, 2007). They damage field crops by sucking, chewing or boring into different plant parts. Damage to stored product is serious as they directly feed, bore and ruin grains and accelerate the process of decay. Chemical pesticides have been in use for a long time around the world to control insect pests. These pesticides are non-biodegradable and highly toxic to non-target organisms like beneficial insects, amphibians, fishes, birds as well as to humans (Da Silva et al., 2012). Continuous use of commercially available synthetic pesticides has resulted in the development of high degrees of resistance in many insect pests. These chemicals are also responsible for resurgence and outbreak of new pests. Pesticide contamination is endangering the sustainability of ecosystems by adversely affecting beneficial insects, microbes, plants, fishes, birds and animals (Aktar, Sengupta, & Chowdhury, 2009). Use of persistent chemicals and their toxic effects toward non-target species is a matter of concern for agricultural scientists and researchers. The uninterrupted use has resulted in the development of resistant strains of various insect pests. Pesticides used in agricultural crops and stored grains accumulate toxic residues on food grains used for human consumption and this may lead to health problems.

Worldwide mortality rate due to pesticide poisoning is also very high. Production workers, formulators, sprayers, mixers, loaders and farm laborers are frequently exposed to harmful chemical pesticides (Aktar et al., 2009). Many synthetically derived pesticides like organochlorines, organophosphates, carbamates and organophthalides have been banned because of their hazardous risks posed to the environment and non-target organisms (Ntalli & Menkissoglu-Spiroudi, 2011). The restrictions or prohibitions on the use of many pesticides due to their harmful effects and toxicity have increased interest in the use of botanical insecticides to control insect pests. Natural compounds known for bioactivity against insects are considered as safe, economical, biodegradable and easy to use alternatives in pest management of food crops and stored products.

Plants have developed many ways to fight against insects by using secondary metabolites. The search for plant-derived compounds could be a valuable source in the development of biopesticides for sustainable and healthy agriculture (Silva, Jander,

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Samaniego, Ramsey, & Figueroa, 2012). Many secondary compounds present in plants were recognized as feeding deterrents for stored product insect pests (Nawrot & Harmatha, 2012). Saponins are an interesting class of steroidal or triterpenoidal compounds found in plants with a diverse range of bioactivities (Podolak, Galanty, & Sobolewska, 2010). Saponins are non-volatile compounds characterized by the presence of an aglycone (or sapogenin) moiety attached with one, two or three saccharide chains. The presence of polar (sugar chains) and non-polar (aglycone moiety) group makes them surface-active compounds (Vincken, Heng, de Groot, & Gruppen, 2007). Saponins have many commercial applications due to their wetting, emulsifying and foaming properties (Balandrin, 1996). These compounds have antimicrobial, antioxidant, insecticidal, nematicidal and molluscicidal activities (Sparg, Light, & Van-Staden, 2004; Podolak et al., 2010; D'Addabbo et al., 2011). They have been used in stored grains to minimize food grain damage and loss due to insect pests (Stevenson, Dayarathna, Belmain, & Veitch, 2009; Taylor, Fields, & Sutherland, 2004). Applebaum, Marco, and Birk (1969) were first to report the defensive role of saponins synthesized by legume seeds against insect attack. Many researchers have tested insecticidal activities of these compounds against important insect pests (Adel, Sehnal, & Jurzysta, 2000; Da Silva et al., 2012; Faizal & Geelen, 2013; Golawska, Sprawka, & Qukasik, 2014; Harmatha, Mauchamp, Arnault, & Slama, 1987; Horber, Leath, Berrang, Marcaria, & Hanson, 1974; Hussein, Dimetry, Zidan, Iss-hak, & Sehnal, 2005; Nawrot & Harmatha, 2012; Nozzolillo, Arnason, Campos, Donskov, & Jurzysta, 1997; Shany, Gestetner, Birk, & Bondi, 1970; Sylwia, Bogumil, & Wieslaw, 2006).

Plant saponins possessing broad-spectrum insecticidal activities have gained attention in sustainable pest management practices. In this review article, our interest is focused on compilation of information available in the literature on plant derived saponins and their reported insecticidal activities.

2. Plant saponins

2.1. Structure and properties

Saponins are the glycosides that derive their name from their soap-like properties. They are composed of hydrophilic saccharide chains attached to hydrophobic triterpenic or steroidic structures (aglycone). Saponins are categorized into three main types according to the carbon skeleton of aglycone region: triterpenoidal, steroidal and steroidal-glycoalkaloid saponins (Fig. 1). Saponins have a polycyclic ring system in their aglycone or sapogenin structure with either 27 carbon steroid or 30 carbon triterpene (Moses, Papadopoulou, & Osbourn, 2014). The saccharide chain of saponins generally consists of linear oligosides having the length of 2–5 sugar units. The sugar residues include D-glucose, D-mannose, D-fructose, D-xylose, D-galactose, L-arabinose, L-rhamnose, and D-glucuronic acid (Fenwick, Price, Tsukamoto, & Okubo, 1991, pp. 285–327).

Saponins are categorized as monodesmosides (having a single sugar chain linked to C-3 of aglycone) and bidesmosides (having one sugar chains linked to C-3 and second to C-28, C-27, C-26 or C-22 of aglycone). Zanhic acid glycoside (oleanane type triterpenoidal saponin) is categorized as tridesmosidic with three sugar chains linked to aglycone and no free carboxyl group (Oleszek et al., 1992). Monodesmosidic glycosides are more potent in biological activity than bidesmosides or tridesmosides (Jain & Tripathi, 1991; Oleszek et al., 1992). Monodesmosidic saponins with a glycosyl group at C-3 are more bioactive than those having it at C-28. Saponins cannot be classified on the basis of their origin or plant source as there is no correlation between plant species and the saponins they produce.

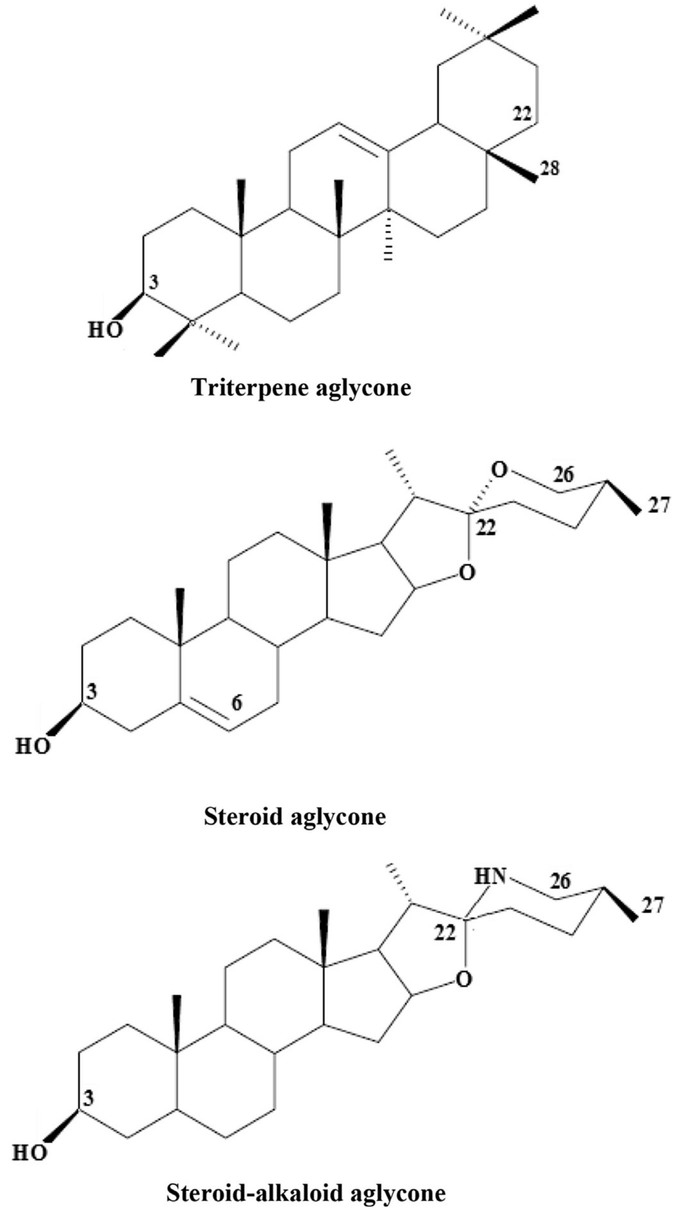

Fig. 1. Skeletal types of three different classes of saponins.

Saponins show detergent-like properties when shaken with water as they form micelles. The linkage between fat-soluble aglycone and water-soluble oligosaccharide chains makes saponin an amphipathic molecule processing surfactant properties leading to the interaction between saponins and cell membranes. Due to this interaction, saponins show variety of biological effects on living organisms like membrane permeabilising, haemolysis, insecticidal, allelopathic and antifungal activities. Saponins affect food intake, survival, growth rate and reproduction in some insects, fungi, bacteria, viruses, mollusks and animals (Thakur, Melzig, Fuchs, & Weng, 2011).

2.2. Saponins in plants

Saponins are present in many wild as well as cultivated plant species (Faizal & Geelen, 2013; Moses et al., 2014). The common plants studied for saponins are soapbark, alfalfa, yucca, ginseng, soybean, sugar beet, chickpea and asparagus (Cheok, Salman, &