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Review Article

Ecological Management of Stored Cereal and Legume Insects in Morocco: Status and Future Prospects

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Abstract

Postharvest losses caused by pests in cereal and legume stocks are a major food security challenge in Morocco. These losses can be harmful and seriously affect food supply chains. Synthetic insecticides are widely used to combat pest proliferation in stored foodstuffs. Although these chemicals are shown to be effective in controlling storage pests, their use may induce increased resistance in exposed species, resulting in additional health and ecological repercussions. In addition, some synthetic insecticide residues can contaminate stored foods and pose risks to human and animal health. In this context, several studies on ecological management, particularly natural plant-based extracts, have been conducted to fight storage pests without affecting the quality of stored foodstuffs. This work reviews the ecological management of stored cereal and legume pests, as well as the state of the art of research on these aspects in Morocco. Indeed, several emerging technologies have been identified, including varietal resistance, semiochemicals, and physical and biological control, with a particular emphasis on the exploitation of biopesticides in Morocco. The challenges and research perspectives of these ecological practices were also discussed. Based on the literature, ecological control is both safer and more effective in the long term and not only benefits the environment but also human health by reducing exposure to hazardous substances.

Keywords: Ecological management; Insecticides; Morocco; Storage pests

Introduction

At the worldwide level, cereals are of great importance with an annual production that varies between 2.8 and 3.2 billion tonnes from 2015 to 2020. Maize is the most important cereal produced, followed by wheat, with a total global production of 760 million tons by 2020 (FAOSTAT 2022).

In Morocco, cereals are the main agricultural lever, with average areas cultivated ranging from 3.7 to 5.5 million hectares (Mha) between 2000 and 2020 i.e., 80% of the country's useful agricultural area (El Allaoui *et al.* 2022). Food legumes are ranked second in importance after cereals, with an annual occupation varying from approximately 0.3 to 0.5 Mha. The main legumes cultivated in the country are broad bean (*Vicia faba* L.), chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* Médik), and pea (*Pisum sativum* L) plants (Daoui 2007). To guarantee the country's food security, Morocco imported between 3.2 and 4.7 million tonnes of wheat between 2015 and 2021 (FAOSTAT 2022). This constitutes a food security stock by maintaining its quantity until the next harvest. During the storage period, these commodities can suffer qualitative and quantitative losses due to pests, mainly insects (Benhalima *et al.* 2001). Indeed, the control of pests in stored cereals and legumes is essential to preserve the quality and quantity of crops, guarantee food security, and reduce economic losses. The main control method used in Morocco is based on synthetic pesticides, particularly phosphine gas fumigation (PH_3). However, in addition to the risk of the emergence of resistant ecotypes, excessive use of chemical pesticides has negative consequences on the environment, public health, and food safety (Regnault-Roger *et al.* 2002; Benhalima *et al.* 2004; Stoytcheva 2011). Therefore, more attention is being paid to environmentally friendly and non-chemical methods to control stored food pests. These methods include manipulation of the storage environment, integrated pest management, biological spraying, and the use of traps. Several methods for the integrated management of pests associated with stored agricultural commodities are being developed (Adda *et al.* 2002; Titouhi 2018). The development of biopesticides based on essential oils of plant origin is now an alternative that is attracting growing interest from researchers worldwide. From this perspective, several organs and parts of plants have been exploited to

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reduce the losses caused by insect pests during seed storage through their insecticidal effects.

In Morocco, much research has been conducted in this field, and the results obtained are promising but have not yet been sufficiently exploited. In this study, we provide a comprehensive review of the primary control methods studied globally, with a specific focus on the utilization of plant insecticidal power and ecological techniques in crop preservation in Morocco. The objective of this review was to assess the potential of ecological and non-chemical methods in pest control of stored cereals and pulses and to identify sustainable and safe practices and strategies for their implementation.

Alteration factors in stored grain

Stored cereals and pulses are often exposed to deterioration risk, which can lead to significant economic losses. Factors such as high humidity, insect and pest attacks, fungal contamination, and inadequate storage conditions are the primary causes of deterioration. The degradation factors of stored grains can be summarized into four elements:

Technical causes

Longer the grains are stored, the more they are subjected to loss of quality and nutritional value. Therefore, it is important to monitor the storage time and ensure that the grain is bought or used before it deteriorates excessively. In addition, the condition of the grain (cleanliness) and the state of storage structures and packaging must be well-designed to prevent the attack of stocks by various biological agents of degradation (Cruz and Diop 1989).

Respiration

As a living organism, in the presence of oxygen, starch degrades the production of carbon dioxide, water, and heat. To guarantee good conservation of the grains, it is necessary to act on this reaction and limit this phenomenon to the extent possible by intervening in the temperature and humidity (Cruz and Diop 1989).

The degradation phenomenon can be observed in lots of grain stored too humid, where strong heating can encourage germination and the development of fungi, ultimately leading to a loss of grain mass (Cruz *et al.* 2016). The rate of degradation of the product can be determined precisely in the laboratory by measuring the quantity of CO_2 released by 100 g of grain dry matter in 24 h (Cruz *et al.* 2016). The loss of 0.5% of dry matter due to respiration phenomena is a criterion for the deterioration of cereals which makes it possible to evaluate the maximum storage time without risk (Steele *et al.* 1969).

Physical factors

Humidity and temperature accelerate respiration, which is an important factor in grain degradation (Cruz and Diop 1989). High humidity in storage installations creates an ideal environment for the development of fungi, which causes the formation of molds and the production of mycotoxins that can be harmful to human health. Insect infestations cause physical damage to grains and reduce their nutritional quality by consuming nutritive components. In addition, inadequate storage conditions, such as exposure to sunlight or extreme temperatures, can lead to rancidity of oils in cereals and pulses.

Bio-aggressors

Fungi, mites, insects, birds, and rodents are the most important aggressors of cereal and pulse stock (Banga *et al.* 2018). Insects cause considerable damage in terms of their quantity. Global losses of cereals due to insect infestation are estimated at 10–40% per year (Asrar *et al.* 2016; Banga *et al.* 2018).

Under optimal temperature and humidity conditions, a large number of micro-organisms (moulds, fungi, bacteria) multiply on grains. For cereals, species of the *Fusarium* genus predominate in the field, while others such as *Aspergillus* and *Penicillium* appear during the storage period. Their development reduces the quality of grain, but especially risks causing health problems by producing mycotoxins, substances that are toxic to humans and animals (Cruz *et al.* 2016).

Pests of cereals and pulses in morocco

Cereals and pulses are a group of insects that damage stored food products by feeding on them. These pests include several types of beetles, weevils, mites, and acarids. Coleoptera and Lepidoptera are considered the main pests of stored foods, so those that attack healthy seeds are classified as primary pests, whereas those that take advantage of the damage caused by primary pests and do not have the ability to pierce the seed coat are called secondary pests (Cruz *et al.* 1988; Jerraya 2003).

Cereals are subjected to significant insect pest attacks. The main pests of stored cereals in Morocco are listed in Table 1. The most dominant pests are *Rhyzopertha dominica*, *Tribolium castaneum*, *Cryptolestes ferrugineus* and *Oryzaephilus surinamensis*, *T. castaneum* is the predominant secondary pest (Hagstrum *et al.* 2013). Pests of stored food pulses cause significant damage in terms of quality and quantity and consequently reduce the germinability of seeds. Their losses in developed countries do not exceed 3%, but in Africa, they are on the order of 40% after only six months of storage (Stamm 2014).

Pulses are subjected to numerous attacks by a multitude of pests, both in the field and in storage. At the storage level, Coleoptera is the most dangerous pest, especially the families Chrysomelidae or Bruchidae (Table 2; El-Miziani *et al.* 2016; Tapondjou *et al.* 2002). This

Table 1: Pests of stored cereals in Morocco

Order	Famille	Nom scientifique	Infested food stuff	Reference
Coleoptera		*Sitophilus granarius*	Wheat, Barley, Rye	Bartali *et al.* (1990); Hagstrum et *al.* (2013)
	Curculionidae	*Sitophilus oryzae*	Wheat, Rice	Hagstrum et *al.* (2013); Idouaarame et *al*. (2018)
		Sitophilus zeamais	Maize	Hagstrum et *al.* (2013)
	Bostrichidae	*Rhyzopertha dominica*	Wheat	Bartali et *al.* (1990) ; Hagstrum et *al.* (2013) ; Idouaarame et *al.* (2018)
	Dermastidae	*Trogoderma granarium*	Wheat	Hagstrum et *al.* (2013) ;
	Tenebrionidae	*Tribolium castaneum*	Wheat	Bartali et *al.* (1990) ; Hagstrum et *al.* (2013) ; Abbad et *al.* (2014)
		Tribolium confusum	Wheat	Hagstrum et *al.* (2013); Abbad et *al.* (2014)
		Gnatocerus cornutus	Cereals	Hagstrum et *al.* (2013)
	Silvanidae	*Oryzaephilus surinamensis*	Wheat, Barley, Maize	Hagstrum et *al.* (2013);
	Cucujidae	*Cryptolestes ferrugineus*	Cereals	Bartali et *al.* (1990) ; Hagstrum et *al.* (2013)
	Anobiinae	*Stegobium paniceum*	Cereals	Hagstrum et *al.* (2013)
Lepidoptera	Gelechidae	*Sitotroga cerealella*	Wheat, Barley, Maize, Sorghum	Hagstrum et *al.* (2013);
		Corcyra cephalonica	rice	Hagstrum et *al.* (2013)
	Pyralidae	*Plodia interpunctella*	Cereals	Hagstrum et *al.* (2013)
		Nemapogon granella	Cereals	Hagstrum et *al.* (2013)
	Tineidae	*Ephestia kuehniella*	Cereals	Hagstrum et *al.* (2013)

Table 2: Pests of stored pulses in Morocco

Order	Famille	Nom scientifique	Infested food stuff	Reference
Coléoptera	Chrysomelidae monovoltine	*Bruchus lentis*	Lentils	Hagstrum et *al.* (2013) ; El-Miziani et al. (2016)
		Bruchus ervi	Lentils	Hagstrum et *al.* (2013)
		Bruchus pisorum	Lathyrus, Peas	Hagstrum et *al.* (2013) ; El-Miziani et al. (2016)
		Bruchus rufimanus	Faba Bean, Lentils	Boughdad *et al.* (1997) ; El-Miziani *et al.* (2016)
	Chrysomelidae polyvoltine	*Callosobruchus maculatus*	Cowpeas	El-Miziani *et al.* (2016)
		Callosobruchus chinensis	Lentils	Yus-Ramos (2010) El-Miziani *et al.* (2016)
		Bruchidius atrolineatus	Chickpeas, Lentils.	Hagstrum et *al.* (2013)
		Acanthoscelides obtectus	Haricot bean	Hagstrum et *al.* (2013)

family is composed of two groups: the first group includes bruchids of one annual generation (univoltine), such as *Bruchus rufimanus* (bean bruchid), *B. lentis* (lentil bruchid), or *B. pisorum* (pea bruchid) (Delobel and Tran 1993). The second group is composed of bruchids from multiple annual generations (polyvoltine) such as *Callosobruchus maculatus* (cowpea bruchid) and *C. chinensis* (Chinese bruchid) (El-Miziani *et al.* 2016).

Traditional storage methods for cereal and pulse seeds

Traditional techniques for preserving food stocks, particularly cereals and pulses, have been used for centuries by farmers and local communities worldwide. Before storage, farmers often carry out solarization by exposing harvested grain to the sun to reduce moisture and kill insects and pathogens. One of the most common traditional techniques is storage in silos or cylindrical structures made of wood, earth, or stone, which are used to store cereals and pulses (Mobolade *et al.* 2019). Granary storage is another form of grain and pulse seed storage within wooden or bamboo structures that are often built on stilts to avoid moisture and insect growth (Henríquez-Valido *et al.* 2020). Storage in earthenware jars is used in many crops in Africa to store cereals and pulses (Nukenine 2010). Another old technique is to store seeds as straw in dry, aerated locations (Shelke *et al.* 2021). Canvas bags are used to store grains and pulses in many crops. Other traditional techniques were also cited such as open-air/air storage, near the fire in the farm hut, mud lozenge, grain storage with natural/botanical products, etc. (Mobolade *et al.* 2019).

In Morocco, farmers use traditional storage methods to control pests and diseases in stored products, such as: (1) drying grains in the sun to eliminate attacks by insect pests and microorganisms, (2) elimination of weed parts that have not yet dried to prevent the development of fungi and insect

Table 3: Insecticides authorized for use in food products (extracted from the list of pesticides homologated by the ONSSA (ONSSA 2023)

Active substance(s)	Dose	Commercial name	Usage
Deltaméthrine (0,2%)	50 g/q	K-OBIOL	Treatment of stored products
Deltaméthrine (25 g/L) & Pipéronyl butoxyde(225 g/l)	2 cc/q	K-OBIOL EC 25 PB ; VALENS	Treatment of stored cereals (eggs, larvae and adults)
Spinosade (1,25%)	75 g/ql	SPINTOR 0.125 D	Capuchin beetle; grain weevils; grain beetle.
Cyperméthrine (20 g/L) & Pipéronyl butoxyde (57 g/L)	0,084 l/t de grains	TALISMA UL	Grain weevils Post-harvest spray treatment
Malathion (2%)	50 g/q	MALYPHOS GRAIN	Processing of stored products (cereals and pulses)
Phosphure d'aluminium (56%)	6 comprimés/m³	QUICKPHOS TABLETS ; CELPHOS ; FUMITOXIN COMPRIMES SPHERIQUES ; FUMITOXIN PILULES ; PHOSTOXIN COMPRIMES	Fumigation of stored food.
Phosphine (2%)	100 g/m3	ECO2FUME	Fumigation of stored food.
Bromure de méthyle (98%) & Chloropicrine (2%)	18-100 g/m3	METABROM 98	Fumigation of stored food.

larvae in the stock, (3) use of plants with biocidal effects to protect stored foodstuffs from harmful agents and. (4) application of plant protection products to seed pests (Allali *et al.* 2020a). The predominant storage method is the use of hermetic bags, followed by the traditional method of underground storage (Matmouras). Insects are the main pests of cereals and pulses in Morocco, followed by fungi and rats (Allali *et al.* 2020a).

These traditional techniques are often adapted to local conditions and based on the practical experience of farmers and local communities. However, some of these techniques may not be adapted to the current climate or conditions. Thus, they are vulnerable to rodents, diseases, and insect pests that cause significant food loss, and it is important to continue to explore new techniques for preserving food stocks to meet the changing needs of farmers and local communities. Traditional methods of storing cereals and pulses are limited in their ability to preserve the nutrient content and quality of grains, which has led to the excessive use of chemical pesticides for the management of pests associated with cereals and pulses in storage (Kuyu *et al.* 2022).

Insecticides used in stock preservation in Morocco

Pest management is conducted using synthetic insecticides, especially in developed countries that are still testing different molecules against stored food pests (Wasala *et al.* 2015). According to the National Office of Food Safety (ONSSA 2023), the Moroccan organization responsible for the homologation of chemical products for agricultural use, the active substances homologated for the treatment of stored products in the Moroccan market are fumigants (aluminum phosphide and methyl bromide) and contact products (Deltamethrin, Spinosade, Cypermethrin, Piperonyl butoxide, and malathion) (Table 3).

Secondary effects related to use insecticides for preservation of stored products

Despite the effectiveness of insecticides in preserving stored food products, serious concerns have been raised regarding the risks to human health and the environment in Morocco. The exposure of the workforce and residues found in food and drinking water is alarming. Insecticides can cause respiratory problems, allergies, headaches, nausea, and vomiting in workers handling these products. Insecticide residues can also contaminate food and drinks, leading to long-term health problems such as cancer, liver disease, and nervous system disorders. In addition, adverse effects on the environment and other living organisms through spray drift, leaching, and runoff have been reported (Damalas and Eleftherohorinos 2011). Insecticides can contaminate the soil, groundwater, and nearby waterways. These chemicals can also kill non-target organisms, such as beneficial insects, fish, and birds, thus affecting the ecological balance. Methyl bromide, which has been used since 1930 to control quarantine insects (Fields and White 2002), has been identified as an ozone-depleting and climate-affecting gas (WMO/UNEP/NOAA/NASA 1995).

Insects can develop resistance to insecticides when exposed over a long period of time. This resistance can render insecticides ineffective, forcing farmers to use stronger products or higher doses to achieve the same results. The continuous and regular use of fumigants to preserve stored food products induces resistance to phosphine and other insecticides at different stages of insect development (Pimentel *et al.* 2007; Nayak *et al.* 2012). Benhalima *et al.* (2004) has focused on the resistance of *Sitophilus oryzae* populations to phosphine taken from stored wheat.

Alternatives to chemical control of stored food pests

Several alternative forms of insect control have been developed in response to the side effects of chemical control (Fields and White 2002). These are discussed below.

Varietal resistance

Nineteen maize varieties resistant to attack by *Prostephanus truncatus* (Horn.) (Coleoptera: Bostrichidae) were selected (Kumar 2002). The results showed that the weight, hardness, and nature of the grain surface can mitigate losses caused by *C. maculatus* by reducing the growth and multiplication rates of insect populations (Sulehrie *et al.* 2003). Thandar *et al.* (2021) showed resistance of the cowpea cultivar Tvu 2027 which was bred by the International Institute for Tropical Agriculture (IITA) in Ibadan, Nigeria against *C. chinensis* and *C. maculatus*. In Morocco, Boughdad *et al.* (1986) showed the influence of the tegument in the resistance of ripe grains of the "Giant Portuguese" variety of *V. faba*, which acts as a barrier to the larval development of the bruchid *C. maculatus*.

Physical control

In contrast to most pests, stored food pests live in an environment that is largely determined by humans. Therefore, control of storage conditions can slow the growth rate of insect populations and can eventually be used to eliminate infestation (Fields and White 2002). Optimal conditions for the development of storage insects are between 25 and 32°C, and a relative humidity range of 65–75% (Howe 1965; Fields 1992). Outside these intervals and under the most extreme conditions, insect development slows, and many individuals eventually die (Fields and White 2002).

Heat treatment

Heat treatment, an old technique dating back 100 years (Dean 1911), consists of increasing the temperature of the entire installation to between 50 and 60°C to kill insects in stored products (Mahroof *et al.* 2003; Roesli *et al.* 2003; Stejskal *et al.* 2019). Fields (1992) determined the temperature and exposure time required to control several storage insects, most stored food pests are killed in the following combinations:24 h exposure at 40°C, 12 h at 45°C, 5 min at 50°C, 1 min at 55°C and 30 s at 60°C.

Temperature affects development and reproduction of adult populations, as in the case of C. chinensis, where the lifespan of the insect's eggs, larvae, pupae and adults decreased as the temperature increased to 16, 24 and 32°C (Omar and Mahmoud 2020)

Cold treatment

In Canada and the northern USA, the intense periods of winter cold have long been used by millers to protect him against insects (Bell 2014). The use of low temperatures for the preservation of stored food products is a good alternative to chemical treatments, especially for cereals (Navarro *et al.* 2012). A minimum temperature for the development of most stored grain pests is 15°C (Fields 1992). At temperatures below −10°C, most insects succumb to exposure within a few days while below 10°C insect reproduction ceases and population levels of most pests slowly decline (Fields 1992). The stage of development of the pest is a factor in its cold resistance: eggs are more sensitive, and adults or larvae, especially those in diapause, are the coldest tolerant. Nevertheless, adults of most species can survive temperatures around 4°C for many months and so can readily overwinter in buildings in temperate climates (Bell 2014). Techniques to progressively cool grains are being developed (Arthur and Casada 2010; Flinn and Scholler 2012). Although these methods have proven successful, they are not used in Africa because of the high cost of basic equipment and energy (Guèye *et al.* 2011).

Treatment using diatomaceous earth

Diatomaceous earth deposits are found worldwide, and each type of diatomaceous earth deposit has its own characteristics and insecticidal actions. Silicon dioxide (SiO_2) is the main component of these diatomaceous earth elements (Korunic 1998; Subramanyam and Roesli 2000; Baliota and Athanassiou 2020). Diatomaceous earth exerts insecticidal effects by desiccating pests (Korunic *et al.* 1996). According to Dowdy and Fields (2001), diatomaceous earth can be used in combination with other treatments. Vayias and Vassiliki (2009) proved the effectiveness control of the two parameters: temperature and humidity. Indeed, high mortality rates for *S. oryzae*, *T. confusum* and *C. ferrugineus* are recorded by increasing the temperature from 20 to 30°C and lowering the humidity from 75 to 55%, which indicates that the efficiency of the operation depends on high temperatures and low humidity in addition to the commodity treated and the insect considered.

Biological control

Biological control is primarily based on the use of parasitoids, parasites, and predators. Several studies have demonstrated the effectiveness of this method in the control of stored food pests (Abd El-Aziz 2011). Rahman *et al*. (2009) demonstrated the effect of the anthocoridae predator *Xylocoris flavipes* against *T. castaneum*, *T. confusum* and *C. pusillus*. Several families of parasitoids, the most important of which are Braconidae, Ichneumonidae, Pteromalidae and Bethylidae, limit the development of storage insects (Abd El-Aziz 2011). Based on the study by Boughdad and Laugé (1997), *Triaspis luteipes* (Curtis) is the most effective parasitoid of *B. rufimanus*. This occurs after bean harvest and attacks the L3 and L4 larval stages and pupae of this bruchid (Titouhi *et al.* 2017). Insects of the genus *Dinarmus* (Hymenoptera: Pteromalidae) have been identified as the most effective natural antagonists of bruchids (Ketoh *et al.* 2002). Sanon *et al*. (1998) showed that releases of the parasitoid *Dinarmus basalis* at the beginning of storage controlled the population of *C. maculatus* and limited the weight loss of stored cowpeas.

Among the biological control agents, entomopathogenic microorganisms, including viruses, bacteria, fungi, nematodes and protozoa, are considered the most promising biocontrol agents, as they are currently being developed to control many agricultural pests, such as termites (Rath 2000; Sindhu *et al.* 2011). These fungi cause the death of attacked insects by the penetration of the mycelium into the cuticle and its development in the hemocoel (Gabarty *et al.* 2014). According to Batta and Kavallieratos (2018), the most studied entomopathogenic fungus is *Beauveria bassiana*. Encouraging results have been obtained with this fungus against stored grain pests, in combination with chemical insecticides, natural products, and diatomaceous earth. Thus, it has been suggested that it should be integrated as a means of control in several storage systems (Dowdy and Fields 2001).

The efficacy of entomopathogenic fungi is affected by high light intensities. In addition, ultraviolet light is harmful to the fructification of the conidia of these fungi (Ekesi *et al.* 2001; Acheampong *et al.* 2020). Another determining factor for the development of a fungal infection is high relative humidity (Daoust and Roberts 1983). As stored grains are hygroscopic, the moisture and humidity content of the grains must be kept low to avoid spoilage of stored products, which limits the use of this technique (Ekesi *et al.* 2001). In addition, the bacteria *Bacillus thuringiensis* has been widely studied as a means of biological control of stored food pests (Hongyu *et al.* 2000).

Semiochemical control

Semiochemicals are compounds or signals that are naturally produced by insects to communicate with each other and can modify pest behavior. They can be used to control crop pests, including pests of stored cereals and legumes (El-Ghany 2019). They can be used either as attractants or as repellents against stored cereals and pulse pests. When deployed in a controlled environment, synthetic semiochemicals can limit pest numbers and preserve grain quality by interrupting reproductive protocols between insects, thereby preventing population growth (Guru *et al.* 2022).

Although they are mainly used inside warehouses, these approaches offer maximum efficacy for insect management. Several semiochemicals have been identified as being present in insects in stored products (Philip and Throne 2010). Sexual pheromones have been observed in insects of incorporated grains, including Anobiidae, Pyralidae, Bruchidae, Cucujidae, Silvanidae, Dermestidae, Bostrichidae, Curculionidae and Tenebrionidae (Philip and Throne 2010; Rodríguez 2018). Different types of traps have been developed and tested for their efficacy in dispersing synthetic baits to attract insects from the stored grains. Similarly, a range of semiochemicals have been shown to attract adult insects by modifying the behavior of *C. ferrugineus* (Losey *et al.* 2019). Trapping monitoring systems based on pheromones or food attractants can provide early warning of pest problems, so that necessary interventions can be carried out in time to exterminate invasive species and thus preserve grain for human consumption while avoiding the use of pesticides.

Use of biopesticides based on plant extracts against stored food pests

Owing to the harmful effects of the chemical molecules used in the preservation of stored products, it is difficult to use the previously mentioned alternatives in Morocco. Thus, considering the great biodiversity and richness of Moroccan botanical heritage, which can be a source of many bio-insecticides (Balahbib *et al*. 2019). Several studies have been carried out on the insecticidal activity of plant extracts and their essential oils to cope with insect pests of stored products (Abbad *et al*. 2014; Alaoui-Jamali *et al.* 2016; Allali *et al.* 2018; Ainane *et al.* 2019; Alilou and Akssira 2021).

According to an investigation carried out by Allali *et al.* (2020b) in the regions of Casablanca-Settat and Fez-Meknes, 14 families of plants were identified as being used by farmers against stored food pests. These are the families Urticataceae, Solanaceae, Apocynaceae, Apiaceae, Cucurbitaceae, Zingiberaceae, Geraniaceae, Myrtaceae, Thymelaeceae, Cupressaceae, Liliaceae, Rutaceae, Asteraceae and Lamiaceae. Most farmers use the aerial parts of whole plants. These parts are known to be toxic to pests.

The insecticidal activity of plants against stored food pests has been evaluated by many researchers since 1994 (Bourarach *et al.* 1994). This insecticidal activity concerned the following pests: *T. castaneum*, *T. confusum*, *S. oryzae*, *Acanthoscelides obtectus*, *Rizopertha dominica*, *C. maculatus* and *B. rufimanus* (Abbad *et al.* 2014; Hannour *et al.* 2018; Alilou and Akssira 2021; Benayad *et al.* 2012; El Moussaoui *et al.* 2022). Table 4 presents a summary of the results of all published studies on the insecticidal power of Moroccan plants against stored food pests. More than 50 species have been studied against pests of stored products in Morocco, including *Rosmarinus officinalis*, *Artemisia herba* alba, *Ruta chalepensis*, *A. absinthium*, *Piper nigrum*, *Ricinus communis* and *Smyrnium olusatrum*. These plants belong to more than 20 botanical families, including the Alliaceae, Apiaceae, Apocynaceae, Aristolochiaceae, Asteraceae, Brassicaceae, Cupressaceae, Dennstaedtiaceae, Zygophyllaceae, etc. Studies have revealed the insecticidal and larvicidal effects of these plants against pests of cereal or legume crops using powders, essential oils, and methanolic extracts.

Use of powders

Lamnaouer *et al.* (1995) evaluated the effect of powders of 15 plants including *P. nigrum*, *A. herba alba*, *Astragalus lusitanicus*, *Mandragora automnalis*, and *Thymus serpyllum* against two stored grain pests (*S. oryzae* and *R. dominica*). The results demonstrated that *P. nigrum* powder was the most effective, with a maximum mortality of 98% against *R. dominica* and 96% against *S. oryzae*, followed by *Hyocyamus niger* powder, which caused a mortality of 96 and 91%, respectively. A mortality rate of 95% against *R.*

Table 4: Overview of studies on bio-pesticides based on plant extracts against stored food pests in Morocco

Family	Species	Parts used	Extract	Principal compounds	Target pests	Main conclusions	Reference
Myrtaceae	*Eucalyptus camaldulensis* L	Not reported	Essential oil	N.R.	*Rhyzopertha dominica (F), Sitophilus oryzae (L) et Tribolium castaneum (herbst)*	100% mortality after the first day of exposure at the concentration of 0.21 and 0.11 µL.cm^{-3} against *Rhyzopertha dominica*. 100% mortality at the concentration of 0.21 µL.cm^{-3} after 1 day of exposure for S. oryzae. 100% mortality at the concentration of 0.21 µL.cm^{-3} against *Tribolium castaneum.*	Idouaarame *et al.* (2018)
Asteraceae	*Artemisia arborescens* L	Not reported	Essential oil	N.R.	*Rhyzopertha dominica (F), Sitophilus oryzae (L) et Tribolium castaneum (herbst)*	100% mortality at 0.21 µL.cm^{-3} against *Rhyzopertha dominica*. 100% mortality after 4 days at a concentration of 0.11 µL.cm^{-3} for S. oryzae. Low mortality of *Tribolium castaneum*	
Asteraceae	*Artemisia herba alba Asso*	Not reported	Essential oil	N.R.	*Rhyzopertha dominica (F), Sitophilus oryzae (L) et Tribolium castaneum (herbst)*	100% mortality at 0.21 µL.cm^{-3} against *Rhyzopertha dominica*. Low mortality of *Tribolium castaneum*	
Cupressaceae	*Cupressus sempervirens* L	Not reported	Essential oil	N.R.	*Rhyzopertha dominica (F), Sitophilus oryzae (L) et Tribolium castaneum (herbst)*	Low mortality of *Rhyzopertha dominica*. 43% mortality was observed after four days of exposure on *S. oryzae* (0.053 µL.cm^{-3}). Low mortality of *T. castaneum*	
Asteraceae	*Tanacetum annuum* L	Not reported	Essential oil	N.R.	*Rhyzopertha dominica (F), Sitophilus oryzae (L) et Tribolium castaneum (herbst)*	Low mortality of *Rhyzopertha dominica*. 78% mortality at 0.053 µL.cm^{-3} on *S. oryzae*. Low mortality of *Tribolium castaneum*	
Lamiaceae	*Rosmarinus officinalis*	Aerial parts	Essential oil	Oxygenated monoterpenes (1,8-cineole and camphor) (Middle Atlas: 79.4%; Loukkos: 48.78%) and terpenes (α and β pinene and camphene) (Middle Atlas: 14.71%; Loukkos: 32.33%)	*Bruchus rufimanus*	i- LC50 of male insects is 46.53 to 1.19 µL.L^{-1} of air for Middle Atlas rosemary and 58.85 to 11.57 µL.L^{-1} of air for Loukkos rosemary. ii- LC50 of female insects is 53.00 to 5.38 µL.L^{-1} of air for Middle Atlas rosemary and 58.85 to 11.57 µL.L^{-1} of air for Loukkos rosemary	Hannour *et al.* (2018)
Asteraceae	*Artemisia herba alba*	Aerial parts	Essential oil	Camphor (37.8%) and cis-thujone (23.6%)	*Tribolium castaneum* et *Tribolium confusum*	Significant effect on adults of the two insect pests by fumigation	Abbad *et al.* (2014)
Rutaceae	*Ruta chalepensis*	Aerial parts	Essential oil	2-undecanone (93.1%)	*Tribolium castaneum* et *Tribolium confusum*	For contact toxicity LD50 = 0.13 µL/cm² (36.3 h)	
Lamiaceae	*Satureja calamintha*	Aerial parts	Essential oil	Pulegone (53.5%), menthone (22.1%) and menthol (17.1%)	*Tribolium castaneum* et *Tribolium confusum*	For contact toxicity the LD50 = 0.09 µL/cm² (32.5 h) For fumigation toxicity the LD50= 10.5 µL.L^{-1} of air for *T. confusum* and 7.8 µL.L^{-1} of air for *T. castaneum*	
Lamiaceae	*Lavandula stoechas*	Aerial parts	Essential oil	N.R.	*Tribolium castaneum*	Significant effect on the pest on contact test and repellent test a TL50=9.16 days per 100 µL. According to the research *L.stoechas* showed a superior insecticidal effect to *Lavandula pedunculata*	Bachiri *et al.* (2018)
Lamiaceae	*Lavandula pedunculata*	Aerial parts	Essential oil	N.R.	*Tribolium castaneum*	Significant effect on the pest in the contact test and the repulsion test at TL50=16.00 days per 100 µL	
Pinaceae	*Cedrus atlantica*	Aerial parts (stems, leaves and flowers)	Essential oil	α-himachalene 15.63%, β-himachalene 31.24% and γ-himachalene 14,46%	*Tribolium confusum*	100% mortality of insects after 5 days of contact treatment at a dose of 3.5 × 10^{-2} µL.cm^{-3}	Ainane *et al.* (2019)
Rutaceae	*Citrus limonum*	Aerial parts (stems, leaves and flowers)	Essential oil	Neral 13.60%, neryl acetate 10.77% and α-Pinene 9.46	*Tribolium confusum*	100% mortality of insects after 5 days of contact treatment at a dose of 3.5×10² µL.cm^{-3}	
Lamiaceae	*Rosmarinus officinalis*	Aerial parts (stems, leaves and flowers)	Essential oil	Camphor31.16%, β-Caryophyllene 18.55% and 2,4-hexadiene, 3,4-dimethyl-, (Z, Z) 9.08%	*Tribolium confusum*	100% mortality of insects after 1 day of contact treatment at a dose of 12×10^{-2} µL.cm^{-3}	
Myrtaceae	*Syzygium aromaticum*	Aerial parts (stems, leaves and flowers)	Essential oil	1,1,4,8-tetramethyl-cis, cis, 4,7,10-cycloundecatriene 28.74%, caryophyllene oxide 25.34% and Eugenol 18.63	*Tribolium confusum*	100% mortality of insects after 1 day of contact treatment at a dose of 12×10^{-2} µL.cm^{-3}	
Myrtaceae	*Eucalyptus globulus*	Aerial parts (stems, leaves and flowers)	Essential oil	Estragole 28.14%, Terpinolene 7.12% and 1,4-Hexadiene, 5-methyl-3-(1 methylethylidene) 7.01	*Tribolium confusum*	100% mortality of insects after 1 day of contact treatment at a dose of 12×10^{-2} µL.cm^{-3}	
Lamiaceae	*Thymus satureioides*	Aerial parts (stems, leaves and flowers)	Essential oil	thymol (1.2%), carvacrol (26.5%), borneol (20.1%), p-cymene (5.4%) and γ-terpinene (5.6%).	*Tribolium castaneum*	LD50= 0,23 µL/cm²	Alaoui-Jamali *et al.* (2016)
Lamiaceae	*Thymus broussonetii*	Aerial parts (stems, leaves and flowers)	Essential oil	carvacrol 43,4 %,	*Tribolium castaneum*	LD50= 0,20 µL/cm²	
Lamiaceae	*Thymus maroccanus*	Aerial parts (stems, leaves and flowers)	Essential oil	carvacrol 72,1 %,	*Tribolium castaneum*	LD50= 0,19 µL/cm²	
Lamiaceae	*Thymus ciliatus*	Aerial parts (stems, leaves and flowers)	Essential oil	Thymol (17,3 %), le carvacrol (26,2 %), le bornéol (3,4 %), le p-cymène (19,6 %) et le γ-terpinène (14,6 %).	*Tribolium castaneum*	DL50= 0,22 µL/cm²	
Lamiaceae	*Thymus pallidus*	Aerial parts (stems, leaves and flowers)	Essential oil	Thymol (26,8 %), le carvacrol (1,4 %), le bornéol (5,4 %), le p-cymène (18,9 %) et le γ-terpinène (29,6 %).	*Tribolium castaneum*	DL50= 0,22 µL/cm²	
Lamiaceae	*Thymus leptobotrys*	Aerial parts (stems, leaves and flowers)	Essential oil	Carvacrol 79,1%,	*Tribolium castaneum*	LD50= 0.08 µL/cm² highest contact toxicity compared to other species with a LT50=32.80 at 17.18 hours	
Apiaceae	*Thapsia transtagana*	Leaves, flowers, stems and roots	Essential oil	The most abundant components are: 2,6-Dimethylnaphthalene, Pinane and Hexahydrofarnesyl acetone	*Sitophilus oryzae* and *Acanthoscelides obtectus*	Essential oils from roots and inflorescence have a significant effect against *Acanthoscelides obtectus* and *Sitophilus oryzae* when evaluated by contact, inhalation and ingestion.	Alilou and Akssira (2021)
Lamiaceae	*Mentha pulegium*	Leaves, flowers	Essential oil	The main components are pulegone (68.86, 71.97 and 81.46% respectively for Khénifra, Azrou and Mrirt) and piperenone (24.79% and 26.04% respectively for Azrou and Mrirt)	*Sitophilus oryzae*	LC 50 = 2.65 µL /L air for 48 h for the fumigation test for Azrou origin	Zekri *et al.* (2013)
Lamiaceae	*Mentha suaveolens*	Not reported	Essential oil	Piperitenone (33.03%), pulegone (17.61%), piperitone (9.18%);	*Sitophilus oryzae* et *Rizopertha dominica*	Mortality is 100% for doses of 50 µL and 12 µL at 24 h and for 3 µL at 48 h	Benayad *et al.* (2012)
Lamiaceae	*Mentha pulegium*	Not reported	Essential oil	Pulegone(73.33%), menthone (8.63%)	*Sitophilus oryzae* et *Rizopertha dominica*	100% mortality at 24h for 3, 12 and 50 µL doses	
Rutaceae	*Ruta chalepensis*	Aerial parts (stems, leaves and flowers)	Essential oil	2-undecanone (64.35%), piperonyl piperazine (11.9%), 2-decanaone (5.12%), 2-dodecanone (4.52%), decipidone (3.9%), 2-tridecanone (2.36%)	*Tribolium castaneum*	The dose of 0.038 µL.mL^{-1} represents a significant (100%) repulsion after 15 min of exposure. LD50= 0.447; 0.257; 0.20, and 0.176 µL.L^{-1} for exposure times of 12, 24, 36, and 48 h respectively.	Najem *et al.* (2020)

Table 4: Continued

Table 4: Continued

Asteraceae	*Artemisia absinthium*	Aerial parts	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	low insecticidal activity	Lamnaouer *et al.* (1995)
Asteraceae	*Artemisia herba-alba*	Aerial parts	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	low insecticidal activity	
Asteraceae	*Astragalus lusitanicus*	Aerial parts	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	medium insecticidal activity	
Asteraceae	*Atractylis gummifera*	Roots	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	medium insecticidal activity	
Solanaceae	*Datura stramonium*	Roots	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	medium insecticidal activity	
Solanaceae	*Hyocyamus niger*	Roots	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	96% mortality rate (q3=0.450 g) for *R. dominica* and 91% (q1 =0.250 g) for *S. oryzae.*	
Lauraceae	*Laurus nobilis*	Leaves	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	medium insecticidal activity	
Solanaceae	*Mandragora automnalis*	Roots	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	mortality rate 73% (q3=0.450 g) for *R. dominica* and 33%(q3=0.450 g) for *S. oryzae*.	
Ranunculaceae	*Nigella sativa*	Seeds	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	100% mortality for *Sitophilus oryzae*	
Piperaceae	*Piper nigrum*	Seeds	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	the most effective with a maximum mortality of 98% against *Rizopertha dominica* (q1 =0.250 g) and 96% against *Sitophilus oryzae* (q3=0.450 g)	
Euphorbiaceae	*Ricinus communis*	Seeds	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	95% mortality rate against *R. dominica* and 90% against *S. oryzae* for the quantity (q3=0.450 g).	
Apiaceae	*Smyrnium olusatrum*	Seeds	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	95% mortality for *Rizopertha dominica*	
Solanaceae	*Solanum nigrum*	Seeds	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	medium insecticidal activity	
Lamiaceae	*Thymus serpyllum*	Aerial parts	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	low insecticidal activity	
Loranthaceae	*Viscum album*	Seeds	powders	N.R.	*Sitophilus oryzae* et *Rizopertha dominica*	95% mortality for *Rizopertha dominica* for q2= 0.350g	
Solanaceae	*Withania frutescens*	Leaves	Essential oil	Carvacrol (31,87%), thymol (30,08%) et camphre (9,13%)	*Callosobruchus maculatus*	LC50=13.28 ±2.62 $\mu L.L^{-1}$ of air volume (24h) for the inhalation test and 18.41 ± 1.29 $\mu L.L^{-1}$ of air volume (24h) for the contact test. a maximum reduction of oviposition of 81.26± 2.01% was recorded with an air volume of 20 μL of essential oil/L. essential oils have a strong repellent activity against C. maculatus with a rate of 95.12±3.42	El Moussaoui *et al.* (2022)
Asteraceae	*Artemisia herba alba Asso.*	Leaves	Essential oil	Thujone (57.6%) and chrysanthenone (11.8%).	*Callosobruchus maculatus*	LC50 = 2.18 $\mu L.L^{-1}$ of air (24 h) for inhalation test. LC50 = 3.78 $\mu L.L^{-1}$ of air (24 h) for contact test	Allali *et al.* (2022)
Asteraceae	*Dittrichia viscosa* L.	Leaves	Essential oil	Isocostic acid (72.3%); Junipercamphor (5.1%).	*Callosobruchus maculatus*	LC50 = 19.96 $\mu L.L^{-1}$ of air (24 h) for the inhalation test LC50 = 14.34 $\mu L.L^{-1}$ of air (24 h) for the contact test a repellent effect of 72.5% against adults	
Asteraceae	*Maticaria Recutita* L.	Leaves	Essential oil	Santolina alcohol (40.7%); germacrene D (8.9%).	*Callosobruchus maculatus*	LC50 = 19.96 $\mu L.L^{-1}$ of air (24 h) for the inhalation test LC50 = 14.34 $\mu L.L^{-1}$ of air (24 h) for the contact test a repellent effect of 72.5% against adults	
Myrtaceae	*Jambosa caryophyllus (Thunb.)*	Floral buds	Essential oil	Eugenol (26.80%), β-caryophyllene (16.03%) and eugenyl acetate (5.83%).	*Callosobruchus maculatus*	LD50=2.32 $\mu L.L^{-1}$ of air for inhalation test (96h) LD50=5.51 $\mu L.L^{-1}$ of air for contact test (96h)	Zouirech *et al*. (2022)
Asteraceae	*Dittrichia viscosa* L.	Leaves	Essential oil	Bornyl acetate (41%) is the main constituent, followed by borneol (9.3%), α-amorphene (6.6%), and Caryophyllene oxide (5.7%).	*Callosobruchus maculatus*	a mortality rate of 97.5 ± 5.0% after 96 h for the inhalation test and LC50=7.8 ±0.3 μL EO/L, a mortality rate of 60.0 ± 8.3% after 96 h for the ingestion test and LC50=15.0 ± 2.1 μL EO/L 20 μL EO causes a 91% reduction in eggs laid.	Mssillou *et al*. (2022)
Lamiaceae	*Lavandula dentata* L.	Aerial part	Essential oil	Linalool (45.06%), camphor (15.62%) , borneol (8.28%)	*Callosobruchus maculatus*	LC50 = 5.90 $\mu L.L^{-1}$ of air for 24 h for the inhalation test. LC50 = 4.01 $\mu L.L^{-1}$ air for 24 h for the contact test. A significant reduction in the number of eggs laid (99.2%) and adult emergence (100%). A repellent effect of 34.44% against adults.	El Abdali *et al.* (2022)
Myrtaceae	*Syzygium aromaticum*	Floral buds	Essential oil	80.26% Eugenol, 9.62% Eugenyl acetate, 6.74% β-Caryophyllene and 1.14% C-Humulene.	*Callosobruchus Maculatus*	A mortality rate of 53.33 ± 11.55% after 4 days for a dose of 1 μL HE/L of air and 100% after 72h for the dose of 20 $\mu L.L^{-1}$ of air for the inhalation tests a mortality rate of 96% after 3 days for the inhalation test for the dose of 20 $\mu L.L^{-1}$. A repellent effect of 56.67% against adults after 2h for a dose of 20 $\mu L.L^{-1}$.	Allali *et al.* (2021b)
Lamiaceae	*Rosmarinus Officinalis*	Aerial part	Essential oil	Eucalyptol (1,8-cineol) (50,42%), camphor (17.73%), borneol (5.99%), 3-carene (12.05%)	*Callosobruchus Maculatus*	EO significantly affected adult longevity (treated lot: 1-7 days, control lot: 2-12 days), fecundity (10-48 eggs/10 females vs 437-491 eggs/10 females) and fertility (66.67-85.00% vs 93.75-95.44%). For an exposure between 24 and 120h the LC50= 5.51-2.43 $\mu L.L^{-1}$ of air for males and 6.80-3.04 $\mu L.L^{-1}$ of air for females.	Douiri *et al.* (2014)
Lamiaceae	*Origanum compactum*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	The Percentage Mortality is 97.5 % for 2% w/w	Allali *et al.* (2021c)
Asteraceae	*Inula viscosa*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality percentage is 27.38% for 2% w/w	
Lamiaceae	*Rosmarinus officinalis*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	low insecticidal activity	
Lamiaceae	*Calamintha officinalis*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	low insecticidal activity	
Lamiaceae	*Myrtus communis*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	low insecticidal activity	
Lamiaceae	*Mentha rotundifolia*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality percentage is 89.32% for 2%w/w	
Asteraceae	*Artemisia herba alba*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	low insecticidal activity	
Lamiaceae	*Mentha pulegium*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the percentage mortality is 100% for 2%, 1% and 0.5% w/w	
Solanaceae	*Capsicum frutescens* L.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality percentage is 32.6% for 2% w/w	Allali *et al.* (2021a)

Table 4: Continued

Table 4: Continued

Urticaceae	*Urtica dioica* L.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality percentage is 46.52% for 2% w/w	
Lamiaceae	*Origanum compactum* Benth.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the percentage of mortality is 97.5% for 2% w/w (High insecticidal activity)	
Liliaceae	*Allium sativum* L	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the percentage of mortality is 72.84 % for 2% w/w (High insecticidal activity)	
Asteraceae	*Inula viscosa* (Ait.) L.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality percentage is 27.38% for 2% w/w	
Zingiberaceae	*Zingiber officinalis*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality percentage is 50.3% for 2% w/w	
Oléaceae	*Olea europaea* L.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality rate is 14.94% for 2% w/w	
Lamiaceae	*Rosmarinus officinalis* L.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality rate is 11.09% for 2% w/w	
Geraniaceae	*Pelargonium graveolens* L'Hér.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality rate is 25.85% for 2% w/w	
Myrtaceae	*Syzygium aromaticum* L.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the percentage of mortality is 100% for 2%, 1% and 0.5% w/w (High insecticidal activity)	
Lamiaceae	*Calamintha officinalis* L	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality rate is 39.24% for 2% w/w	
Lamiaceae	*Myrtus communis*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*		
Lamiaceae	*Mentha officinalis* L.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality rate is 89.32% for 2% w/w	
Myrtaceae	*Eucalyptus camaldulensis*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality rate is 43.79% for 2% w/w	
Asteraceae	*Artemisia herba Asso.*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality rate is 30.37% for 2% w/w	
Lamiaceae	*Mentha pulegium* L.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality rate is 100% for 2%, 1% and 0.5% w/w (High insecticidal activity)	
Thymelaeaceae	*Daphne gnidium* L.	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality rate is 22.03% for 2% w/w	
Apocynaceae	*Nerium oleander L.*	Aerial part	Powders	N.R.	*Callosobruchus maculatus*	the mortality rate is 31.79% for 2% w/w	
Solanaceae	*Capsicum frutescens*	Leaves	Powders	N.R.	*Callosobruchus maculatus*	Low reduction in egg laying per female, No significant effect on egg fertility. Low effect on adult emergence.	Allali *et al.* (2018)
Lamiaceae	*Lavandula stoechas*	Leaves	Powders	N.R.	*Callosobruchus maculatus*	Low reduction in egg laying per female, No significant effect on egg fertility. No effect on adult emergence.	
Myrtaceae	*Syzygium aromaticum*	Leaves	Powders	N.R.	*Callosobruchus maculatus*	The powder induces the shortest average longevity of 3 days. Nil fertility at 1g. Very strong inhibitory effect on egg fertility at 0.1g, 0.5g and 1g. Clove powders have a marked effect on emergence which shows an effect on the larvae.	
Lamiaceae	*Mentha pulegium* L	Aerial parts	Essential oil	The Loukkos EO is dominated by pulegone (82.40%) / The Middle Atlas EO is rich in both pulegone (67.51%) and isomenthone (15.23%).	*Bruchus rufimanus*	i- LC50 of male insects is 7.15 $\mu L.L^{-1}$ of air after 24 h of fumigation for the Loukkos origin and 11.99 $\mu L.L^{-1}$ of air after 24 h of fumigation for the Middle Atlas origin. ii- LC50 of female insects is 7.70 $\mu L.L^{-1}$ of air after 24 h of fumigation for the Loukkos origin and 14.18 $\mu L.L^{-1}$ of air after 24 h of fumigation for the Middle Atlas origin	Amzouar *et al.* (2016a)
Lamiaceae	*Mentha suaveolens* Ehrh.	Aerial parts	Essential oil	Loukkos EO is dominated by piperitenone oxide (53.12%) followed by cis-Sabinene hydroxide (9.29%), trans-2-Menthenol (6.83%), γ-Terpineo (5.32%) and Germacrene D (2. Middle Atlas EO is rich in piperitenone oxide (54.51%) followed by Limonene (5.61%), Germacrene D (5.11%), 2-Pinen-4-one (4.86%), trans-Sabinene hydrate (3.45%), L-Borneol (2.45%), β-Phellandrene (2.4%).	*Bruchus rufimanus*	i-LC50 of male insects is 23.26 $\mu L.L^{-1}$ of air after 24 h of fumigation for the Loukkos origin and 26.25 $\mu L.L^{-1}$ of air after 24 h of fumigation for the Middle Atlas origin. ii- LC50 of female insects is 24.67 $\mu L.L^{-1}$ of air after 24 h of fumigation for the Loukkos origin and 28.58 $\mu L.L^{-1}$ of air after 24 h of fumigation for the Middle Atlas origin	Amzouar *et al.* (2016b)
Gentianaceae	*Centaurium erythraea*	Aerial parts	Methanol extracts	N.R.	*Tribolium castaneum*	High larval mortality rate of 63% after 10 days of treatment. Reduction of emergence to 34%, suppression of adult emergence (high larvicidal activity)	Jbilou *et al.* (2008)
Zygophyllaceae	*Peganum harmala*	Aerial parts	Methanol extracts	N.R.	*Tribolium castaneum*	High larval mortality rate of 58% after 10 days of treatment. Suppression of adult emergence (high larvicidal activity)	
Lamiaceae	*Ajuga iva*	Aerial parts	Methanol extracts	N.R.	*Tribolium castaneum*	Reduction of larval lifetime to 6.6 days compared to 7.1 days of the control. Suppression of adult emergence.	
Aristolochiaceae	*Aristolochia baetica*	Aerial parts	Methanol extracts	N.R.	*Tribolium castaneum*	Supression of adult emergence	
Dennstaedtiaceae	*Pteridium aquilinum*	Aerial parts	Methanol extracts	N.R.	*Tribolium castaneum*	Reduction of emergence at 81%. Reduction in larval lifespan to 6.1 days compared to 7.1 days for the control	
Brassicaceae	*Raphanus raphanistrum*	Aerial parts	Methanol extracts	N.R.	*Tribolium castaneum*	Very low larvicidal activity	
Asteraceae	*Launaea arborescens*	Aerial parts	Methanol extracts	N.R.	*Tribolium castaneum*	Reduction in larval lifespan from 6 days to 7.1 days in the control	
Zygophyllaceae	*Peganum harmala*	Seeds	Methanol extracts	N.R.	*Tribolium castaneum*	92% mortality of adults during 32 days of exposure and also 58% mortality of larvae during 10 days of treatment (High insecticidal and larvicidal activity)	Jbilou *et al.* (2006)
Aristolochiaceae	*Aristolochia baetica*	Aerial parts	Methanol extracts	N.R.	*Tribolium castaneum*	A mortality rate of 32% of adults during 32 days of exposure	
Lamiaceae	*Ajuga iva*	Aerial parts	Methanol extracts	N.R.	*Tribolium castaneum*	A mortality rate of 45% of adults during 32 days of exposure	
Brassicaceae	*Raphanus raphanistrum*	Aerial parts	Methanol extracts	N.R.	*Tribolium castaneum*	15% mortality of adults during 32 days of exposure and also 34% mortality of larvae during 10 days of treatment (High larvicidal activity)	

Table 4: Continued

Table 4: Continued

Cupressaceae	*Juniperus thurifera*	Leaves	Essential oil	e sabinène (22,4 %), terpinène-4-ol (11,0 %), l'α-pinène (5,9 %).	*Acanthoscelides obtectus, Tribolium castaneum* et *Sitophilus oryzae*	LD50= 0.1×10^{-2} $\mu L.L^{-1}$ for *Acanthoscelides obtectus*/LD50= 0.6×10^{-2} $\mu L.L^{-1}$ for *Tribolium castaneum*/LD50=2.0×10^{-2} $\mu L.L^{-1}$ for *Sitophilus oryzae* in the contact test	El Jemli *et al.* (2018)
Lamiaceae	*Origanum compactum Benth.*	Leaves	Essential oil	Carvacrol (38%) , Thymol (31,46%)	*Callosobruchus maculatus*	Total Adult Mortality at a dose of 20 $\mu L.L^{-1}$ of air (48h) with an LC50 value of 5.3 $\mu L.L^{-1}$ of air for the contact test and an LC50= 33.61 $\mu L.L^{-1}$ of air for the inhalation test. Moderate repellent activity with an average of 39.16% after 60 min.	Aimad *et al.* (2022)
Alliaceae	*Allium sativum*	Bulbs	Essential oil	Trisulfide,di-2-propenyl (46,52%); le disulfide, di-2-propenyl (10,27%); le trisulfide, di-2-propenyl (10,88%) et le diallyl dissulfide (7,15%)	*Callosobruchus maculatus*	i- LC50 of male insects is 2.56 $\mu L.L^{-1}$ of air after 24 h of fumigation. ii- LC50 of female insects is 2.50 $\mu L.L^{-1}$ of air after 24 h of fumigation.	Douiri *et al.* (2013)
Solanaceae	*Capsicum frutescens* L.	-	Powders	N.R.	*Tribolium castaneum*	Low mortality rate for the powder treatment in the contact test. High repellent activity (the average number of *T. castaenum* present on the half discs containing the powder varies from 20 to 26%, which is significantly lower than the control which is 73% to 85%)	Bouchelta *et al.* (2020)
Solanaceae	*Capsicum frutescens* L.	-	Methanol extracts	N.R.	*Tribolium castaneum*	the concentration 30 $g.l^{-1}$ causes a significantly higher mortality (37%) than that obtained in the untreated control. the insect repellent activity shows that the average number of *Tribolium castaneum* present on the half-disc impregnated with the extract is 8 to 28% which is significantly different from the control where the average number varies from 71 to 91%.	

dominica and 90% against *S. oryzae* for the quantity following treatment with *R. communis* powder while *Viscum album* and *S. olusatrum* powders showed a mortality rate of about 95% against *R. dominica*. The powders of other plants showed low to medium insecticidal activity. Furthermore, Allali *et al.* (2021a) tested the insecticidal power of powders of nine plants (*Origanum compactum, Inula viscosa, R. officinalis, Calamintha officinalis, Myrtus communis, Mentha rotundifolia, A. herba alba, M. pulegium*) on cowpea weevil (*C. maculatus*). Their results showed that 2% w/w *M. pulegium*, *O. compactum*, and *M. rotundifolia* powders were the most effective with mortality percentages of 100, 97.5 and 89.32%, respectively. They also reported that treatment with powders of *Syzygium aromaticum* L., *M. pulegium*, *O. compactum*, *M. officinalis*, *Allium sativum* L., resulted in total mortality (100%) of *C. maculatus* adults for the first two species and rates of 97.5, 89.32 and 72.84% for rest of the above-mentioned plants, respectively (Allali *et al.* 2021c). *Capsicum frutescens* L. powder treatment against *T. castaneum* showed significant repellent activity with an average number of adults present on the half-discs containing the powder ranging from 20 to 26%, which was significantly lower than that of the control, i.e., 73 to 85% (Bouchelta *et al.* 2020).

Use of methanolic extracts

Jbilou *et al.* (2006) evaluated the insecticidal and larvicidal activity of methanolic extracts of *Peganum harmala* seeds and the aerial parts of 3 other plants (*Aristolochia baetica, Ajuga iva, Raphanus raphanistrum*) against *T. castaneum*. Their results showed that the methanolic extract of *P. harmala* seeds has high activity against larvae and adults, with a 92% mortality rate of adults during 32 days of exposure and 58% mortality of larvae during 10 days of treatment. In addition, methanolic extracts of *R. raphanistrum* have significant larvicidal activity, with 34% larval mortality after 10 days of treatment.

Furthermore, the methanolic extracts of *C. frutescens* L. tested against *T. castaneum* caused a significantly higher mortality (37%) than the untreated control at a concentration of 30 $g.L^{-1}$. The insect repellent activity showed that the average number of adults present on the half-disc impregnated with the extract was 8–28%, which was significantly different from the control, where the average number varied from 71 to 91%. These data demonstrate the repellent power of the essential oil of *C. frutescens* (Bouchelta *et al.* 2020).

Use of essential oils

A number of research studies are being conducted in Morocco to test essential oils of plants on stored food pests. Essential oils of *M. suaveolens* and *M. pulegium* were tested by Benayad *et al.* (2012) on two stored grain pests (*S. oryzae* and *R. dominica*), The reported results showed 100% mortality for doses of 50 and 12 µL at 24 h and for 3 µL at 48 h; which showed a high efficacy for *M. suaveolens* (piperitenone by 33.03%). Similarly, *M. pulegium* (73.33% pulegone) caused mortality in all *S. oryzae* weevils after one day of treatment at doses of 3, 12 and 50 µL.

Zekri *et al.* (2013) evaluated the insecticidal effect of *M. pulegium*, originating from the Azrou region (Moroccan Middle Atlas), against *S. oryzae*. The study revealed significant insecticidal activity with an LC50 of 2.65 $\mu L.\ L^{-1}$ air for 48 h for the fumigation test. The effect was correlated with monoterpene richness, mainly in pulegone (68.86%), piperitenone (24.81%), thymol (1.01%), limonene (0.9%), and pinene (0.32%).

Furthermore, Abbad et *al.* (2014) conducted research on the insecticidal effect of essential oils of *A. herba alba*, *R. chalepensis* and *Satureja calamintha* on *T. castaneum* and *T. confusum*. The essential oil of *A. herba alba* showed a significant fumigation effect on the adults of both pests. This effect is attributed to the presence of highly volatile monoterpenes, such as camphor, cis-thujone, camphene, and

1,8-cineole. Also, the results of this work showed that for contact toxicity the LD50 is 0.13 μL.cm^{-2} (36.3 h) for *R. chalepensis*. According to the authors of this study, this toxicity is attributed to 2-undecanone, a major component of this essential oil. *S. calamintha* showed a high efficacy for contact toxicity [LD50 = 0.09 μL/cm² (32.5 h)] and fumigation (LD50= 10.5 μL.L^{-1} of air for *T. confusum* and 7.8 μL.L^{-1} of air for *T. castaneum*), which is due to the abundance of oxygenated monoterpenes (menthone, menthol and pulegone) characterized by a high insecticidal activity (Abbad *et al.* 2014).

The essential oils of six plants of the genus Thymus (*T. satureioides*, *T. broussonetii*, *T. maroccanus*, *T. ciliatus*, *T. pallidus* and *T. leptobotrys*) were tested for their insecticidal effects on *T. castaneum*. This study revealed that the essential oils showed significant insecticidal activity. In fact, the essential oil of *T. leptobotrys* showed the highest contact toxicity compared to the other species compared (LD50= 0.08 μL.cm^{-2}, LT50=32.80 at 17.18 h). For the other essential oils, the LD50 was between 0.19 and 0.23 μL.cm^{-2}. The toxic effect of the thyme essential oils can be attributed to phenolic compounds, particularly carvacrol (79.1% for *T. leptobotrys*) and/or its isomer thymol present in large quantities (Alaoui-Jamali *et al.* 2016).

On the other hand, Bachiri *et al.* (2018) compared the insecticidal activity resulting from the application of essential oils extracted from *Lavandula stoechas* and *L. pedunculata* against the pest *T. castaneum*. According to the research *L. stoechas* showed a superior insecticidal effect on *L. pedunculata* in both the contact and repellent tests. El Jemli *et al.* (2018) tested the effect of *Juniperus thurifera* essential oils on stored food pests: *A. obtectus*, *T. castaneum* and *S. oryzae*. The study showed a significant insecticidal effect including an LD50 = 0.1×10^{-2} μL.L^{-1} for *A. obtectus*, LD50 = 0.6×10^{-2} μL.L^{-1} for *T. castaneum* and LD50 = 2.0×10^{-2} μL.L^{-1} for *S. oryzae* for the contact test.

Furthermore, Idouaarame *et al.* (2018) studied the effect of *Eucalyptus camaldulensis* essential oil on *R. dominica*, *S. oryzae* and *T. castaneum*. Their results revealed high insecticidal power with 100% mortality after the first day of exposure at concentration of 0.21 and 0.11 μL.cm^{-3} against *R. dominica* and 100% mortality at the concentration of 0.21 μL.cm^{-3} after 1 d of exposure to *S. oryzae* and *T. castaneum* compared to the essential oils of the plants *A. arborescens*, *A. herba alba*, *Cupressus sempervirens*, and *Tanacetum annuum* (Idouaarame *et al.* 2018).

Ainane *et al.* (2019) conducted a comparative study on the insecticidal power of essential oils from five plants (*Cedrus atlantica*, *Citrus limonum*, *R. officinalis*, *S. aromaticum*, and *E. globulus*) against *T. confusum*. All essential oils showed high insecticidal activity. *R. officinalis*, *S. aromaticum*, and *E. globulus* essential oils were very effective, with 100% insect mortality after 1 d of contact treatment at a dose of 12×10^{-2} μL.cm^{-3}, followed by *C. atlantica* and *C. limonum* with 100% insect mortality after 5 days of contact treatment at a dose of 3.5×10^{-2} μL.cm^{-3}.

A dose of 0.038 μL.mL^{-1} caused total repulsion (100%) after 15 min of exposure, and an LD50 of 0.176 μL.L^{-1} after 48 h of treatment was the result of an investigation of the effect of essential oils of *R. chalepensis* against *T. castaneum*. This result was attributed to 2-undecanone and piperonyl piperazine (Najem *et al.* 2020).

Alilou and Akssira (2021) evaluated the insecticidal activity of essential oils from inflorescences, leaves, roots, and stems of *Thapsia transtagana* against *S. oryzae* and *A. obtectus*. The study revealed that essential oils from the roots and inflorescence have a significant effect on both pests for contact, inhalation, and ingestion treatments. The authors explained the mortality recorded by the richness of the essential oils of the plant in monoterpenoids, which act as neurotoxins.

In the same context, several studies on the insecticidal activity of essential oils of plants against the cowpea bruchid *C. maculatus* have been conducted by several research structures in Morocco. Boughdad *et al.* (2013) tested the effect of essential oils from *A. sativum* bulbs, the lethal concentrations (LC50) were 2.56 and 2.50 μL.L^{-1} of air after 24 h of fumigation for adult female males, respectively. This showed the toxicity of these essential oils against adults (pre-imaginal stages), which also affected the oviposition potential of the insect.

Therefore, *R. Officinalis* essential oils were evaluated against the same insect, as a result the treatment significantly affects adult longevity, fecundity and fertility of adults, especially by exposing the insect for 24–120 h at LC50= 5.51–2.43 and 6.80–3.04 μL.L^{-1} of air for males and females, respectively. The insecticidal potency was mainly attributed to the richness of the essential oils in 1,8-cineole (50.42%) (Douiri *et al.* 2014).

Allali *et al.* (2021b) studied the effect of essential oils from the flower buds of the plant *S. aromaticum* against *C. maculatus*. Their results revealed a mortality rate of 53.33 ± 11.55% after 4 days for a dose of 1 μL.L^{-1} of air and 100% after 72h for a dose of 20 μL.L^{-1} of air for the inhalation test. A mortality rate of 96% was observed after 3 days of the inhalation test at a dose of 20 μL.L^{-1}. The essential oils also showed a repellent effect of 56.67% against adults after 2 h of exposure at a dose of 20 μL.L^{-1}.

Research concerning the insecticidal effect of the essential oil of *Withania frutescens* revealed its high activity against *C. maculatus*. According to the authors of this study, the insecticidal effect is dependent on the richness of the essential oils in monoterpenes, which are neurotoxic to insects. On the other hand, the effect of essential oils on reproduction results from both an inhibition of ovogenesis and an increase in the retention of eggs in the lateral oviducts of females (El Moussaoui *et al.* 2022).

Furthermore, Allali *et al.* (2022) tested the insecticidal effect of *A. herba alba*, *Maticaria Recutita* and *Dittrichia Viscosa* L. against *C. maculatus*. The results showed that the studied essential oils studied had considerable insecticidal activity against the pest, with LC50 values of 3.78, 8.86 and

14.34 μL.L^{-1} of air for the contact test and oviposition reduction rates of 90.02, 70.65 and 48.23%, as well as repellency percentages of 60.83, 50.83 and 72.5% for *A. herba alba*, *M. Recutita* and *D. Viscosa*, respectively. This study suggests that treatment with the essential oil of *A. herba alba* may be a good alternative for managing the pest studied. The literature also reports that essential oil extracted from the leaves of *D. viscosa* L. has been shown to be insecticidal against *C. maculatus*. In addition to a mortality rate of 97.5 ± 5.0% was recorded after 96 h for the ingestion test and an LC50 of 7.8 ± 0.3 μL HE/L, a mortality rate of 60.0 ± 8.3% after 96 h for the ingestion test and an LC50 of 15.0 ± 2.1 μL HE/L. It was reported that 20 μL of essential oil caused a 91% reduction in the number of eggs laid. These results were interpreted to be related to the presence of monoterpenoids, such as bornyl acetate and borneol, which affect insect growth by acting as acetylcholinesterase inhibitors (Mssillou *et al.* 2022).

The essential oil of *L. dentata* was evaluated for its insecticidal activity against *C. maculatus*, which caused a significant reduction in the number of eggs laid per female (99.2%) and adult emergence (100%), in addition to a 34.44% repellent effect against adults. The LC50 was 5.90 μL.L^{-1} air for 24 h for the inhalation test and 4.01 μL.L^{-1} air for 24 h for the contact test. The authors attributed the insecticidal effects of *L. dentata* EO against the studied pest to camphor, eucalyptol and fenchone, the ovicidal effect of the tested EOs was probably caused by blocking of embryogenesis after penetration of the volatile oils into the eggs through the respiratory tract of *C. maculatus* (El Abdali *et al.* 2022).

Aimad *et al.* (2022) tested the insecticidal potential of essential oils of *O. compactum* for *C. maculatus*. Their results showed total mortality of adults at a dose of 20 μL.L^{-1} of air (48h) with an LC50 value of 5.3 μL.L^{-1} of air for the contact test and an LC50 of 33.61 μL.L^{-1} of air for the inhalation test in addition to a moderate repellent activity with an average of 39.16% after 60 min.

In addition, several studies have reported on the bean bruchus (*B. rufimanus*), which is considered one of the most important pests of stored pulses in Morocco. In this regard, the essential oils of *M. pulegium* and *M. suaveolens* Ehrh. showed an inhibition rate of up to 99% against adult male and female *B. rufimanus*. The LC50 of *M. pulegium* essential oils against male insects was 7.15 and 11.99 μL.L^{-1} of air after 24 h of fumigation for the Loukkos and Middle Atlas origin, respectively, Against an LC50 of 7.70 and 14.18 μL.L^{-1} of air after 24 h of fumigation for female insects, respectively (Amzouar *et al.* 2016a). For the result by treatment with *M. suaveolens* essential oils, the LC50 of male insects was 23.26 and 26.25 μL.L^{-1} of air after 24 h of fumigation for plants from Loukkos and Middle Atlas origin, compared to 24.67 and 28.58 μL.L^{-1} for the female insects, respectively (Amzouar *et al.* 2016b). Similarly, Hannour *et al.* (2018) evaluated the insecticidal activity of essential oils from *R. officinalis* against *B. rufimanus*. The LC50 against male insects was 46.53–1.19 and 58.85–11.57 μL.L^{-1} for Middle Atlas and Loukkos rosemary, respectively. However, for female insects was 53.00 to 5.38 μL.L^{-1} and 58.85 to 11.57 μL.L^{-1}, respectively (Hannour *et al.* 2018).

Technological advances in food storage of cereals and pulses

Many technological advances have recently been reported for the preservation of food stocks, particularly cereals and pulses. Modern techniques such as irradiation, microwave (electromagnetic radiation), application of ionizing radiation, temperature control, radio frequency heating systems, infrared, dielectric heating, and modern aeration systems can be used to improve the quality of shelf life and safety of stored cereals and pulses (Chen *et al.* 2022). These advances not only prevent spoilage but also protect against pests such as rodents and insects, which can cause serious financial losses. Innovations such as modified atmospheric storage systems (increasing CO_2 and oxygen deprivation or nitrogen control), which reduce the growth of insect pests and fungal diseases in grains by limiting the amount of oxygen available for respiration, are also becoming increasingly popular (Chen *et al.* 2022; Moirangthem and Baik 2021). Kuyu *et al.* (2022) reported that modern hermetic storage techniques (metal silos, PICS bags, and polyethylene + polypropylene bags) ensured better storage performance in terms of preservation of germination capacity and seed quality compared to storage in conventional bags. Similarly, drying technologies have also been mentioned such as artificial drying of grains by solar dryers (using renewable energy) which has evolved instead of traditional drying by the sun or by non-solar dryers e.g., greenhouse gas emissions, high fuel costs, etc. (Ikegwu *et al.* 2020).

It is important to note that the method of preserving food stocks depends on the specifics of the crop, size of the farm, and available resources. Farmers and producers can consult local agricultural experts to determine the most appropriate preservation method for their situation.

Advantages and constraints of ecological and chemical management methods for stored grain pests

While there are a wide variety of chemicals available to control pests with rapid efficacy and ease of use and implementation, chemical methods have serious limitations, including risks to human and animal health, ecosystem damage, and high costs compared to ecological methods (Deguine *et al.* 2021). The latter offers various advantages through the application of natural methods to combat pests and are often cheaper than chemical methods because they use locally available materials and resources and improve the quality of stored grain

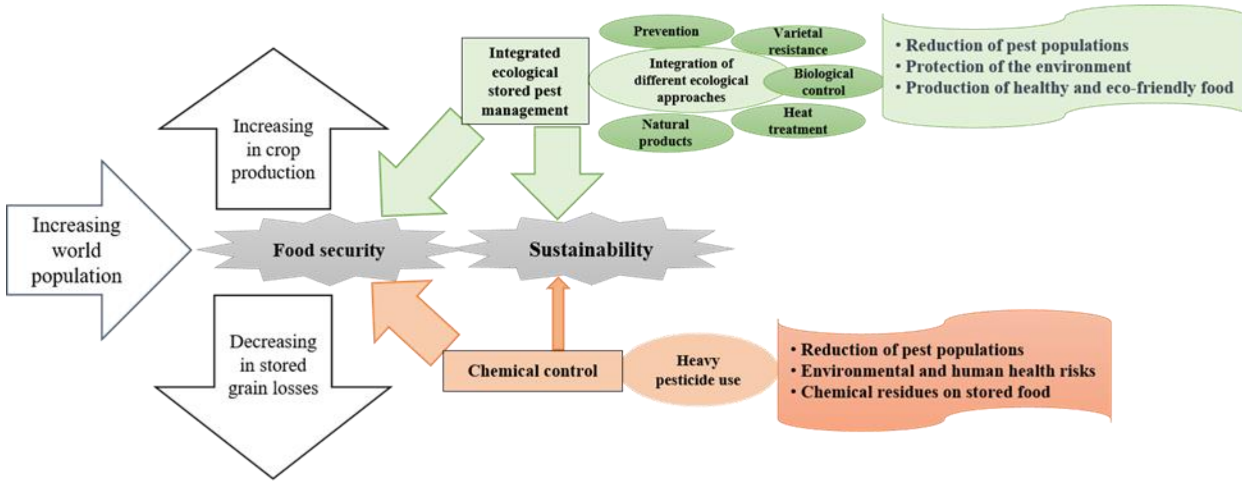

Fig 1: Scheme of ecological and chemical control of pests of stored cereals and pulses

products without harming the environment (Grzywacz *et al.* 2014). However, green techniques present some challenges and may not always be as effective as chemical methods; therefore, the implementation of green controls often requires careful planning and execution and may take longer than chemical methods. Some ecological pest management methods may be geographically limited, because they depend on natural resources and local knowledge (Srivani Maddala 2019).

In brief, the synthetic alternative pest management program for stored cereals and pulses is an important approach to reduce the use of chemical pesticides while ensuring the safety and quality of stored food. This program involves the use of non-toxic and environmentally friendly methods, such as fumigation with essential oils and biological control agents, including parasitoids and predators. These methods are effective against the common pests of stored cereals and pulses. The success of this approach depends on several factors such as adequate monitoring of pest populations, early detection and treatment of infestations, proper storage conditions, and adherence to best pest management practices (Hajam and Kumar 2022). By adopting this synthetic scheme of ecological control of stored grain pests, farmers can reduce their dependence on harmful chemicals, while preserving the environment and ensuring food security (Fig. 1).

Conclusion and Perspectives

In Morocco, although chemical methods are effective in controlling pests, they can also have adverse effects on non-target organisms and contribute to environmental pollution. In addition, growing concerns about pesticide residues in food products make it essential to find non-toxic alternatives. In this sense, environmentally friendly methods can increase the efficiency of food production and provide consumers with better-quality grain and pulse products while reducing waste, which can be a game changer for the global agricultural industry. A big challenge in ecological pest management of stored cereals and pulses is the need to balance pest control with environmental and economic considerations. Despite these constraints, the ecological management of stored cereals and pulse pests has important benefits, such as reducing the use of insecticides, preserving the quality of stored grain, protecting the environment, and ensuring food security.

The use of ecologically integrated pest management strategies, which combine preventive measures such as temperature control, sanitation, and airtight storage with biological control agents and the exploitation of natural resources, offers new possibilities for sustainable pest control. Nonetheless, the success of integrated pest management depends on a complex understanding of pest biology and the ecology of the storage environment. Furthermore, the implementation of these practices requires collaboration between scientists, farmers, regulators, and other stakeholders to ensure their scalability and effectiveness in controlling stored grain pests, while minimizing undesirable side effects. In Morocco, ecological management of stored grain pests of cereals and pulses is an important concern for farmers and authorities. Efforts have been made to encourage the use of biological and ecological pest control methods, including awareness raising programs, training, and subsidies. Indeed, the ecological management of stored grain pests of cereals and legumes in Morocco will depend on collaboration between farmers, authorities, researchers, and international partners to develop solutions adapted to local conditions.

Several perspectives for the ecological management of stored grain pests of cereals and legumes are possible in Morocco. There is a need to develop the capacity of farmers and engineers to better understand the principles and techniques of biological pest control. A warehouse pest monitoring program should be implemented to detect pest infestations at an early stage and to avoid economic losses. The promotion of biological and ecological control methods, such as the use of natural enemies, essential oils, and traps can be encouraged to reduce the use of pesticides. It is important to develop appropriate techniques for ecological pest management, such as improved conservation practices and selection of pest resistant crops and legumes, etc. Further research to better understand the ecological mechanisms involved in the control of stored grain pests is essential for effective long-term ecological management. Thus, research efforts on ecological management methods in Morocco must continue to develop more effective and less costly ecological pest management methods.

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Author Contributions

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Conflicts of Interest

No conflicts of interest are identified or reported in this review.

Data Availability

Data will be made available on a fair request by the requester.

Ethics Approval

Ethical approval was not required for this review.

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