Journal of Stored Products Research 77 (2018) 66–76

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

Postharvest insect resistance in maize

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A R T I C L E I N F O

Article history:
Received 17 January 2018
Received in revised form
9 March 2018
Accepted 11 March 2018

Keywords:
Maize
Pest
Weevil
Grain borer
Insect resistance
Mechanism
Bases
Peroxidase
Phenolic
Response

A B S T R A C T

One of the main challenges for the 21st century is ensuring global food security. Today, maize is the largest staple crop produced worldwide. Postharvest primary insect pests, especially the maize weevil (*Sitophilus zeamais*) and the large grain borer (*Prostephanus truncatus*) cause food-grain losses during storage up to 40% of total production, mainly in developing countries. Alternatives for pest management have been explored, including the implementation of hermetic storage structures and the application of chemical insecticides. Nevertheless, in low-income regions, both strategies are rarely accessible to smallholders. Modern breeding programs have endeavored to develop insect-resistant varieties, which diminish postharvest pest losses. In this review, we report the current status and advances in maize kernel-pest interactions, the bases and mechanisms of kernel resistance and their biotechnological perspectives. We demonstrate that the comprehension of resistance mechanisms has been fundamental for the development of new productive and resistant varieties, representing a sustainable alternative for developing countries. Finally, we analyse the biotechnological perspectives of natural kernel resistance in global food security.

Contents

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https://doi.org/10.1016/j.jspr.2018.03.004
0022-474X/

1. Introduction

Maize (*Zea mays* L. (Poaceae)), is the staple crop with the largest production worldwide, with an estimated of 1026 million tons (Cerquiglini et al., 2016). This cereal is the basic food in developing countries in terms of calories and protein intake, ranging from 61% in Mesoamerica, 45% in Eastern and Southern Africa, 29% in the Andean region, to 25% in West and Central Africa (Shiferaw et al., 2011). In the cited regions, maize is mainly cultivated by smallholder farmers, who take advantage of corn adaptability, high yields and valuable by-products (Rosegrant et al., 2009; Shiferaw et al., 2011). However, biotic and abiotic factors cause losses ranging 30–60% of global yield (Gitonga et al., 2013; Lesk et al., 2016; Ronald, 2011; Shiferaw et al., 2011). Abiotic stress is mainly caused by extreme environmental conditions, which are enhanced by climate change (Lesk et al., 2016; Ronald, 2011; Shiferaw et al., 2011). Biotic stress caused by diseases, weeds, and insects lead to losses of 54% of attainable yield in Africa, 48% in Central and South America, whereas in Asia reached 42% (Oerke, 2006; Shiferaw et al., 2011). Pre-harvest pests represent an average of 35% of potential yield loss worldwide (Oerke, 2006; Popp et al., 2013), whereas postharvest losses range between 14 and 36%. These losses could be observed along the whole food chain, including transport, preprocessing, storage, processing, packaging, marketing and plate waste (Kumar and Kalita, 2017; Popp et al., 2013; Tefera, 2012; Serna-Saldivar and García-Lara, 2016). Postharvest losses caused by insect pests represent 12–36% of grain weight worldwide (Gitonga et al., 2013; Tefera et al., 2016), affecting mainly low-income developing countries, due to poor postharvest management and inappropriate grain storage conditions (Gitonga et al., 2013; Midega et al., 2016; Tefera et al., 2016; García-Lara and Serna-Saldivar, 2016). Furthermore, significant losses in terms of product quality has been observed when infested kernels by insects were used for manufacture end products such as tortillas (García-Lara et al., 2013a,b).

Management programs have explored diverse alternatives to reduce insect postharvest losses, including chemical crop protection and the implementation of hermetical storage structures (Boyer et al., 2012; García-Lara et al., 2013a,b; Gitonga et al., 2013; Mlambo et al., 2017; Tefera et al., 2011a). International breeding efforts have endeavored to develop high yield insect-resistant maize varieties (Abebe et al., 2009; Tefera et al., 2013, 2016), using maize landraces as natural sources of resistance, which are also adapted to the farming conditions of the target regions. (Arnason et al., 1994; Abebe et al., 2009; García-Lara and Bergvinson, 2013; Midega et al., 2016; Mikami et al., 2012; Tefera et al., 2016). Thus, the knowledge of the mechanisms and molecular bases of the natural resistance is crucial to the identification of resistance traits, which can be used in high-yield insect-resistant varieties. In this review, we discuss the current knowledge about the natural resistance to main storage pests in maize.

2. Distribution and impact of post-harvest insect pests

Postharvest maize insect pests include many species from the orders Coleoptera and Lepidoptera, which are distributed worldwide, causing yield and quality losses of grains and by-products, with important economic repercussions (García-Lara and Bergvinson, 2014; Sallam, 1999). However, most of the insect postharvest losses are caused by populations of a single pest, depending of the region and the agroecology, as observed in Table 1. Species such as *Sitophilus zeamais, Prostephanus truncatus*, *Sitotroga cerealella*, *Rhyzopertha dominica* and *Tribolium castaneum* are considered major pests and are a serious concern in global agriculture (CABI, 2017; García-Lara and Bergvinson, 2014; Gitonga et al., 2013; Mohandass et al., 2007; Sallam; 1999; Tefera et al., 2016). In this review we will focus mainly in two species: *Sitophilus zeamais* and *Prostephanus truncatus*.

2.1. Maize weevil (*Sitophilus zeamais* Motschulsky)

Sitophilus zeamais (Coleoptera: Curculionidae) has an ancient origin, about 8.7 million years ago, and has been recognized as predator of modern maize (Corrêa et al., 2016). This pest has been detected in 112 countries worldwide (Fig. 1 and Table 1) (CABI, 2017). *Sitophilus zeamais* is responsible for 12–36% grain weight loss worldwide (García-Lara and Bergvinson, 2014; Gitonga et al., 2013; Tefera et al., 2016), reaching 65–80% in vulnerable zones from tropical and subtropical regions. In western Kenya, 67% of farmers reported very severe losses caused by this pest (Midega et al., 2016), whereas in Ethiopia losses reached 80% (Sori and Ayana, 2012). These scenarios lead to extreme food insecurity and poverty in vulnerable regions (Abass et al., 2014; Affognon et al., 2015; Kumar and Kalita, 2017).

2.2. Large grain borer (*Prostephanus truncatus* Horn)

Prostephanus truncatus (Coleoptera: Bostrichidae) is a pest originated in meso-America and accidentally introduced to Africa in the late 1970s (Hodges, 1986). This pest has been detected in tropical and subtropical regions in 26 countries (Table 1 and Fig. 1) (APHLIS, 2017; CABI, 2017; EPPO, 2017). *P. truncatus* has an enormous impact on the agriculture due to its voracious behavior (Abass et al., 2014; García-Lara and Bergvinson, 2013; Midega et al., 2016). In Latin America, losses caused by this pest can be as high as 50–80% (García-Lara and Bergvinson, 2013; Kumar and Kalita, 2017). In Western Kenya, 84% of farmers experienced severe losses in stored maize caused by *P. truncatus* (Midega et al., 2016), while in Tanzania these losses reached 56.7% (Abass et al., 2014). Thus, this pest is also a major concern in food security of tropical and dry regions.