ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.29, n.1, e279969, 2025
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v29n1e279969

Review

Natural compounds and their potential use in stored grain treatment: A review[1]

Compostos naturais e seu potencial emprego no tratamento de grãos armazenados: Uma revisão

Diana R. Alves[2], Júlio C. de A. Andrade[2] & Danúbia A. C. Nobre[2*]

[1] Research developed at Universidade Federal dos Vales do Jequitinhonha e Mucuri, Campus JK, Diamantina, MG, Brazil
[2] Universidade Federal dos Vales do Jequitinhonha e Mucuri/Departamento de Agronomia, Diamantina, MG, Brazil

HIGHLIGHTS:

Using natural compounds for treating stored grains emerges as an eco-friendly and promising alternative.
The recognized bioactivities of classes of natural compounds can be adapted for application in grain storage.
Research on natural compounds in stored grains is still incipient, requiring more tests to make their application viable.

ABSTRACT: Grain production is steadily increasing; however, the static storage capacity remains inadequate in Brazil. The lack of proper facilities and the precarious and inadequate storage conditions lead to post-harvest losses due to factors interacting with the grains, causing their deterioration. Chemical treatments are commonly used to reverse these effects; however, their replacement with natural substances has been sought due to environmental and human health concerns. The objective of this review was to discuss a sustainable strategy for treating stored grains, focusing on the use of natural compounds with bioactive properties, such as antifungal, antioxidant, and insecticidal activities, with potential for further studies. Natural compounds with useful properties for application in grain storage were outlined. Research on the use of natural compounds in grain treatment is still in its early stages, requiring progress in identifying new promising compounds, understanding the mechanisms of action, and developing and optimizing effective extraction, application, and formulation processes to make the use of these substances viable.

Key words: sustainability, bioactives, storage, natural products

RESUMO: A produção de grãos apresenta crescimento constante, entretanto, a capacidade estatística de armazenamento permanece deficitária no Brasil. A falta de estruturas e a precariedade e inadequação no armazenamento ocasionam perdas na pós-colheita, devido ação de fatores que interagem com os grãos, culminando na sua deterioração. Para reversão desses efeitos, o tratamento químico é realizado, contudo, busca-se por sua substituição por substâncias naturais devido a implicações ambientais e medicinais. Objetivou-se com esta revisão, a discussão de uma potencial estratégia sustentável para o tratamento de grãos armazenados, com foco no uso de compostos naturais com propriedades bioativas como antifúngica, antioxidante e inseticida, que os torna potenciais para serem estudados. Foram delineados compostos naturais que possuem propriedades úteis para aplicação no armazenamento de grãos. Pesquisas a respeito do emprego dos compostos naturais no tratamento de grãos são incipientes, carecendo de avanços na identificação de novos compostos promissores, melhor compreensão dos mecanismos de ação e otimização/desenvolvimento de processos de extração, aplicação e formulação eficazes que viabilizem o futuro uso das substâncias.

Palavras-chave: sustentabilidade, bioativos, armazenamento, produtos naturais

• Ref. 279969 – Received 29 Oct, 2023
* Corresponding author - E-mail: danubia.nobre@ufvjm.edu.br
• Accepted 06 Jul, 2024 • Published 29 Jul, 2024
Editors: Ítalo Herbet Lucena Cavalcante & Walter Esfrain Pereira

Introduction

The grain production sector has been continuously growing due to advances in research (Ygit, 2019; Ziegler et al., 2021). However, this increase has accentuated the deficit in static grain storage capacity, which, combined with improper facilities, inadequate techniques and lack of management, leads to grain losses (Silva et al., 2021; Ziegler et al., 2021). This is one of the major challenges in postharvest management of grains in Brazil, one of the world's leading grain-producing countries (Coradi et al., 2020).

Grains are living organisms and are therefore affected by the environment, which makes proper storage crucial (Bucklin et al., 2019). Biotic and abiotic agents interact with grains, causing their deterioration (Lutz & Coradi, 2022; Sharma et al., 2023), which makes grain treatment, mainly chemical, imperative. Phosphide-based fumigants and pyrethroids and organophosphate insecticides are predominantly used (Agrofit, 2003; Arora et al., 2021). However, these treatments have been discouraged due to insect resistance and environmental and health implications (Mir et al., 2023), leading to the search for alternative treatments.

Storage is essential for increasing profits, reducing losses, and ensuring food quality and safety (Gaban et al., 2017; Cafiero & Nord, 2018). However, the highest postharvest grain losses usually occur during storage, a situation that is even more significant for small-scale growers due to financial and technological limitations (Manandhar et al., 2018).

Therefore, information about the storage ecosystem and the development of new techniques, especially sustainable ones, are essential to optimize the process and ensure profitability, nutritional quality, and food safety (Ariong et al., 2023; Tushar et al., 2023). In this context, the objective aim of this review was to discuss a sustainable strategy for treating stored grains, focusing on the use of natural compounds with bioactive properties, such as antifungal, antioxidant, and insecticidal activities, with potential for further study.

Challenges in Grain Storage: An Overview

Losses of stored grains result from biotic factors, such as harmful insects, microorganisms, rodents, and birds, and abiotic factors, including grain moisture content, relative air humidity, temperature, grain condition at harvest, and storage conditions and facilities (Sharma et al., 2023).

Insect pests account for a significant portion of both quantitative and qualitative losses in stored grains (Rizwan et al., 2022), as they thrive under high humidity and temperature conditions (Garcia-Cela et al., 2019). Infestation by insect pests occurs initially through primary infestation, with insects penetrating, feeding, and completing their lifecycle within healthy grains; this enables secondary infestation, characterized by insects feeding on previously damaged or broken grains (Melo et al., 2018).

Pest damage includes quantitative losses such as gran weight reduction, and qualitative losses such as changes in chemical composition that affect grain nutritional value, contamination with excreta, insect parts, and uric acid, and aesthetic degradation (Covele et al., 2020; Paul et al., 2020; Sharma et al., 2023). Additionally, insect infestations can compromise the germination of stored grains (Mng'ong'o, 2023). Although grains are not typically used as planting inputs, these factors are significant in small-scale and family farms, where grains are often used as seeds.

Moreover, insect infestations can promote pathogenic microorganisms by creating entry points for colonization, increasing the grain temperature and damaging storage facility structures and packaging (Sharma et al., 2023). Thus, the presence of insects in stored grains, especially at high infestation levels, compromises profitability and food safety.

The main insect pests of stored grains include: i) Primary pests, such as *Rhyzopertha dominica* (Coleoptera: Bostrichidae), *Sitophilus oryzae* (Coleoptera: Curculionidae), *Sitophilus zeamais* (Coleoptera: Curculionidae), *Lasioderma serricorne* (Coleoptera: Anobiidae), *Acanthoscelides obtectus* (Coleoptera: Bruchidae), *Sitotroga cerealella* (Lepidoptera: Gelechiidae), and *Plodia interpunctella* (Lepidoptera: Pyralidae); and ii) Secondary pests, such as *Tribolium castaneum* (Coleoptera: Tenebrionidae), *Oryzaephilus surinamensis* (Coleoptera: Silvanidae), *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), and *Ephestia kuehniella* (Lepidoptera: Pyralidae) (Lorini et al., 2015).

Furthermore, microorganisms also pose a threat to stored grains. Grains can be attacked by bacteria, actinomycetes, and fungi during storage (Iztayev et al., 2020). However, bacterial contamination in grains is uncommon during storage due to unfavorable conditions for their growth; when it does occur, it typically involves non-harmful bacteria due to poor hygiene (Briggs & McGuinness, 1993; Laca et al., 2006; Los et al., 2018; Qi et al., 2022). Conversely, fungi require more attention due to their harmful effects on stored products (Jafarzadeh et al., 2023).

Fungi are favored by moisture; fungal colonization is promoted by water activity in grains above the critical threshold, causing grain deterioration and potentially leading to mycotoxin production (Fleurat-Lessard, 2017; Wang et al., 2019). Mycotoxins are toxic substances produced by secondary metabolism (Chen et al., 2023) and seriously threaten food safety due to their high likelihood of causing acute contaminations (El-Sayed et al., 2022). The main fungi species in stored belong to the genera *Aspergillus*, *Fusarium*, *Cladosporium*, *Ustilaginoidea*, and *Wallemia* (Qi et al., 2022); *Fusarium* and *Aspergillus* species are the major mycotoxin producers (Bertuzzi et al., 2019; Araújo et al., 2021).

Therefore, the primary issue caused by fungi in grain storage is their ability to produce mycotoxins, which represent a serious health risk due to their high toxicity even at low concentrations (Gil-Serna et al., 2019; Gallo et al., 2020; Qi et al., 2024). Mycotoxin toxicity can cause severe effects on human and animal health, including liver toxicity, carcinogenicity, immunosuppression, neurotoxicity, reduced fertility, endocrine disorders, gastrointestinal illnesses, and developmental issues (Dai et al., 2019; Gallo et al., 2020; Sun et al., 2022; Penagos-Tabare et al., 2024; Taroncher et al., 2024).

The most significant mycotoxins for the agricultural sector are aflatoxins, produced by species of the genus *Aspergillus*;

fumonisins, trichothecenes, zearalenone, by species of *Fusarium*; ochratoxins and citrinin, by species of *Aspergillus* and *Penicillium*; and patulin, by species of *Penicillium* (Munkvold et al., 2021; Ferrara et al., 2022).

Birds and rodents also cause damage stored grains, albeit to a lesser extent (Shah et al., 2023). These organisms contribute to grain storage losses by consuming grains; however, their greater concern threat lies in transmitting diseases to humans and animals as carriers of various pathogens that contaminate the grain mass through their excreta and feathers, thus promoting the growth of insects and microbes (Rajendran et al., 2003; Dubey et al., 2023; Quasim et al., 2023).

Regarding abiotic factors, grain moisture content is one of the main causes of damage to stored grains (Abdullahi & Dandago, 2021). The safe moisture content range for stored grains usually range from 10 to 13%, with higher and lower levels leading to deterioration of inherent grain properties, such as changes in chemical and physical composition, favoring pest and microorganism attacks (Panigrahi et al., 2020; Sharma et al., 2023). Additionally, relative air humidity can cause damage through water absorption or loss due to the hygroscopic nature of grains (Angelovic et al., 2018).

Water is a precursor for metabolic reactions; therefore, high moisture contents accelerate metabolism, increase the consumption of grain reserves, and decrease the grain nutritional value (Yubonmhat et al., 2019; Wang et al. 2020), as well as favor insect attacks and mainly fungal growth (Garcia-cela et al., 2019; Sharma et al., 2023). Conversely, low moisture contents lead to reduced commercial value due to lower grain weight and can potentially cause physical damage due to grain dryness (Souza & Ruffato, 2021).

Air and grain temperatures, as well as the temperature between grains, are also significant for the quality of stored grains (Sharma et al., 2023). High temperatures accelerate grain metabolism, leading to the consumption of reserves, favoring insect-pest infestation and microbial growth, and causing nutrient degradation (Elias, 2000; Garcia-cela et al., 2019; Gu et al., 2019). These stressors increase grain respiration, generating metabolic heat due to oxidative decomposition, thus causing further losses (Sharma et al., 2023).

Furthermore, grain conditions at harvest and the storage conditions and facilities also affect the quality of stored grains. Intact grains harvested and stored at ideal moisture contents are less susceptible to damage from these factors; proper mechanical and structural storage conditions, with durable facilities, reduce access to harmful insects and microorganisms and minimize grain deterioration (Abdullahi & Dandago, 2021; Sharma et al., 2023). Additionally, sanitation and hygiene conditions around storage areas are crucial, as poor hygiene predispose the grains to more harmful effects (Kuyu et al., 2022).

Use of Natural Compounds: Alternative to Conventional Treatments of Stored Grains

Chemical treatments are the most used method for grain storage, applied preventively in empty spaces before storage or curatively, using insecticides and fumigants (Lorini et al., 2015; Manandhar et al., 2018; Hamel et al., 2020). Preventive treatments protect the grains for several months by uniformly applying chemical insecticides before storing the grains (Lorini et al., 2015; Hamel et al., 2020). Curative treatments involve fumigation to eliminate infestations in stored grains (Abdullahi & Dandago, 2021).

Preventive application of chemical insecticides has a limited efficacy, as the action of the product is restricted to insects on the grain surface, making fumigation more effective (Hamel et al., 2020). The list of chemical pesticides approved for treating stored grains is limited, with a focus on fumigants (Agrofit, 2003; Hamel et al., 2020). Currently, the most used products for grain storage in Brazil are pyrethroids, followed by organophosphates (Table 1) (Agrofit, 2003). Regarding fumigation, methyl bromide was largely used worldwide, but has been banned and replaced by phosphine, sulfuryl fluoride, and carbon dioxide, the latter considered more environmentally friendly (Hamel et al., 2020). In Brazil, aluminum phosphide and magnesium phosphide are the most used for fumigation, followed by phosphine (Table 1) (Agrofit, 2003).

There are currently no chemical fungicides approved for controlling fungi in grain storage in Brazil (Agrofit, 2003). Considering the widespread occurrence of fungi in storage facilities and the significant threat of mycotoxin to health (Taroncher et al., 2024), seeking solutions, especially sustainable ones, is imperative to prevent and control the presence of these organisms in stored grains to ensure food safety.

Although highly effective, chemical treatments have drawbacks (Akinneye et al., 2018), including the potential for residue in food, which can be harmful to human health; environmental impact, especially when products are mishandled; the development of resistance in organisms due to excessive and continuous use of substances; strict regulations; and health risk to workers exposed to toxic products (Ayalew, 2020; Dias et al., 2020).

Physical treatments involve the manipulation of the physical environment to control pests and pathogens, including the use of lethal temperatures that are non-damaging to grains; reduction of relative air humidity to unfavorable levels; controlled atmosphere, modifying CO_2, O_2, or N_2 concentrations to harmful levels; use of inert dusts such as diatomaceous earth for desiccation as an insecticidal method; physical removal of pests with sieves; exposure of pests to ionizing radiation for their elimination or sterilization; application of sound waves at frequencies harmful to insects; application of radiofrequency and microwave energy for selective dielectric heating of insects to lethal temperatures; and use of hermetic packaging (Lorini et al., 2015; Tanguy et al., 2019; Yanagawa et al., 2020; Abed et al., 2023; Jian, 2024).

The use of diatomaceous earth stands out among physical environment treatments. It has been used as an alternative to conventional insecticides and has shown effectiveness against various insect-pest species of stored grain (Baliota & Athanassiou, 2023). Diatomaceous earth is an inert dust derived from fossilized microscopic algae, containing 60 to 93% amorphous silica, with emphasis on silicon dioxide,

Table 1. Approved active ingredients for use in storage of grain products in Brazil

Active ingredient	Target	Product	Toxicological class/ Environmental class	Mechanism of action
Deltamethrin (pyrethroid)	*Rhyzoperta dominica*	Rice, maize, wheat	IV/III	Sodium channel modulator
Permethrin (pyrethroid)		Rice, maize, wheat	I/II	Sodium channel modulator
Bifenthrin (pyrethroid)		Rice, maize	IV/II	Sodium channel modulator
Aluminum phosphide			I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Esfenvalerate (pyrethroid) + fenitrothion (organophosphate)		Wheat	III/I	Acetylcholinesterase inhibitors / Sodium channel modulator
Pirimiphos-methyl (organophosphate)	*Sitophilus oryzae*	Rice	V/II	Acetylcholinesterase inhibitors
Magnesium phosphide		Rice	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Aluminum phosphide		Rice	I/III	Complex IV inhibitors in the mitochondrial electron transport chain
Deltamethrin (pyrethroid)		Wheat, maize	IV/III	Sodium channel modulator
Esfenvalerate (pyrethroid) + fenitrothion (organophosphate)		Wheat	III/I	Acetylcholinesterase inhibitors / Sodium channel modulator
Pirimiphos-methyl (organophosphate)	*Sitophilus zeamais*	Rice, maize, wheat	V/II	Acetylcholinesterase inhibitors
Magnesium phosphide		Rice, maize, wheat	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Permethrin (pyrethroid)		Rice, maize, wheat	I/II	Sodium channel modulator
Bifenthrin (pyrethroid)		Rice, maize, wheat	IV/II	Sodium channel modulator
Aluminum phosphide		Maize, soybean meal	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Deltamethrin (pyrethroid)		Maize	IV/III	Sodium channel modulator
Deltamethrin (pyrethroid)	*Sitophilus granarius*	Maize	IV/III	Sodium channel modulator
Aluminum phosphide	*Lasioderma serricorne*	Soybean meal	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Phosphine		Soybean meal	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Pirimiphos-methyl (organophosphate)	*Sitotroga cerealella*	Rice, maize	V/II	Acetylcholinesterase inhibitor
Deltamethrin (pyrethroid)		Rice, maize, wheat	IV/III	Sodium channel modulator
Magnesium phosphide		Rice, maize, wheat	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Aluminum phosphide		Maize	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Permethrin (pyrethroid)		Maize	I/II	Sodium channel modulator
Magnesium phosphide	*Plodia interpunctella*	Flours	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Aluminum phosphide		Flours, wheat flour	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Phosphine		Flours	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Deltamethrin (pyrethroid)	*Tribolium castaneum*	Rice	IV/III	Sodium channel modulator
Magnesium phosphide		Wheat flour	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Aluminum phosphide		Wheat flour, and soybean meal	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Aluminum phosphide	*Ephestia kuehniella*	Flours, wheat flour	I/III	Complex IV inhibitor in the mitochondrial electron transport chain
Phosphine		Flours	I/III	Complex IV inhibitor in the mitochondrial electron transport chain

Toxicological classification: I - Extremely toxic product; II - Highly toxic product; III - Moderately toxic product; IV - Slightly toxic product; V - Unlikely to cause acute harm. Environmental classification: I - Highly hazardous to the environment; II - Very hazardous to the environment; III - Hazardous to the environment; IV - Slightly hazardous to the environment. Source: Agrofit (2003)

which causes insect mortality through desiccation (Baliota & Athanassiou, 2020).

Some limitations are associated with physical treatments, including reduced grain quality, especially with temperatures that degrade chemical compounds, high operational costs and time, the need for large amounts of material, and limited efficacy (Souza et al., 2013; Lorini et al., 2015). Despite its low toxicity to mammals, efficiency, and long-term effect, diatomaceous earth has some disadvantages such as effects on the physical properties of grains, including reduced bulk density (Rigopoulou et al., 2023), as well as and mechanical abrasion (Losic & Korunic, 2018), which hinders direct mixing with grains (Hamel et al., 2020).

Biological pest control in storage facilities is not yet a well-established method but has been studied as an alternative to chemical pesticides. These studies have considered the use of pathogens, parasitoids, and predators for protecting stored grains (Hamel et al., 2020; Abdullahi & Dandago, 2021).

Biological treatments are low or non-toxic by nature, therefore, they have some limitations, mainly related to limited and variable efficacy, potential contamination of stored grains with organism fragments (Montoya-Martínez et al., 2024), a lack of detailed and critical analysis of their use in the field against specific insect pests in crops, and organizational, geographical, and methodological biases; these factors hinder the scientific progress in this area (Wyckhuys et al., 2024).

Currently, innovative approaches for treating stored grains have emerged driven by the demand for reducing food waste. Some techniques have shown promise for treating stored grains, including ozonation for controlling atmosphere with the potential to reduce mycotoxins and microorganisms, dielectric heating, non-thermal plasma, high hydrostatic pressure, microwave energy, ultraviolet light, and the use of natural compounds, especially essential oils (Schmidt et al., 2018; Dias et al., 2020; Paul et al., 2020). The use of natural compounds has stood out among these techniques for their low-cost and easy availability.

Traditional treatment methods, such as the use of chemical agents, show efficacy but have disadvantages like environmental persistence, adverse effects on human and animal health and the environment, impacts on the nutritional quality of grains, development of resistance, and commercial limitations due to restrictions and regulations on synthetic compounds (Subramanyam et al., 1998; Morrison et al., 2019; Singh et al., 2021; Sruthi & Rao, 2021). These drawbacks drive the search for sustainable alternatives.

In this context, natural compounds provide a wide range of biological activities with the potential to replace traditional treatments. These substances are derived from secondary metabolism of organic sources, primarily plants, but also from animals and microorganisms, and exhibit several pharmacological and medicinal bioactivities (Bouyahya et al., 2022). Their potential agricultural applications include antioxidant, insecticidal, antimicrobial, and nutraceutical activities.

Research into natural compounds for agricultural use, particularly in grain storage, is promising as these substances can potentially replace synthetic inputs. Their advantages include easy acquisition at low cost due to a wide availability, absence of residues, and safety due to low toxicity (Sánchez & Aznar, 2015; Ooi et al., 2018; Atanasov et al., 2021).

Considering the importance of preserving postharvest products, the search for natural compounds for treating stored grains is essential for reducing the use of chemical pesticides and, consequently, their environmental and health impacts. Therefore, there is a growing need for studies involving medicinal, aromatic, and forest species to promote the sustainable use of natural resources and their agricultural application.

Potential Natural Compounds

Natural compounds were selected for investigation based on their relevance for the protection and treatment of stored grains, mainly due to their bioactive properties. These compounds have potential against major storage issues such as fungal and insect attacks and promote grain preservation by delaying oxidation and preventing deterioration. Essential oils have well-documented antimicrobial and antioxidant properties, including applications in agriculture. Phenolic compounds are recognized for their high antioxidant and antimicrobial activities. Alkaloids have antimicrobial and insecticidal properties, whereas sulfur compounds have antioxidant, antifungal, and insecticidal activities. Carotenoids and natural polysaccharides were addressed due to their antioxidant properties.

A search for scientific articles using the term "bioactive natural compounds" in the Web of Science database, filtered by "entomology," "mycology," and "agronomy", returned a total of 973 studies conducted between 1976 and 2023, with 861 articles and 112 are review articles; there was a noticeable increase from 2020 onwards (Figure 1).

Importantly, the extensive search for bioactive natural compounds can be attributed to their beneficial properties for grain storage, which makes them as potential options for integration into pest and disease control during storage.

Essential oils are substances extracted from plants with a significant relevance in agricultural research due to their biochemical properties, which confer important biological functions (Elshafie et al., 2019). Essential oils consist of a various volatile compounds derived from secondary metabolism, such as terpenes, the major compounds, along with those of aromatic and aliphatic groups, such as aldehydes, alcohols, esters, and ketones; these compounds have characteristic aromas that provide insecticidal, antimicrobial, herbivory-protective, and repellent properties (Langenheim, 1994; Tohidi et al., 2019; Falleh et al., 2020).

Essential oils are synthetized in small quantities in various plant organs, mainly flowers, buds, leaves, seeds, stems, and fruits (Dhifi et al., 2016). Extraction methods include conventional techniques such as hydrodistillation, steam distillation, hydrodiffusion, and solvent extraction (Wang et al., 2017), as well as innovative methods such as supercritical fluid extraction, subcritical extraction, solvent-free microwave extraction, and microwave-assisted hydrodistillation (Aziz et al., 2018). These processes result in a liquid, volatile, translucent, colored product with a lower density than water (Nazzaro et al., 2017). Several studies have confirmed the potential of essential oils for agricultural applications, emphasizing their effectiveness as bioinsecticides, biological antibiotics, and natural antioxidants (Borotová et al., 2021; Loi et al., 2023; Santos et al., 2023). Additionally, using essential oils in stored products provides the advantage of preserving sensory characteristics (Borotová et al., 2021).

Currently, research on essential oils is extensive among various authors, including Brazilian researchers investigating their potential as agents to control important storage pests and fungi, including *Callosobruchus chinensis, Callosobruchus musculatus, Lasioderma serricorne, Tribolium castaneum, Ephestia kuehniella, Caryedon serratus,* and fungal species of the genera *Fusarium, Aspergillus,* and *Penicillium* (Mattos et al., 2021; Olinto et al., 2021; Jiang et al., 2022; Luchesi et al.,

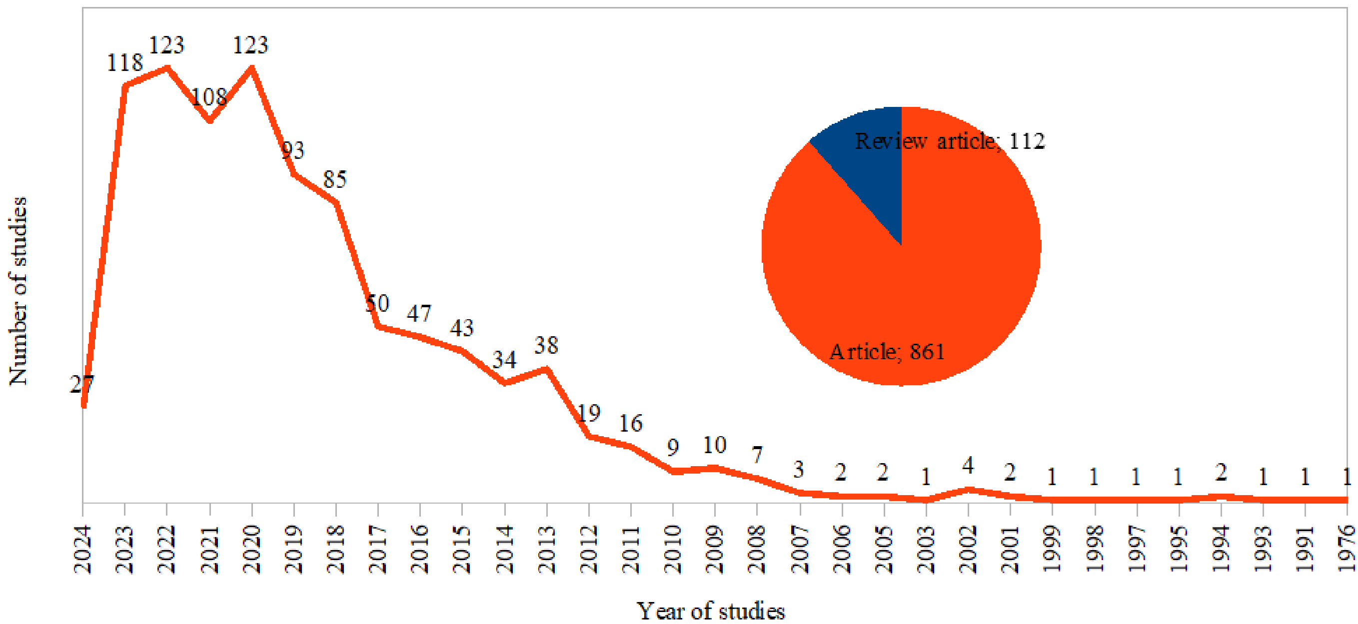

Figure 1. Studies on bioactive natural compounds from 1976 to 2023 in the Web of Science database

2022; Farias et al., 2023; Lopes et al., 2023; Duan et al., 2024; Gao et al., 2024; Liu et al., 2024; Hamidian et al., 2024; Oliveira et al., 2023; Paul et al., 2024; Sulhath et al., 2024; Tewari et al., 2024; Torre et al., 2024).

However, despite many current studies indicating the promising use of essential oils in agriculture, there is still a demand for more research regarding standardization of methods, systematic correlations between various studies, and conduction of sensory analyses to determine effective and acceptable rates that do not compromise organoleptic characteristics of food products (Střelková et al., 2024).

Phenolic compounds are secondary metabolites synthesized by plants that act on physiological processes and defense systems (Pratyusha, 2022). The main sources of phenolic compounds are fruit and vegetable species, but woody vascular plants have gained prominence (Tanase et al., 2019). These compounds can be extracted using conventional and unconventional solvents, negative pressure, supercritical CO_2 extraction, pressurized liquid extraction, subcritical water extraction, ultrasound-assisted extraction, and membrane filtration (Barba et al., 2016).

Phenolic compounds have aromatic rings in their chemical structure, which enables them to execute biological functions (Pratyusha, 2022). They are widely recognized in industry and medicine for their antioxidant, anti-inflammatory, antimicrobial, antiatherosclerotic, antidiabetic, antiallergic, prebiotic, and antimutagenic properties (Tanase et al., 2019), which are advantageous for stored grains.

Alkaloids, synthesized in plants, animals, and microorganisms, have antioxidant, antimicrobial, anticarcinogenic, and insecticidal properties (Thawabteh et al., 2019), making them promising for grain treatment. Chemically, alkaloids are amines that contain heterocyclic rings and nitrogen derived from amino acids (Dey et al., 2020).

Sulfur compounds consist of a group of organic compounds derived from the secondary metabolism of plants, bacteria, and fungi, characterized by their sulfur-containing structure (Liu et al., 2022). These compounds are closely related to vegetable species of the families Alliaceae, Cruciferae, and Leguminosae; they exist initially as non-volatile hydrophilic compounds, which are converted into volatile lipophilic compounds by enzymes upon tissue damage, thus providing them with aroma and flavor (Lu et al., 2022).

Organosulfur compounds are reactive and can donate hydrogen sulfide (H_2S); this may be due to their antioxidants, anti-inflammatory, antibacterial, antifungal, and insecticidal activities (Shang et al., 2019; Lu et al., 2022), which make them potential alternatives for use in grain treatment.

Carotenoids are lipophilic pigments (yellow, red, and orange) found in plants predominantly, and in microorganisms (Amengual, 2019; Wang et al., 2021). They belong to the chemical class of terpenes, which are hydrocarbons produced by plants and composed of isoprene units, associated with several biological activities (Cox-Georgian, 2019).

The chemical structure of carotenoids consists mainly of unsaturated polyene chains, containing a high number of conjugated double bonds (Wang et al., 2021). They are classified into carotenes and xanthophylls, the latter containing oxygen atoms in addition to carbon and hydrogen (Amengual, 2019). Recognized carotenoids for pharmacological purposes include β-carotene, lycopene, astaxanthin, lutein, zeaxanthin, β-cryptoxanthin, and fucoxanthin, which differ mainly in their chemical structure (Honda, 2020).

Carotenoids have potential for stored grain treatment because they are precursors of vitamin A (Bezerra et al., 2019), which improves nutritional value and provides high antioxidant properties, especially against peroxyl and singlet oxygen radicals (Moreira et al., 2018; Honda, 2020).

Natural polysaccharides are bioactive compounds obtained in large quantities from plants, animals, microorganisms, and algae, widely used in the food and pharmaceutical industries (Tudu & Samantha, 2023). They can be extracted using methods such as hot water extraction method, dimethyl sulfoxide, methoxyethanol, acidic aqueous solution, lithium chloride, dilution, alkaline water, and enzymolysis (Hasnain et al., 2019).

The chemical structure of polysaccharides contains monosaccharides linked to peptides, amino acids, and/or lipids through glycosidic or covalent bonds (Tudu & Samantha, 2023). They are useful for use for improving formulations and have antioxidant activity, a characteristic of interest for grain storage (Xie et al., 2016; Tudu & Samantha, 2023).

Considering the bioactive properties of the natural compounds mentioned, they are promising alternatives to replace chemical fumigants (the main chemical products used) and insecticides, which is a significant current environmental concern worldwide, along with an increasingly demanding consumer market regarding food consumption due to greater health concerns post-Covid-19 pandemic (Oliveira et al., 2021). Furthermore, the incorporation of natural compounds contributes to the achievement of the United Nations (UN) Sustainable Development Goals, especially those related to health, environmental protection, sustainability, and responsible production (Brasil, 2024).

Additionally, some of chemical pesticides, mainly fumigants, are classified as extremely toxic and hazardous to the environment; therefore, studying alternative methods is essential due to the risks of these classes of pesticides pose to human health and wildlife, causing acute intoxications to chronic damage, and to the environment through terrestrial and aquatic contamination, even in the short term, thus harming biodiversity (Agrofit, 2003). Substituting them with sustainable practices, including the use of natural compounds, is crucial to ensure increasingly responsible agriculture.

Natural compounds have become increasingly important due to their antifungal properties, which can highly benefit the management of grain storage due to issues related to the presence of fungi and mycotoxin development (Taroncher et al., 2024). This is even more significant when considering the lack of approved chemical pesticides for controlling fungi in grain storage and the limited efficacy and high costs of available treatments, such as irradiation (Ferreira et al., 2021; Agrofit, 2003).

Integrated Pest Management (IPM) is the most important technology available for pest and disease prevention and control in agriculture (Grijalva et al., 2024). Natural compounds can integrate IPM as a relevant sustainable strategy for pest and disease control due to their antifungal and insecticidal properties (Bouyahya et al., 2022). This integration can help balance pest control and environmental conservation by reducing the use of chemical pesticides and their impacts (Hazra et al., 2024).

Natural compounds stand out for their low toxicity and potential selective based on according their chemical properties and mechanisms of action, thus posing a lower risk of adverse impacts on non-target organisms (Ooi et al., 2018; Atanasov et al., 2021; Upmanyu et al., 2022). They also have low environmental persistence, promoting conservation (Barba-Ostria et al., 2022).

Natural compounds are found in a wide variety in nature, indicating diverse chemical properties and distinct mechanisms of action; therefore, advances in research can improve their effectiveness within IPM (Barba-Ostria et al., 2022).

Furthermore, natural compounds can be used as a complement to control methods, thus optimizing pest and disease control while reducing dependence on chemical products ant the associate risks of chemical residues in food and the environment (Leach et al., 2022; Hazra et al., 2024). However, integrating natural compounds into IPM requires advances in research, which is still in its early stages (Barba-Ostria et al., 2022).

Table 2 presents, as an example of the mentioned natural compounds, studies related to the use of natural compounds with antioxidant, antifungal, and insecticidal properties in storage. In this context, essential oils have a greater number of studies conducted, which may be linked to the fact that they are a mix of bioactive compounds and may even contain other so-called promising components. The other components are studied in other areas, showing potential to also be explored for the treatment of stored grains.

Mechanisms of Action of Natural Compounds

Currently, there are no approved natural compounds for use in grain storage in Brazil as in field production; consequently, these products are not found in the market (Agrofit, 2003). Natural compounds have been used empirically for grain conservation during storage, primarily in research studies, and in small-scale, family, and organic production farms (Chunarkar-Patil et al., 2024).

Information on the biological action mechanisms of natural compounds is essential for their use in the grain treatment; however, research is still incipient, although significant progress has been made in studies on antioxidant activity (Ootani et al., 2013).

Natural compounds promote biological homeostasis by preventing free radical action, which inhibits oxidation chain reactions (Ferreira et al., 2009).

The antioxidant action of natural compounds has been well-documented. It can be primary, delaying or inhibiting the activity of components involved in the initiation or propagation of the oxidative process; or it can be secondary, neutralizing or scavenging free radicals, transforming them into less reactive substances, and enhancing the primary action by donating hydrogen (Boulebd & Spiegel, 2023).

Distinct mechanisms of antioxidant action involve the modulation of the activity of reactive oxygen species (ROS) and protein-coding genes active in the defense system, redox reactions that neutralize and stabilize free radicals, stimulation of endogenous antioxidants such as enzymes, chelation of pro-oxidant metal ions, and competition for active sites (Ferreira et al., 2009; Lichota et al., 2019).

The antimicrobial activity of natural compounds occurs by disturbing cell membrane permeability and inhibiting respiration, resulting in coagulation of vital cellular components and destabilization of the lipid bilayer due to disruption of bonds, ultimately resulting cell death (Hassan et al., 2020; Radunz et al., 2020). Membrane damage can also compromise the electrical gradients of cells, which affect energy generation and cellular homeostasis (Nourbakhsh et al., 2022).

Table 2. Promising natural compounds for treating stored grains: bioactive properties and relevant studies

Promising natural compound	Primary bioactive compound	Source matrix	Potential effect	Reference
Natural polysaccharide	Chitosan	Shrimp heads	Delays the growth of *Aspergillus parasiticus*	Cota-Arriola et al. (2011)
Essential oil	Bornyl and camphene acetate	*Valeriana officinalis*	*Tribolium castaneum*: contact toxicity and repellency; *Liposcelis bostrychophila*: contact and fumigant toxicity and attraction	Feng et al. (2019)
Essential oil	Thymol and carvacrol	*Rosmarinus officinalis, Thymus vulgaris, Origanum majoricum, Origanum vulgare, Origanum virens,* and *Satureja montana*	Inhibition of *Aspergillus flavus* growth and aflatoxin production in stored maize grains	García-Díaz et al. (2019)
Essential oil	Thymol, cis-sabinene hydrate, ascaridole, dihydrotagetone, spathulenol, and ocimenone	*Origanum vulgare* spp. *virens*, *Origanum x applii, Origanum vulgare* spp. *Vulgare*, *Chenopodium ambrosioides*, and *Tagetes riojana*	Antifungal action against *Fusarium verticillioides*	Pizzolitto et al. (2019)
Essential oil	Thymol, carvacrol, p-cymene and γ-terpinene	*Satureja intermedia*	Mortality (90%) of storage pests (*Trogoderma granarium*, *Rhyzopertha* dominica, *Tribolium castaneum,* and *Oryzaephilus surinamensis*)	Ebadollahi & Setzer (2020)
Essential oils	((Z)-citral, (E)-citral, carvacrol, limonene, and cinnamaldehyde	Cinnamon (*Cinnamomum* spp.), oregano (*Origanum* spp.) and lemongrass (*Cymbopogon citratus*)	Inhibition of *Aspergillus flavus* growth in maize grains; the combination of oils has synergistic effects and inhibits aflatoxin production	Xiang et al. (2020)
Sulfur compound	Allyl isothiocyanate	Commercial formulation	High toxicity and reduction in oviposition and progeny of *Callosobruchus maculatus* when applied to cowpea beans	Vilela et al. (2020)
Phenolic compounds	Benzoic acid, quinol, salicylic acid, myricetin, and rutin	*Eucalyptus camaldulensis*	Antifungal effect on *Fusarium culmorum, Rhizoctonia solani, Botrytis cinerea*; contact and fumigant toxicity on *Tribolium castaneum* and *Sitophilus oryzae*	Abdelkhalek et al. (2020)
Alkaloids	Capsaicin and piperine	*Capsicum chinense* and *Piper nigrum*	Reduction in growth and germination rate of spores *Aspergillus parasiticus* and reduction in the production of aflatoxins, with emphasis on *P. nigrum*	Buitimea-Cantúa et al. (2020)
Alkaloids and flavonoids	Alkaloids and flavonoids	*Acanthus montanus, Acanthospermum hispidum, Argyreia nervosa,* and *Alchornea laxiflora*	Mortality, reduction in egg laying and emergence of *Sitophilus zeamais* adults in stored maize grains, with significant effects of *A. montanus*	Ileke et al. (2020)
Essential oil	1,8-cineole	*Laurus nobilis*	Inhibition of *Aspergillus flavus* growth and aflatoxin B1production, even in wheat grains stored for 6 months, and antioxidant activity through free radical scavenging and inhibition of linoleic acid oxidation	Belasli et al. (2020)
Sulfur compound in essential oil	Allicin	*Allium sativum*	Antifungal effect on *Gibberella zeae, Aspergillus parasiticus,* and *Fusarium verticillioides,* with lower rates effective on the latter two species in maize grains stored for 30 days	Bocate et al. (2021)
Alkaloids	Guineensine and piperine	*Piper guineense*	Mortality (>80%) and reduction in oviposition of *Sitophilus zeamais* females	Akinbuluma et al. (2021)
Essential oil	β-eudesmol, elemol, α-terpineol, methyl eugenol, and caryophyllene	*Rhynchanthus beesianus*	Fumigant effect on *Liposcelis entomophila* and *Tribolium castaneum* adults	Pan et al. (2022)
Phenolic compounds	Enol, o-cresol, m-cresol, p-cresol, p-cymene, thymol, carvacrol, guaiacol, creosol, and vanillin	Essential oils and similar compounds	Thymol and carvacrol are toxic to *Sitophilus zeamais*, with thymol functioning as a repellent and carvacrol as both repellent and attractant	Rodríguez et al. (2022)
Natural polysaccharide	Chitosan	Commercial chitosan	Inhibition of mycelial growth of *Aspergillus flavus* and *Aspergillus fumigatus*, with effect on fungal metabolism	Ke et al. (2022)
Essential oil	Eugenol and pulegone	*Syzygium aromaticum* and *Mentha pulegium*	Mortality of *Sitophilus zeamais* (90%) and reduction of losses (45%) caused by them in maize grains stored for 5 months	Sousa et al. (2023)
Essential oil	Thymol, ρ-cymene, z-caryophyllene, and γ-terpinene	*Thymus vulgaris*	Inhibition of the growth of *Penicillium* spp. in wheat stored for 6 months	Ziyat et al. (2023)

Natural compounds can be used as insecticides due to their toxic and repellent effects and inhibition of feeding, growth, and reproduction of organisms (Hammoud et al., 2022). One of their insecticidal mechanisms of action is neurotoxicity, which may occur through the induction of nerve impulses due to changes in the permeability of sodium-excited nerve cells, disturbances in food-related neurotransmitters and chemosensors, and activation of neurotransmitter receptors, which alter cellular functions and block essential ions (Lee et al., 2019; Vanegas-Estévez et al., 2024).

Additionally, natural insecticides induce deterrence, altering insect behavior through anti-feeding effects and hormonal changes, mainly juvenile and ecdysteroid hormones, which affects insect growth and development and directly damages tissue structure (Mordue & Blackwell, 1993; Mossa, 2016)

Some natural compounds also function as repellents, with effective effects on grain-damaging insects, or as attractants, mainly as pheromones and alarm synomones for pest monitoring and control (Luu-dam et al., 2021; Hammoud et al., 2022).

Another insecticidal mechanism of action of natural compounds is stomach damage, where toxins introduced damage the epithelial cells of the insect's stomach, preventing feeding (Ibrahim et al., 2010). Furthermore, some natural compounds have ovicidal activity by affecting gas exchange and water balance, causing hormonal and enzymatic changes, coagulation of protoplasm, and damage to the egg's outer structure, which will prevent the hatching of new individuals (Smith, 1952).

Chemical active ingredients approved for use in stored grains in Brazil have three distinct action mechanisms: modulation of sodium channels, inhibition of complex IV in the mitochondria electron transport chain, and inhibition of acetylcholinesterase/modulation of sodium channels (Agrofit, 2003).

Despite the efficacy of chemical pesticides, the number of approved active ingredients and their associated mechanisms of action is limited, which challenges pest control in grain storage facilities and contributes to the emergence of resistance due to excessive use of insecticides and fumigants with similar mechanisms of action (Agrofit, 2003; Li et al., 2024). Moreover, some natural compounds share similar mechanisms of action with approved insecticides (Peng et al., 2023; Vanegas-Estévez et al., 2024; Wang et al., 2024). These factors underscore the potential of natural compounds in replacing chemical pesticides for controlling pests in stored grains, mainly in the absence of approved fungicides, and the benefits of using natural antioxidants over synthetic ones.

Limitations of the Use of Natural Compounds

Natural compounds shown promise across various sectors; however, gaps remain in their utilization. Limited availability of studies in the literature remains a key constraint in their application for treating stored grains. Furthermore, it is important to emphasize the lack of approved natural products specifically for use in grain storage in Brazil (Agrofit, 2003), which makes the use of natural compounds an empirical approach (Chunarkar-Patil et al., 2024).

Essential oils are the most widely researched natural compounds for insect pest control, which is attributed to their complex composition rich in diverse bioactive substances rather than single isolated substance (Giunti et al., 2019; Kavallieratos et al., 2021; Remesh & Babu, 2023). Despite initial research progress, challenges persist in their identification, extraction, and application, including difficulties in isolation, extraction efficiency, low concentrations (especially in plants), stability, bioavailability, and legal considerations (Albuquerque et al., 2021).

Limitations in selecting the source matrix arise from the inability to cultivate organisms and the reduced production of target compounds outside their natural habitats (Atanasov et al., 2021). Therefore, exploring genetic manipulation and gene expression related to compound synthesis is necessary for cultivating organisms and inducing substance biosynthesis outside their natural habitats (Atanasov et al., 2021).

Natural compounds from non-abundant sources often result in limited availability, which hinders their industrial applicability (Yang et al., 2020), as overexploitation is not sustainable and threatens species survival.

Several methods, such as elicitation and metabolic engineering, have been investigated to increase compound concentration in organisms (Albuquerque et al., 2021). Elicitation boosts the production of bioactive compounds in plant secondary metabolism under stress conditions (Zlotek et al., 2019). Metabolic engineering stimulates compound production in microorganisms via de novo biosynthesis (Albuquerque et al., 2021).

Concerning stability, natural compounds are generally less stable than synthetic counterparts (Lourenço et al., 2019), requiring careful storage and potentially shorter shelf life.

Most natural compounds show low bioavailability and bioaccessibility, which results in reduced activity (Albuquerque et al., 2021; Rodrigues et al., 2022). Influencing factors include chemical structure, solubility, processing, synergistic/antagonistic effects with other compounds, and biotransformation (Domínguez-Ávila et al., 2017).

Research into natural compound applications for treating stored grains remains at an empirical stage, lacking standardized methods, which limits their effectiveness. Variations in application methods can yield inconsistent results and hinder replications and widespread implementation, requiring further research. Researchers have achieved promising results by incorporating these compounds to packaging (Feng et al., 2019; Bocate et al., 2021); however, this applicability in broader spaces remains unverified.

Legal considerations also challenge natural compound application studies. Patent acquisition can be complex, especially in some countries that do not grant intellectual property rights to natural products in their origin forms (Burton & Evans-Illidge, 2014; Harrison, 2014; Atanasov et al., 2021). This complexity extends to patent registration in Brazil (INPI, 2020).

Considering these challenges, finding effective solutions for studying the application of natural compounds in stored grains is crucial. Biotechnology and nanotechnology provide potential pathways for sustainable exploration, addressing agricultural demands and consumer needs.

Future Perspectives on the Use of Natural Compounds in Stored Grains

The integration of natural compounds into available methods for treating stored grains holds promise due to their potential benefits, low toxicity, and minimal environmental impact, despite some limitations. The growing demand for sustainable alternatives, especially following the development of the UN Sustainable Development Goals, stimulates research into effective and stable production, extraction methods, and formulations. Genetic improvement, encapsulation, and controlled release of natural compounds are promising technologies and strategies to enhance the efficacy of these substances in protecting stored grains.

Furthermore, advancements in regulations and certifications for natural products, along with their added value, can contribute to the standardization and widespread adoption of these compounds in agriculture. Additionally, Collaboration among stakeholders—from producers and consumers to the private sector and regulatory bodies—is essential for promoting these biological solutions within the sustainable agriculture context.

Conclusions

1. The study of natural compounds for treatments of stored grains offers promising new sustainable approaches for grain storage management.

2. There is a demand for further research to identify new useful natural compounds, enhance the understanding of their mechanisms of action and safety, as well as the extraction, application, and formulation processes that enable the use of these substances as a method for treating stored grains.

Contribution of authors: Diana Ribeiro Alves: Methodology, Literature Review, Draft Writing - Original, Writing - Review and Editing and Visualization; Júlio César de Almeida Andrade: Methodology, Literature Review, Draft Writing – Original and Writing - Review and Editing; Danúbia Aparecida Costa Nobre: Conceptualization, Writing - Review and Editing and Supervision.

Supplementary documents: There are no supplementary data available from the research.

Conflict of interest: The authors declare no conflict of interest.

Financing statement: The authors declare that there were no funding sources for the development of this article.

Literature Cited

Abdelkhalek, A.; Salem, M. Z. M.; Kordy, A. M.; Salem, A. Z. M.; Behiry, S. I. Antiviral, antifungal, and insecticidal activities of *Eucalyptus* bark extract: HPLC analysis of polyphenolic compounds. Microbial Pathogenesis, v.147, e104383, 2020. https://doi.org/10.1016/j.micpath.2020.104383

Abdullahi, N.; Dandago, M. A. Postharvest losses in food grains – A Review. Turkish Journal of Food and Agriculture Sciences, v.3, p.25-36, 2021. https://doi.org/10.53663/turjfas.958473

Abed, M. S.; Abdul-Nabe, R. A.; Petrescu, L.; Mihailescu, D. F. Effectiveness of microwave radiation in eliminating different insect species contaminating grain crops. Journal of Stored Products Research, v.102, e102121, 2023. https://doi.org/10.1016/j.jspr.2023.102121

Agrofit 2003 - Ministério da Agricultura, Pecuária e Abastecimento. 2003. Apresenta informações sobre produtos fitossanitários. Disponível em: <http://www.agricultura.gov.br/agrofit> Acess on: 05 may 2024.

Akinbuluma, M. D.; Ewete, F. K.; Oladosu, I. A. Amide alkaloids from *Piper guineense* and its crude extract as protectants against *Sitophilus zeamais*. Journal of Plant Diseases and Protection, v.128, p.1557–1564, 2021. https://doi.org/10.1007/s41348-021-00518-y

Akinneye, J. O.; Adeleye, O. A.; Adesina, F. P.; Akinyemi, M. I. Assessment of pesticide residue on cocoa beans in Ondo State, Nigeria. Brazilian Journal of Biological Sciences, v.5, p.577-588, 2018. https://doi.org/10.21472/bjbs.051031

Albuquerque, B. R.; Heleno, S. A.; Oliveira, M. B.; Barros, L.; Ferreira, I. C. Phenolic compounds: current industrial applications, limitations and future challenges. Food & Function. v.12, p.14-29, 2021. https://doi.org/10.1039/D0FO02324H

Amengual, J. Bioactive properties of carotenoids in human health. Nutrients, v.11, 2388, 2019. https://doi.org/10.3390/nu11102388

Angelovic, M.; Krištof, K.; Jobbágy, J.; Findura, P.; Križan, M. The effect of conditions and storage time on course of moisture and temperature of maize grains. BIO Web of Conferences, v.10, p.1-6. 2018. https://doi.org/10.1051/bioconf/20181002001

Araújo, R. I.; Freire, C.; Cruz, S.; Peters, L. P.; Ferreira, J. Identificação de isolados de *Fusarium* encontrados em grãos de milho durante o armazenamento em silos no estado do Acre. Enciclopédia Biosfera, v.18, p.132-146, 2021. https://doi.org/10.18677/EnciBio_2021D30

Ariong, R. M.; Okello; D. M.; Otim, M. H.; Paparu, P. Agriculture & Food Security, v.12, p.1-22, 2023. https://doi.org/10.1186/s40066-023-00423-7

Arora, S.; Stanley, J.; Srivastava, C. Temporal dynamics of phosphine fumigation against insect pests in wheat storage. Crop Protection, v.144, e105602, 2021. https://doi.org/10.1016/j.cropro.2021.105602

Atanasov, A. G.; Zotchev, S. B.; Dirsch, V. M.; Atanasov, A. G., Zotchev, S. B., Dirsch, V. M., Supuran, C. T. Natural products in drug discovery: Advances and opportunities. Nature Reviews Drug Discovery, v.20, p.200–216, 2021. https://doi.org/10.1038/s41573-020-00114-z

Ayalew, A. A. Insecticidal activity of Lantana camara extract oil on controlling maize grain weevils. Toxicology Research and Application, v.4, p.1-10, 2020. https://doi.org/10.1177/2397847320906491

Aziz, Z.; Ahmad, A.; Setapar, S.; Karakucuk, A.; Azim, M.; Lokhat, D.; Rafatullah, M.; Ganash, M.; Kamal, M.; Ashraf, G. Essential oils: Extraction techniques, pharmaceutical and therapeutic potential - A review. Current Drug Metabolism, v.19, p.1100-1110, 2018. https://doi.org/10.2174/1389200219666180723144850

Baliota, G. V.; Athanassiou, C. G. Evaluation of a Greek diatomaceous earth for stored product insect control and techniques that maximize its insecticidal efficacy. Applied Sciences., v.10, e6441. 2020. https://doi.org/10.3390/app10186441

Baliota, G. V.; Athanassiou, C. G. Evaluation of inert dusts on surface applications and factors that maximize their insecticidal efficacy. Applied Sciences, v.13, e2767, 2023. https://doi.org/10.3390/app13052767

Barba, F.; Zhu, Z.; Koubaa, M.; Sant'Ana, A.; Orlien, V. Green alternative methods for the extraction of antioxidant bioactive compounds from winery wastes and by-products: A review. Trends in Food Science and Technology, v.49, p.96-109, 2016. https://doi.org/10.1016/j.tifs.2016.01.006

Barba-Ostria, C.; Carrera-Pacheco, S. E.; Gonzalez-Pastor, R.; Heredia-Moya, J.; Mayorga-Ramos, A.; Rodríguez-Pólit, C.; Zúñiga-Miranda, J.; Arias-Almeida, B.; Guamán, L. P. Evaluation of biological activity of natural compounds: current trends and methods. Molecules, v.27, e4490, 2022. https://doi.org/10.3390/molecules27144490

Belasli, A.; Ben Miri, Y.; Aboudaou, M.; Ouahioune, L. A.; Montañes, L.; Ariño, A.; Djenane, D. Antifungal, antitoxigenic, and antioxidant activities of the essential oil from laurel (*Laurus nobilis* L.): Potential use as wheat preservative. Food Science Nutrition, v.8, p.4717–4729, 2020. https://doi.org/10.1002/fsn3.1650

Bertuzzi, T.; Romano, M.; Rastelli, S.; Giorni, P. Mycotoxins and related fungi in Italian paddy rice during the growing season and storage. Toxins, v.11, e151, 2019. https://doi.org/10.3390/toxins11030151

Bezerra, P. Q. M.; Matos, M. F. R.; Ramos, I. G.; Magalhaes-Guedes, K. T.; Druzian, J. I.; Costa, J. A. V.; Nunes, I. L. Innovative functional nanodispersion: Combination of carotenoid from Spirulina and yellow passion fruit albedo. Food Chemistry, v.285, p.397–405, 2019. https://doi.org/10.1016/j.foodchem.2019.01.181

Bocate, K. P.; Evangelista, A. G.; Luciano, F. B. Garlic essential oil as an antifungal and anti-mycotoxin agent in stored corn. Food Science and Technology, v.147, e111600, 2021. https://doi.org/10.1016/j.lwt.2021.111600

Borotová, P.; Galovičová, L.; Valková, V.; Ďúranová, H.; Vuković, N.; Vukić, M.; Babošová, M.; Kačániová, M. Biological activity of essential oil from *Foeniculum vulgare*. Acta Horticulturae et Regiotecturae, v.24, p.148–152, 2021. https://doi.org/10.2478/ahr-2021-0037

Boulebd, H.; Spiegel, M. Computational assessment of the primary and secondary antioxidant potential of alkylresorcinols in physiological media. RSC Advances, v.13, p.29463–29476, 2023. https://doi.org/10.1039/d3ra05967g

Bouyahya, A.; Guaouguaou, F-E.; Omari, N. E.; Menyiy, N. E.; Balahbib, A.; El-Shazly, M.; Bakri,Y. Anti-inflammatory and analgesic properties of Moroccan medicinal plants: Phytochemistry, in vitro and in vivo investigations, mechanism insights, clinical evidences and perspectives. Journal of Pharmaceutical Analysis, v.12, p.35-57, 2022. https://doi.org/10.1016/j.jpha.2021.07.004

BRASIL. Objetivos de Desenvolvimento Sustentável. 2024. Available on: <https://brasil.un.org/pt-br/sdgs>. Accessed on: April 2024.

Briggs, D. E.; McGuinness, G. Microbes on barley grains. Journal of the Institute of Brewing, v.99, p.249–255, 1993. https://doi.org/10.1002/j.2050-0416.1993.tb01168.x

Bucklin, R; Thompson, Sid; Montross, M.; Abdel-Hadi, A. Grain storage systems design. In: Kutz, M. Handbook of farm, dairy and food machinery. Academic Press. 2019. Cap.9, p.175-223. https://doi.org/10.1016/B978-0-12-814803-7.00009-9

Buitimea-Cantúa, G. V.; Velez-Haro, J. M.; Buitimea-Cantúa, N. E.; Molina-Torres, J.; Rosas-Burgos, E C. GC-EIMS analysis, antifungal and anti-aflatoxigenic activity of *Capsicum chinense* and *Piper nigrum* fruits and their bioactive compounds capsaicin and piperine upon *Aspergillus parasiticus*. Natural Product Research, v.34, p.1452-1455, 2020. https://doi.org/10.1080/14786419.2018.1514395

Burton, G.; Evans-Illidge, E. A. Emerging R and D law: the Nagoya Protocol and its implications for researchers. ACS Chemical Biology, v.9, p.588–591, 2014. https://doi.org/10.1021/cb500045t

Cafiero, C.; Viviani, S.; Nord, M. Food security measurement in a global context: The food insecurity experience scale. Measurement, v.116, p.146–152, 2018. https://doi.org/10.1016/j.measurement.2017.10.065

Chen, Y.; Xing, M.; Chen, T.; Tian, S.; Li, B. Effects and mechanisms of plant bioactive compounds in preventing fungal spoilage and mycotoxin contamination in postharvest fruits: A review. Food Chemistry, v.415, e135787, 2023. https://doi.org/10.1016/j.foodchem.2023.135787

Chunarkar-Patil, P.; Kaleem, M.; Mishra, R.; Ray, S.; Ahmad, A.; Verma, D.; Bhayye, S.; Dubey, R.; Singh, H.N.; Kumar, S. Anticancer drug discovery based on natural products: from computational approaches to clinical studies. Biomedicines, v.12, e201, 2024. https://doi.org/10.3390/biomedicines12010201

Coradi, P. C.; Oliveira, M. B. de; Carneiro, L. de O.; Souza, G. A. C. de; Elias, M. C.; Brackmann, A.; Teodoro, P. E. Technological and sustainable strategies for reducing losses and maintaining the quality of soybean grains in real production scale storage units. Journal of Stored Products Research, v.87, e101624, 2020. https://doi.org/10.1016/j.jspr.2020.101624

Cota-Arriola, O.; Cortez-Rocha; M. O.; Rosas-Burgos, E. C.; Burgos-Hernández, A.; López-Franco, Y. L.; Plascencia-Jatomea, M. Antifungal effect of chitosan on the growth of *Aspergillus parasiticus* and production of aflatoxin B1. Polymer International, v.60, p.937-944, 2011. https://doi.org/10.1002/pi.3054

Covele, G.; Gulube, A.; Tivana, L.; Ribeiro-Barros, A. I.; Carvalho, M. O.; Ndayiragije, A.; Nguenha, R. Effectiveness of hermetic containers in controlling paddy rice (*Oryza sativa* L.) storage insect pests. Journal of Stored Products Research, v.89, e101710, 2020. https://doi.org/10.1016/j.jspr.2020.101710

Cox-Georgian, D.; Ramadoss, N.; Dona, C.; Basu, C. Therapeutic and medicinal uses of terpeness. In: Joshee, N., Dhekney, S., Parajuli, P. Medicinal plants. Springer, Cham. 2019. Cap.15, p.333-359. https://doi.org/10.1007/978-3-030-31269-5_15

Dai, C.; Xiao, X.; Sun, F; Zhang, Y.; Hoyer, D.; Shen, J.; Tang, S.; Velkov, T. T-2 toxin neurotoxicity: role of oxidative stress and mitochondrial dysfunction. Archives of Toxicology, v.93, p.3041–3056, 2019. https://doi.org/10.1007/s00204-019-02577-5

Dey, P.; Kundu, A.; Kumar, A.; Gupta, M.; Lee, B. M.; Bhakta, T.; Dash, S.; Kim, H. S. Analysis of alkaloids (indole alkaloids, isoquinoline alkaloids, tropane alkaloids). In: Nabavi, S. M.; Saeedi, M.; Nabavi, S. F.; Silva, A. S. Recent Advances in Natural Products Analysis, 2020. Cap.15, p.505–567. https://doi.org/10.1016/B978-0-12-816455-6.00015-9

Dias, T. F. V.; Arcanjo, L. L.; Costa, G. L.; Souza, C. S.; Lima, C. A. R. Controle de pragas e tratamento de grãos armazenados para uso em rações para animais. Research, Society and Development, v.9, e739996964, 2020. https://doi.org/10.33448/rsd-v9i9.69641

Dhifi, W.; Bellili, S.; Jazi, S.; Bahloul, N.; Mnif, W. Essential oils' chemical characterization and investigation of some biological activities: A Critical Review. Medicines, v.3, p.25, 2016. https://doi.org/10.3390/medicines3040025

Domínguez-Avila, J. A.; Wall-Medrano, A.; Velderrain-Rodríguez, G. R.; Chen, C. O.; Salazar-López, N. J.; Robles-Sánchez, M.; González-Aguilar, G. A. Gastrointestinal interactions, absorption, splanchnic metabolism and pharmacokinetics of orally ingested phenolic compounds. Food & Function, v.8, p.15-38, 2017. https://doi.org/10.1039/c6fo01475e

Duan, W.-Y.; Zhu, X.-M.; Zhang, S.-B.; Lv, Y.-Y.; Zhai, H.-C.; Wei, S.; Ma, P.-A.; Hu, Y.-S. Antifungal effects of carvacrol, the main volatile compound in *Origanum vulgare* L. essential oil, against *Aspergillus flavus* in postharvest wheat. International Journal of Food Microbiology, v.410, e110514, 2024. https://doi.org/10.1016/j.ijfoodmicro.2023.110514

Dubey, V. K.; Mandal, S. K.; Chowdhury, S. Insight into management of rodents in storage grain. Just Agriculture, v.3, p.609-615, 2023. https://doi.org/10.13140/RG.2.2.35345.92005

Ebadollahi, A.; Setzer, W. N. Evaluation of the toxicity of *Satureja intermedia* C. A. mey essential oil to storage and greenhouse insect pests and a predator ladybird. Foods, v.9, e712, 2020. https://doi.org/10.3390/foods9060712

Elias, M. C. Secagem e armazenamento de grãos de milho e de sorgo na propriedade rural. In: Parfitt, J. M. B. Produção de milho e sorgo em várzea. Pelotas: Embrapa Clima Temperado. 2000. Cap.12, p.107-146.

El-Sayed, R. A.; Jebur, A. B.; Kang, W.; El-Demerdash, F. M. An overview on the major mycotoxins in food products: characteristics, toxicity, and analysis. Journal of Future Foods, v.2, p.91-102, 2022. https://doi.org/10.1016/j.jfutfo.2022.03.002

Elshafie, H. S.; Gruľová, D.; Baranová, B.; Caputo, L.; De Martino, L.; Sedlák, V.; Camele, I.; De Feo, V. Antimicrobial activity and chemical composition of essential oil extracted from *Solidago canadensis* l. growing wild in Slovakia. Molecules, v.24, e1206, 2019. https://doi.org/10.3390/molecules24071206

Falleh, H.; Jemaa, M. B.; Saada, M.; Ksouri, R. Essential oils: A promising ecofriendly food preservative. Food Chemistry, v.330, e127268, 2020. https://doi.org/10.1016/j.foodchem.2020.127268

Farias, O. R. de; Cruz, J. M. F. de L.; Duarte, I. G.; Veloso, J. S.; Nascimento, L. C. Controle de fungos com óleo de eucalipto e transmissão de *Fusarium* sp. em sementes de Mimosa caesalpiniifolia. Pesquisa Florestal Brasileira, v.43, e202002144, p.1-9, 2023. https://doi.org/10.4336/2023.pfb.43e202002144

Feng, Y. X.; Wang, Y.; Chen, Z. Y; Guo, S. S.; You, C. X.; Du, S. S. Efficacy of bornyl acetate and camphene from *Valeriana officinalis* essential oil against two storage insects. Environmental Science and Pollution Research, v.26, p.16157–16165, 2019. https://doi.org/10.1007/s11356-019-05035-y

Ferrara, M.; Perrone, G.; Gallo, A. Recent advances in biosynthesis and regulatory mechanisms of principal mycotoxins. Current Opinion in Food Science, v.48, e100923, 2022. https://doi.org/10.1016/j.cofs.2022.100923

Ferreira, C. D.; Lang, G. H.; Lindemann, I. S.; Timm, N. S.; Hoffmann, J. F.; Ziegler, V.; Oliveira, M. Postharvest UV-C irradiation for fungal control and reduction of mycotoxins in brown, black, and red rice during long-term storage. Food Chemistry, v.339, e127810, 2021. https://doi.org/10.1016/j.bioorg.2019.103043

Ferreira, I.; Barros, L.; Abreu, R. M. V. Antioxidants in wild mushrooms. Current Medicinal Chemistry, v.16, p.1543-1560, 2009. https://doi.org/10.2174/092986709787909587

Fleurat-Lessard, F. Integrated management of the risks of stored grain spoilage by seedborne fungi and contamination by storage mould mycotoxins – An update. Journal of Stored Products Research, v.71, p.22-40, 2017. https://doi.org/10.1016/j.jspr.2016.10.002

Gaban, A. C.; Morelli, F.; Brisola, M. V.; Guarnieri, P. Evolução da produção de grãos e armazenagem: perspectivas do agronegócio brasileiro para 2024/25. Informe GEPEC. v.21, p.28–47, 2017. https://doi.org/10.48075/igepec.v21i1.15407

Gallo, A.; Ghilardelli, F.; Doupovec, B.; Faas, J.; Schatzmayr, D.; Masoero, F. Kinetics of gas production in the presence of Fusarium mycotoxins in rumen fluid of lactating dairy cows. JDS Communications, v.2, p.243-247, 2021. https://doi.org/10.3168/jdsc.2021-0100

Gao, Q.; Qi, J.; Tan, Y.; Ju, J. Antifungal mechanism of Angelica sinensis essential oil against Penicillium roqueforti and its application in extending the shelf life of bread. International Journal of Food Microbiology, v.408, e110427, 2024. https://doi.org/10.1016/j.ijfoodmicro.2023.110427

Garcia-Cela, E.; Kiaitsi, E.; Sulyok, M.; Krska, R.; Medina, A.; Damico, I. P.; Magan, N. Influence of storage environment on maize grain: CO2 production, dry matter losses and aflatoxins contamination. Food Additives & Contaminants, v.36, p.175–185, 2019. https://doi.org/10.1080/19440049.2018.1556403

García-Díaz, M.; Patiño, B.; Vázquez, C.; Gil-Serna, J. A novel niosome-encapsulated essential oil formulation to prevent aspergillus flavus growth and aflatoxin contamination of maize grains during storage. Toxins, v.11, e646, 2019. https://doi.org/10.3390/toxins11110646

Gil-Serna, J.; García-Díaz, M.; Vázquez, C.; González-Jaén, M. T.; Patiño, B. Significance of *Aspergillus nige*r aggregate species as contaminants of food products in Spain regarding their occurrence and their ability to produce mycotoxins. Food Microbiology, v.82, p.240-248, 2019. https://doi.org/10.1016/j.fm.2019.02.013

Giunti, G.; Palermo, D.; Laudani, F.; Algeri, G. M.; Campolo, O.; Palmeri,V. Repellence and acute toxicity of a nano-emulsion of sweet orange essential oil toward two major stored grain insect pests. Industrial Crops and Products, v.142, e111869, 2019. https://doi.org/10.1016/j.indcrop.2019.111869

Grijalva, I.; Skidmore, A. R.; Milne, M. A.; Olaya-Arenas, P.; Kaplan, I.; Foster, R. E.; Yaninek, J. S. Integrated pest management enhances biological control in a US midwestern agroecosystem by conserving predators and non-pest prey. Agriculture, Ecosystems & Environment, v.368, e109009, 2024. https://doi.org/10.1016/j.agee.2024.109009

Gu, F.; Gong, B.; Gilbert, R. G.; Yu, W.; Li, E.; Li, C. Relations between changes in starch molecular fine structure and in thermal properties during rice grain storage. Food Chemistry, v.295, p.484-492, 2019. https://doi.org/10.1016/j.foodchem.2019.05.168

Hamel, D.; Rozman, V.; Liška, A. Storage of cereals in warehouses with or without Pesticides. Insects, v.11, e846, 2020. https://doi.org/10.3390/insects11120846

Hamidian, M.; Salehi, A.; Naghiha, R.; Dehnavi, M. M.; Mohammadi, H.; Nejad Mirfathi, M.; Mojarab-Mahboubkar, M. Biological activity of essential oils from Ferulago angulata and Ferula assa-foetida against food-related microorganisms (antimicrobial) and *Ephestia kuehniella* as a storage pest (insecticidal); an in vitro and in silico study. Fitoterapia, v.175, e105937, 2024. https://doi.org/10.1016/j.fitote.2024.105937

Hammoud, Z.; Abada, M. B.; Greige-Gerges, H.; Elaissari, A.; Jemâa, J. M. B. Insecticidal effects of natural products in free and encapsulated forms: An overview. Journal of Natural Pesticide Research, v.1, e100007, 2022. https://doi.org/10.1016/j.napere.2022.100007

Harrison, C. Patenting natural products just got harder. Nature Biotechnology, v.32, p.403-404, 2014. https://doi.org/10.1038/nbt0514-403a

Hasnain, S. M. M.; Hasnain, Md. S.; Nayak, A. K.; Natural polysaccharides: sources and extraction methodologies. In: Hasnain, Md. S.; Nayak, A. K. Natural polysaccharides in drug delivery and biomedical applications. Academic Press. 2019. Chapter 1, p.1-14. https://doi.org/10.1016/B978-0-12-817055-7.00001-7

Hassan, H. A.; Genaidy, M. M.; Kamel, M. S.; Abdelwahab, S. F. Synergistic antifungal activity of mixtures of clove, cumin and caraway essential oils and their major active components. Journal of Herbal Medicine, v.24, e100399, 2020. https://doi.org/10.1016/j.hermed.2020.100399

Hazra, S.; Das, D.; Moulick, D.; Hossain, A. Endophytes: the treasure house of bioactive compounds with potential applications in sustainable agriculture and other sectors. In: Kumar, A.; Santoyo, G.; Singh, J. Biocontrol Agents for Improved Agriculture - Plant and Soil Microbiome. Academic Press. 2024. Chpter 20, p.477-506. https://doi.org/10.1016/B978-0-443-15199-6.00001-4

Honda, M. Nutraceutical and pharmaceutical applications of carotenoids. In: Jacob-Lopes, E.; Queiroz, M.; Zepka, L. Pigments from microalgae handbook. Springer, Cham. 2020. Chapter.18, p.449-469.https://doi.org/10.1007/978-3-030-50971-2_18

Ibrahim, M. A.; Griko, N.; Junker, M.; Bulla, L. A. *Bacillus thuringiensis*: A genomics and proteomics perspective. Bioengineered Bugs, v.1, p.31–50, 2010. https://doi.org/10.4161/bbug.1.1.10

INPI. Instituto Nacional da Propriedade Industrial. Brasil. Patentes. 2020. Available on: https://www.gov.br/inpi/pt-br/servicos/perguntas-frequentes/patentes. Accessed on: May 2024.

Ileke, K. D.; Idoko, J. E.; Ojo, D. O.; Adesina, B. C. Evaluation of botanical powders and extracts from Nigerian plants as protectants of maize grains against maize weevil, *Sitophilus zeamais* (Motschulsky) [coleoptera: Curculionidae]. Biocatalysis and Agricultural Biotechnology, v.27, e101702, 2020. https://doi.org/10.1016/j.bcab.2020.101702

Iztayev, A.; Baibatyrov, T.; Mukasheva, T.; Muldabekova, B.; Yakiyayeva, M. Experimental studies of the baisheshek barley grain processed by the ion-ozone mixture. Tchê Química, v.17, p.239-258, 2020. https://doi.org/10.52571/ptq.v17.n35.2020.22_iztayev_pgs_239_258.pdf

Jafarzadeh, S.; Hadidi, M.; Forough, M.; Nafchi, A. M.; Khaneghah, A. M. The control of fungi and mycotoxins by food active packaging: A review. Critical Reviews in Food Science and Nutrition, v.63, p.6393-6411, 2023. https://doi.org/10.1080/10408398.2022.2031099

Jiang, H.; Zhong, S.; Schwarz, P.; Chen, B.; Rao, J. Chemical composition of essential oils from leaf and bud of clove and their impact on the antifungal and mycotoxin inhibitory activities of clove oil-in-water nanoemulsions. Industrial Crops and Products, v.187, e115479, 2022. https://doi.org/10.1016/j.indcrop.2022.115479

Jian, F. Lethal and mobile variation of stored product insects and mites under low temperatures. Journal of Stored Products Research, v.105, e102240, 2024. https://doi.org/10.1016/j.jspr.2023.102240

Kavallieratos, N. G.; Skourti, A.; Nika, E. P.; Mártonfi, P.; Spinozzi, E.; Maggi, F. *Tanacetum vulgare* essential oil as grain protectant against adults and larvae of four major stored-product insect pests. Journal of Stored Products Research, v.94, e101882, 2021. https://doi.org/10.1016/j.jspr.2021.101882

Ke, Y.; Ding, B.; Zhang, M.; Dong, T.; Fu, Y.; Lv, Q.; Ding, W.; Wang, X. Study on inhibitory activity and mechanism of chitosan oligosaccharides on *Aspergillus flavus* and *Aspergillus fumigatus*. Carbohydrate Polymers, v.275, e118673, 2022. https://doi.org/10.1016/j.carbpol.2021.118673

Kuyu, C. G.; Tola, Y. B.; Mohammed, A.; Mengesh, A.; Mpagalile, J. J. Evaluation of different grain storage technologies against storage insect pests over an extended storage time. Journal of Stored Products Research, v.96, e101945, 2022. https://doi.org/10.1016/j.jspr.2022.101945

Laca, A.; Mousia, Z.; Diaz, M.; Webb, C.; Pandiella, S. S. Distribution of microbial contamination within cereal grains. Journal of Food Engineering, v.72, p.332–338, 2006. https://doi.org/10.1016/j.jfoodeng.2004.12.012

Langenheim, J. H. Higher plant terpenoids: a phytocentric overview of their ecological roles. Journal of Chemical Ecology, v.20, p.1223–1280, 1994. https://doi.org/10.1007/BF02059809

Leach, A.; Pecenka, J.; Kaplan, I. Does IPPM bear fruit? Evaluating reduced-risk insecticide programmes on pests, pollinators and marketable yield. Journal of Applied Ecology, v.59, p.2993-3002, 2022. https://doi.org/10.1111/1365-2664.14294

Lee, J. P.; Kang, M. G.; Lee, J. Y.; Oh, J. M.; Baek, S. C.; Leem, H. H.; Park, D.; Cho, M.-L.; Kim, H. Potent inhibition of acetylcholinesterase by sargachromanol I from *Sargassum siliquastrum* and by selected natural compounds. Bioorganic Chemistry, v.89, e103043, 2019. https://doi.org/10.1016/j.foodchem.2020.127810

Li, X.-Y.; Si, F.-L.; Zhang, X.-X.; Zhang, Y.-J.; Chen, B. Characteristics of trypsin genes and their roles in insecticide resistance based on omics and functional analyses in the malaria vector *Anopheles sinensis*. Pesticide Biochemistry and Physiology, v.201, e105883, 2024. https://doi.org/10.1016/j.pestbp.2024.1058

Lichota, A.; Gwozdzinski, L.; Gwozdzinski, K. Therapeutic potential of natural compounds in inflammation and chronic venous insufficiency. European Journal of Medicinal Chemistry, v.176, p.68-91, 2019. https://doi.org/10.1016/j.ejmech.2019.04.075

Liu, Z.; Li, M.; Wang, S.; Huang, H.; Zhang, W. Sulfur-containing metabolites from marine and terrestrial fungal sources: Origin, structures, and bioactivities. Marine Drugs, v.20, p.1-18, 2022. https://doi.org/10.3390/md20120765

Liu, J.; Deng, Y.; Zhao, Z.; Zhang, J.; Hua, J.; Luo, S. The chemical diversity of essential oils from galls of two *Artemisia* spp., and their insecticidal activity against the storage pest *Callosobruchus chinensis*. Industrial Crops and Products, v.214, e118505, 2024. https://doi.org/10.1016/j.indcrop.2024.118505

Loi, N. V.; Binh, P. T.; Thanh, K. T.; Ngoc, N. T. T. Study to determine the chemical constituents, antibacterial ability, and antioxidant activity of the red pepper (*Piper Nigrum* l.) essential oil in Gia Lai Province, Vietnam. Food Science and Technology, v.43, e28723, 2023. https://doi.org/10.5327/fst.28723

Los, A.; Ziuzina, D.; Bourke, P. Current and future technologies for microbiological decontamination of cereal grains. Journal of Food Science, v.83, p.1484-1493, 2018. https://doi.org/10.1111/1750-3841.14181

Lopes, S. Z. B.; Monkolski, A.; Monkolski, J. G. de F. Siqueira, D. J. S. Influência do óleo essencial de citronela na repelência e mortalidade de *Sitophilus zeamais*. Scientific Electronic Archives, v.4, p.15-22, 2023. http://dx.doi.org/10.36560/16420231692

Lorini, I.; Krzyzanowski, F. C.; França-Neto, J. B.; Henning, A. A.; Henning, F. A. Manejo integrado de pragas de grãos e sementes armazenadas. Brasília: Embrapa, 2015. 86p.

Losic, D.; Korunic, Z. Diatomaceous earth, a natural insecticide for stored grain protection: recent progress and perspectives. In: Losic, D. Diatomaceous nanotechnology: progress and emerging applications. The Royal Society of Chemistry, 2018. Chapter 10, p.219-247. https://doi.org/10.1039/9781788010160-00219

Lourenço, S. C.; Moldão-Martins, M.; Alves, V. D. Antioxidants of natural plant origins: From sources to food industry applications. *Molecules*, v.*24*, p.1-25, 2019. https://doi.org/10.3390/molecules24224132

Lu, Y.; Zhang, M.; Huang, D. Dietary organosulfur-containing compounds and their health-promotion mechanisms. Annual Review of Food Science and Technology, v.13, p.287-313, 2022. https://doi.org/10.1146/annurev-food-052720-010127

Luchesi, L. A.; Paulus, D.; Busso, C.; Frata, M. T.; Oliveira, J. B. Chemical composition, antifungal and antioxidant activity of essential oils from *Baccharis dracunculifolia* and *Pogostemon cablin* against *Fusarium graminearum*. Natural Product Research, v.36, p.849–852, 2022. https://doi.org/10.1080/14786419.2020.1802267

Lutz, E.; Coradi, P. C. Applications of new technologies for monitoring and predicting grains quality stored: Sensors, internet of things, and artificial intelligence. Measurement, v.188, e110609, 2022. https://doi.org/10.1016/j.measurement.2021.110609

Luu-Dam, N. A.; Tabanca, N.; Estep, A. S.; Nguyen, D. H.; Kendra, P. E. Insecticidal and attractant activities of *Magnolia citrata* leaf essential oil against two major pests from Diptera: *Aedes aegypti* (Culicidae) and *Ceratitis capitata* (Tephritidae). Molecules, v.26, e2311, 2021. https://doi.org/10.3390/molecules26082311

Manandhar, A.; Milindi, P.; Shah, A. An overview of the post-harvest grain storage practices of smallholder farmers in developing countries. *Agriculture*, v.*8*, e57, 2018. https://doi.org/10.3390/agriculture8040057

Mattos, A. P. M. N.; Krewer, A. M. A.; Eccel, C; Will, J. Uso de óleos essenciais para o controle de pragas do milho. Estrabão, v,2, p.139–147, 2021. https://doi.org/10.53455/re.v2i.17

Melo, A. L. de; Silva, S. B.; Albuquerque, J. Armazenamento, proteção de grãos e controle orgânico em pequenas propriedades. Belém: Edufra, 2018. 62p.

Mir, S. A.; Mir, M. B.; Shah, M. A.; Hamdani, A. M.; Sunooj, K. V.; Phimolsiripol, Y.; Khaneghah, A. M. New prospective approaches in controlling the insect infestation in stored grains. Journal of Asia-Pacific Entomology, v.26, e102058, 2023. https://doi.org/10.1016/j.aspen.2023.102058

Mng'ong'o, M. Assessment of maize and beans storage insect pest in major grain markets, Morogoro-Tanzania. Saudi Journal of Biological Sciences, v.30, e103491, 2023. https://doi.org/10.1016/j.sjbs.2022.103491

Montoya-Martínez, A. C.; Valenzuela Ruiz, V.; Chávez-Luzanía, R. A.; Villa-Rodríguez, E. D.; Villalobos, S. d. l. S. Biological control agents for mitigating plant diseases. In New insights, trends, and challenges in the development and applications of microbial inoculants in agriculture. Developments in Applied Microbiology and Biotechnology. 2024. Chapter 4, p.27-35. https://doi.org/10.1016/B978-0-443-18855-8.00004-7

Mordue, A. J.; Blackwell, A. Azadirachtin: An update. Journal of Insect Physiology, v.39, p.903–924, 1993. https://doi.org/10.1016/0022-1910(93)90001-8

Moreira, M. D.; Melo, M. M.; Coimbra, J. M.; Reis, K. C.; Schwan, R. F.; Silva, C. F. Solid coffee waste as alternative to produce carotenoids with antioxidante and antimicrobial activities. Waste Management, v.82, p.93-99, 2018. https://doi.org/10.1016/j.wasman.2018.10.017

Morrison, W. R.; Larson, N. L.; Brabec, D., Zhang, A. Methyl benzoate as a putative alternative, environmentally friendly fumigant for the control of stored product insects. *Journal of Economic Entomology*, v.112, p.2458–2468, 2019. https://doi.org/10.1093/jee/toz179

Mossa, A. T. H. Green pesticides: Essential oils as biopesticides in insect-pest management. Journal of Environmental Science and Technology, v.9, p.354-378, 2016. https://doi.org/10.3923/jest.2016.354.378

Munkvold, G. P.; Proctor, R. H.; Moretti, A. Mycotoxin production in fusarium according to contemporary species concepts. Annual Review of Phytopathology, v.59, p.373-402, 2021. https://doi.org/10.1146/annurev-phyto-020620-102825

Nazzaro, F.; Fratianni, F.; Coppola, R.; Feo, V. D. Essential oils and antifungal activity. Pharmaceuticals, v.10, e86, 2017. https://doi.org/10.3390/ph10040086

Nourbakhsh, F.; Lotfalizadeh, M.; Badpeyma, M.; Shakeri, A.; Soheili, V. From plants to antimicrobials: Natural products against bacterial membranes. Phytotherapy Research, v.36, p.33–52, 2022. https://doi.org/10.1002/ptr.7275

Olinto, F. A.; Oliveira, V. S.; Nunes, M. S.; Silva, H. F.; Porcino, M. M.; Nascimento, L. C. Óleos essenciais no tratamento de sementes florestais nativas do semiárido brasileiro. Revista Principia, v.60, p.610–633, 2023. http://dx.doi.org/10.18265/1517-0306a2021id6299

Oliveira, L. V.; Rolim, A. C. P.; Silva, G. F. da, Araújo, L. C. de, Braga, V. A. de L.; Coura, A. G. L. Changes in dietary habits related to the COVID-19 pandemic: a literature review. Brazilian Journal of Health Review, v.4, p.8464-8477, 2021.

Oliveira, R. V.; Sousa, A. H. de; Tamwing, G. da S.; Silva, M. C. da; Silva, M. C. da; Mota, B. B. Óleo essencial de *Piper aduncum* L.: toxicidade e sinergismo como estratégias de controle de *Sitophilus zeamais* Motschulsky, 1855 (Coleoptera: Curculionidae): uma revisão de literatura. Scientia Naturalis, v.5, p.925-941, 2023. https://doi.org/10.29327/269504.5.2-30

Ooi, B. K.; Chan, K. G.; Goh, B. H.; Yap, W. H. The role of natural products in targeting cardiovascular diseases via nrf2 pathway: novel molecular mechanisms and therapeutic approaches. Frontiers in Pharmacology, v.15, e1308, 2018. https://doi.org/10.3389/fphar.2018.01308

Ootani, M. A.; Aguiar, R. W.; Ramos, A. C. C; Brito, D. R.; Silva, J. B; Cajazeira, J. P. Use of essential oils in agriculture. Journal of Biotechnology and Biodiversity, v.4, p.162-174, 2013. https://doi.org/10.20873/jbb.uft.cemaf.v4n2.ootani

Pan, X.; Xiao, H.; Hu, X.; Liu, Z. L. Insecticidal activities of the essential oil of *Rhynchanthus beesianus* rhizomes and its constituents against two species of grain storage insects. Zeitschrift für Naturforschung C, v.78, p.83-89, 2022. https://doi.org/10.1515/znc-2022-0017

Panigrahi, S.S.; Singh, C.B.; Fielke, J.; Zare, D. Modeling of heat and mass transfer within the grain storage ecosystem using numerical methods: A review. Drying Technology, v.38, p.1677-1697, 2020. https://doi.org/10.1080/07373937.2019.1656643

Paul, A.; Radhakrishnan, M.; Anandakumar, S.; Shanmugasundaram, S.; Anandharamakrishnan, C. Disinfestation techniques for major cereals: A status report. Comprehensive Reviews in Food Science and Food Safety, v.19, p.1125-1155, 2020. https://doi.org/10.1111/1541-4337.12555

Paul, A.; Visakh, N. U.; Pathrose, B.; Mori, N.; Baeshen, R. S.; Shawer, R. Exploring the chemical characterization and insecticidal activities of *Curcuma angustifolia* roxb. leaf essential oils against three major stored product insects. Saudi Journal of Biological Sciences, v.31, e103986, 2024. https://doi.org/10.1016/j.sjbs.2024.103986

Penagos-Tabares, F.; Khiaosa-ard, R.; Faas, J.; Papst, F.; Egger-Danner, C.; Zebeli, Q. A 2-year study reveals implications of feeding management and exposure to mycotoxins on udder health, performance, and fertility in dairy herds. Journal of Dairy Science, v.107, p.1124-1142, 2024. https://doi.org/10.3168/jds.2023-23476

Peng, J.; Chen, Z.; Chen, X.; Zheng, R.; Lu, S.; Seyab, M.; Yang, F.; Li, Q.; Tang, Q. Insecticidal potential of a *Consolida ajacis* extract and its major compound (ethyl linoleate) against the diamondback moth, Plutella xylostella. Pesticide Biochemistry and Physiology, v.195, e105557, 2023. https://doi.org/10.1016/j.pestbp.2023.105557

Pizzolitto, R. P.; Jacquat, A. G.; Usseglio, V. L.; Achimón, F.; Cuello, A. E.; Zygadlo, J. A.; Dambolena, J. S. Quantitative-structure-activity relationship study to predict the antifungal activity of essential oils against *Fusarium verticillioides*. Food Control, v.108, e106836, 2019. https://doi.org/10.1016/j.foodcont.2019.106836

Pratyusha, S. Phenolic compounds in the plant development and defense: An overview. In: Hasanuzzaman, M; Nahar, K. Plant stress physiology-perspectives in agriculture. IntechOpen. 2022. Cap.7, p.125-140. https://doi.org/10.5772/intechopen.102873

Qi, Z.; Tian, L.; Zhang, H.; Zhou, X.; Lei, Y.; Tang, F. Mycobiome mediates the interaction between environmental factors and mycotoxin contamination in wheat grains. Science of The Total Environment, v.928, e172494, 2024. https://doi.org/10.1016/j.scitotenv.2024.172494

Quasim, M. A.; Karn, A. K.; Paul, S.; Hmar, E. B. L.; Sharma, H. K. Herbal rodent repellent: A dependable and dynamic approach in defiance of synthetic repellent. Bulletin of the National Research Centre, v.47, e82, 2023. https://doi.org/10.1186/s42269-023-01055-4

Radunz, M.; Hackbart, H. C. S.; Camargo, T. M.; Nunes, C. F. P.; Barros, F. A. P.; Magro, J. D.; Filho, P. J. S.; Gandra, E. A.; Radünz, A. L.; Zavareze, E. R. Antimicrobial potential of spray drying encapsulated thyme (*Thymus vulgaris*) essential oil on the conservation of hamburger-like meat products. International Journal of Food Microbiology, v.330, e108696, 2020. https://doi.org/10.1016/j.ijfoodmicro.2020.108696

Rajendran, S. Grain storage: perspectives and problems. In: Chakraverty, A.; Mujumdar, A. S.; Raghavan G. S. V. Handbook of postharvest technology. CRC Press. 2003. Cap.8, p.183-214.

Remesh, A. V.; Babu, C. S. V. Fumigant and contact toxicities of individual and additive combinations of biorational-essential oils for control of rice weevil (*Sitophilus oryzae*). Natural Product Research, v.37, p.2748-2752, 2023. https://doi.org/10.1080/14786419.2022.21

Rigopoulou, M.; Baliota, G. V.; Athanassiou, C. G. Persistence and efficacy of diatomaceous earth against stored product insects in semi-field trials. Crop Protection, v.174, e106416, 2023. https://doi.org/10.1016/j.cropro.2023.106416

Rizwan, M.; Atta, B.; Ali, M. Y.; Ashraf, I.; Arshad, M.; Tahir, M.; Rizwan, M.; Sabir, A. M.; Shehzadi, N.; Khalid, U. B.; Iqbal, S.; Pan, M-Z.; Liu T-X. The comparison of interstitial relative humidity and temperatures of hermetic and polypropylene bag for wheat grain storage under different agro-climatic conditions of rice-wheat ecosystem of Pakistan: Effect on seed quality and protection against insect pests. Journal of Stored Products Research, v.96, e101936, 2022. https://doi.org/10.1016/j.jspr.2022.101936

Rodrigues, D. B.; Marques, M. C.; Hacke, A.; Filho, P. S. L.; Cazarin, C. B. B.; Mariutti, L. R. B.; Trust your gut: Bioavailability and bioaccessibility of dietary compounds, Current Research in Food Science, v.5, p.228-233, 2022. https://doi.org/10.1016/j.crfs.2022.01.002

Rodríguez, A.; Beato, M.; Usseglio, V. L.; Camina, J.; Zygadlo, J. A.; Dambolena, J. S.; Zunino, M. P. Phenolic compounds as controllers of *Sitophilus zeamais*: a look at the structure-activity relationship. Journal of Stored Products Research, v.99, e102038, 2022. https://doi.org/10.1016/j.jspr.2022.102038

Sánchez, G.; Aznar, R. Evaluation of natural compounds of plant origin for inactivation of enteric viroses. Food and Environmental Virology, v.7, p.183-187, 2015. https://doi.org/10.1007/s12560-015-9181-9

Santos, N. C.; Silva, J. E.; Santos, A. C. C.; Dantas J. O.; Tavares, S. R. S. A.; Andrade V. S.; Oliveira, S. D. D. S.; Blank, A. F.; Araújo, A. P. A; Bacci, L. Bioactivity of essential oils from *Croton grewioides* and its major compounds: Toxicity to soybean looper *Chrysodeixis includens* and selectivity to the predatory stink bug *Podisus nigrispinus*. Environmental Science and Pollution Research International, v.30, p.18798–18809, 2023. https://doi.org/10.1007/s11356-022-23414-w

Schmidt, M.; Zannini, E.; Arendt, E.K. Recent advances in physical post-harvest treatments for shelf-life extension of cereal crops. Foods, v.7, e45, 2018. https://doi.org/10.3390/foods7040045

Shah, M. A.; Manj, I. A.; Naseer, J.; Anjum, K.; Hafeez, S.; Ahmad, H. M.; Faridi, T. Padrões de danos de diferentes aves e espécies de roedores em armazenamentos de grãos em Bahawalpur, Paquistão. Revista de Ciências Agrícolas, v.5, p.28–37, 2023. https://doi.org/10.56520/asj.v5i2.270

Shang, A.; Cao, S.-Y.; Xu, X.-Y.; Gan, R.-Y.; Tang, G.-Y.; Corke, H.; Mavumengwana, V.; Li, H.-B. Bioactive compounds and biological functions of garlic (*Allium sativum* L.). Foods, v.8, e246, 2019. https://doi.org/10.3390/foods8070246

Sharma, S.; Semwal, A. D.; Murugan, M. P.; Khan, M. A.; Wadikar, D. Grain storage and transportation management. In: Nayik, G. A.; Tufail, T.; Anjum, F. M.; Javed Ansari, M. Cereal grains: composition, nutritional attributes, and potential applications. CRC Press. 2023. Chapter14, p.269-296. https://doi.org/10.1201/9781003252023

Silva, A. O. da; Silva, A. O. da; Gomes, J. A.; Oliveira, R. C. de; Silva, D. A. S.; Viégas, I. de J. M. Grain storage in family agriculture: main problems and ways of storage in the northeast paraense region. Research, Society and Development, v.10, e36610111835, 2021. http://dx.doi.org/10.33448/rsd-v10i1.11835

Singh, K. D.; Mobolade, A. J.; Bharali, R.; Sahoo, D.; Rajashekar, Y. Main plant volatiles as stored grain pest management approach: A review. Journal of Agriculture and Food Research, v.4, e100127, 2021. https://doi.org/10.1016/j.jafr.2021.100127

Smith, E. H. Tree spray oils. In: American Chemical Society. agricultural applications of petroleum products. Advances in Chemistry Series. 1952. Chapter 1, p.3–11. https://doi.org/10.1021/ba-1951-0007.ch001

Sousa, P. A. S.; Neto, J.; Barbosa, J. V.; Peres, J.; Magro, A.; Barros, G.; Sousa, J. M.; Magalhães, F. D.; Mexia, A.; Aguiar, A. A. R. M.; Bastos, M. M. S. M. Novel approach for a controlled delivery of essential oils during long-term maize storage: Clove bud and pennyroyal oils efficacy to control *Sitophilus zeamais*, reducing grain damage and post-harvest losses. Insects, v.14, 366, 2023. https://doi.org/10.3390/insects14040366

Souza, I. P.; Ruffato, S. Cinética de secagem e qualidade de grãos de milho secados naturalmente. Research, Society and Development, v.10, e44010817334, 2021. http://dx.doi.org/10.33448/rsd-v10i8.17334

Souza, W. F. de; Vargas, A. N.; Val, J. B. R. do; Freitas, A. de M. A.; Lorini, M. Control of temperature to suppress the population of *Rhyzopertha dominica* (F.) (Coleoptera, Bostrichidae) in a grain silo prototype. In: European Control Conference, 2013, Zurich. Proceedings. Zurich: European Control Association, p.4089-4093, 2013.

Sruthi, N. U.; Rao, P. S. Effect of processing on storage stability of millet flour: A review. Trends in Food Science & Technology, v.112, p.58-74, 2021. https://doi.org/10.1016/j.tifs.2021.03.043

Střelková, T.; Jurkaninová, L.; Bušinová, A.; Nový, P.; Klouček, P. Essential oils in vapour phase as antifungal agents in the cereal processing chain. Trends in Food Science & Technology, v.143, e104293, 2024. https://doi.org/10.1016/j.tifs.2023.104293

Subramanyam, B.; Madamanchi, N.; Norwood, S. Effectiveness of insecto applied to shelled maize against stored-product insect larvae. Journal of Economic Entomology, v.91, p.280-286, 1998. https://doi.org/10.1093/jee/91.1.280

Sulhath, T. A. A.; Visakh, N. U.; Pathrose, B.; George, S. B. Investigating the insecticidal properties of essential oils extracted from wild turmeric (*Curcuma aromatica* salisb) leaves waste against three key stored product pests. Sustainable Chemistry and Pharmacy, v,38, e101482, 2024. https://doi.org/10.1016/j.scp.2024.101482

Sun, Y.; Huang, K.; Long, M.; Yang, S.; Zhang, Y. An update on immunotoxicity and mechanisms of action of six environmental mycotoxins. Food and Chemical Toxicology, v.163, e112895, 2022. https://doi.org/10.1016/j.fct.2022.112895

Tanase, C.; Coşarcă, S.; Muntean, D-L. A critical review of phenolic compounds extracted from the bark of woody vascular plants and their potential biological activity. *Molecules*, v.*24*, 1182, 2019. https://doi.org/10.3390/molecules24061182

Tanguy A.; Deudon O.; Crepon K. Disponibilidade média de resfriamento para aeração de grãos na França nos últimos 20 anos. In: Conti B., Trematerra P., editors. Anais do Livro de Resumos da 12ª Conferência do Grupo de Trabalho Proteção Integrada de Produtos Armazenados; Pisa, Itália. 3 a 6 de setembro de 2019 https://doi.org/10.3390/insects11090598

Tewari, H.; Kasana, V. K.; Jyothi, K. N.; Tewari, G. Efficacy of essential oils from three Mentha species against postharvest groundnut pest, *Caryedon serratus* (Olivier) (Coleoptera: Bruchidae). Journal of Natural Pesticide Research, v.7, e100063, 2024. https://doi.org/10.1016/j.napere.2023.100063

Taroncher, M.; Fuentes, C.; Rodríguez-Carrasco, Y.; Ruiz, M.-J. Assessment of the genotoxic and mutagenic effects induced by T-2 mycotoxin in HepG2 cells. Toxicology, v.501, e153712, 2024. https://doi.org/10.1016/j.tox.2023.153712

Thawabteh, A.; Juma, S.; Bader, M.; Karaman, D.; Scrano, L.; Bufo, S. A.; Karaman, R. The biological activity of natural alkaloids against herbivores, cancerous cells and pathogens. Toxins, v.11, e656, 2019. https://doi.org/10.3390/toxins11110656

Tohidi, B.; Rahimmalek, M.; Trindade, H. Review on essential oil, extracts composition, molecular and phytochemical properties of *Thymus* species in Iran. Industrial Crops and Products, v.134, p.89-99, 2019. https://doi.org/10.1016/j.indcrop.2019.02.038

Torre, R.; Pereira de Medeiros, E. A. D.; Pereira, C. S. B.; Menezes, A. C. R.; Fontes, I. S.; Pereira, L. V. R.; Paiva, D. H. F.; Santos, A. M. D.; Damasceno Junior, P. C.; Souza, M. A. A. D. Protection of cowpea seeds and toxicity against cowpea weevils by the essential oils from Lippia alba (verbenaceae) and Schinus terebinthifolius (anacardiaceae). Crop Protection, v.180, e106670, 2024. https://doi.org/10.1016/j.cropro.2024.106670

Tudu, M; Samantha, S. Natural polysaccharides: Chemical properties and application in pharmaceutical formulations. European Polymer Journal, v.184, e111801, 2023. https://doi.org/10.1016/j.eurpolymj.2022.111801

Tushar, S. R; Alam, Md. F. B.; Zaman, S. Md.; Garza-Reyes, J. A; Bari, A. B. M. M; Karmaker, C. L. Analysis of the factors influencing the stability of stored grains: Implications for agricultural sustainability and food security. Sustainable Operations and Computers, v.4, p.40-52, 2023. https://doi.org/10.1016/j.susoc.2023.04.003

Upmanyu, V.; Sapra, L.; Srivastava, R. K. Employment of selective pharmacologically active natural compounds in treatment and management of osteoporosis. Studies in Natural Products Chemistry, v.75, p.161-241, 2022. https://doi.org/10.1016/B978-0-323-91250-1.00005-7

Vanegas-Estévez, T.; Duque, F. M.; Urbina, D. L.; Vesga, L. C.; Mendez-Sanchez, S. C. Design and elucidation of an insecticide from natural compounds targeting mitochondrial proteins of *Aedes aegypti*. Pesticide Biochemistry and Physiology, v.198, e105721, 2024. https://doi.org/10.1016/j.pestbp.2023.105721

Vilela, A. de O.; Faroni, L. R. A.; Sousa, A. H.; Pimentel, M. A. G.; Gomes, J. L. Toxicological and physiological effects of allyl isothiocyanate upon *Callosobruchus maculatus*. Journal of Stored Products Research, v.87, e101625, 2020. https://doi.org/10.1016/j.jspr.2020.101625

Wang, H.; Yih, K.; Yang, C.; Huang, K. Anti-oxidant activity and major chemical component analyses of twenty-six commercially available essential oils. Journal of Food and Drug Analysis, v.25, p.881–889, 2017. https://doi.org/10.1016/j.jfda.2017.05.007.

Wang, L.; Liu, B.; Jin, J.; Mal, L.; Dai, X.; Pan, L.; Liu, Y.; Zhao, Y.; Xing, F. The complex essential oils highly control the toxigenic fungal microbiome and major mycotoxins during storage of maize. Frontiers in Microbiology, v.10, e1643, 2019. https://doi.org/10.3389/fmicb.2019.01643

Wang, Q.; Feng, J.; Han, F.; Wu, W.; Gao, S. Analysis and prediction of grain temperature from air temperature to ensure the safety of grain storage. International Journal of Food Properties, v.23, p.1200-1213, 2020. https://doi.org/10.1080/10942912.2020.1792922

Wang, R.; Wang, Y.; Guo, W.; Zeng, M. Stability and bioactivity of carotenoids from *Synechococcus* sp. PCC 7002 in Zein/NaCas/Gum Arabic composite nanoparticles fabricated by pH adjustment and heat treatment antisolvent precipitation. Food Hydrocolloids, v.117, e106663, 2021. https://doi.org/10.1016/j.foodhyd.2021.106663

Wang, K.; Yan, Y.; Huang, L.; Sun, H.; Yu, N.; Liu, Z. Insecticidal activity of the spider neurotoxin PPTX-04 through modulating insect voltage-gated sodium channel. Pesticide Biochemistry and Physiology, v.201, e105853, 2024. https://doi.org/10.1016/j.pestbp.2024.105853

Wyckhuys, K. A. G.; Akutse, K. S.; Amalin, D. M.; Araj, S. E.; Barrera, G.; Beltran, M. J. B.; Ben Fekih, I. B.; Calatayud, P. A.; Cicero, L.; Cokola, M. C.; Colmenarez, Y. C.; Dessauvages, K.; Dubois, T.; Durocher-Granger, L.; Espinel, C.; Fallet, P.; Fernández-Triana, J. L.; Francis, F.; Gómez, J.; Haddi, K.; Hadi, B. A. R. Global scientific progress and shortfalls in biological control of the fall armyworm *Spodoptera frugiperda*. Biological Control, v.191, e105460, 2024. https://doi.org/10.1016/j.biocontrol.2024.105460

Xiang, F.; Zhao, Q.; Zhao, K.; Pei, H.; Tao, F. The efficacy of composite essential oils against aflatoxigenic fungus *Aspergillus flavus* in maize. Toxins, v.12, e562, 2020. https://doi.org/10.3390/toxins12090562

Xie, J. H.; Jin, M. L.; Morris, G. A; Zha, X. Q.; Chen, H. Q.; Yi, Y.; Li, J. E; Wang, Z. J.; Gao, J.; Nie, S. P.; Shang, P.; Xie, M. Y. Advances on bioactive polysaccharides from medicinal plants. Critical Reviews in Food Science and Nutrition, v.29, p.60-84, 2016. https://doi.org/10.1080/10408398.2015.1069255

Yanagawa, A.; Tomaru, M.; Kajiwara, A.; Nakajima, H.; Quemener, E. D. L.; Steyer, J. P.; Mitani, T. Impact of 2.45 GHz Microwave irradiation on the fruit fly, Drosophila melanogaster. Insects, v.11, e598, 2020. https://doi.org/10.3390/insects11090598

Yang, D.; Park, S. Y.; Park, Y. S.; Eun, H.; Lee, S. Yu. Metabolic engineering of *Escherichia coli* for natural product biosynthesis. Trends in Biotechnology, v.38, p.745-765, 2020. https://doi.org/10.1016/j.tibtech.2019.11.007

Ygit, E. Development of an expression for the volume of off-centered conical pile inside a cylindrical silo. Measurement, v.146, p.903–911, 2019. https://doi.org/10.1016/j.measurement.2019.07.036

Yubonmhat, K.; Chinwong, S.; Nattawoot, M.; Saowadee, N.; Youngdee, W. Cellular water and proton relaxation times of Thai rice kernels during grain development and storage. Journal of Cereal Science, v.88, p.65–70, 2019. https://doi.org/10.1016/j.jcs.2019.05.005

Ziegler, V.; Paraginski, R. T.; Ferreira, C. D. Grain storage systems and effects of moisture, temperature and time on grain quality - A review. Journal of Stored Products Research, v.91, e101770, 2021. https://doi.org/10.1016/j.jspr.2021.101770

Ziyat, H.; Naciri Bennani, M.; Arif, S.; Houssaini, J.; Hajjaj, H. Fungicide formulation based on *Thyme* essential oil and clay for wheat protection. Research on Chemical Intermediates, v.49, p.2769–2792, 2023. https://doi.org/10.1007/s11164-023-05013-7

Złotek, U.; Szymanowska, U.; Jakubczyk, A.; Sikora, M.; Świeca, M. Effect of arachidonic and jasmonic acid elicitation on the content of phenolic compounds and antioxidant and anti-inflammatory properties of wheatgrass (*Triticum aestivum*, L.). Food Chemistry, v.288, p.256–261, 2019. https://doi.org/10.1016/j.foodchem.2019.02.124