



Review Article

Botanical Pesticidal Products in the World and in Pakistan: A Comparative Review

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Abstract | Plant-derived pesticides, also known as botanicals or green pesticides, constitute a vital research area of biorational plant protection. This review documents a comparative database of plant-based green pesticidal products developed and registered in different countries. Although Pakistan is far behind in this regard, a substantial number of green pesticides have been developed in other countries. Here we present a comprehensive list of these botanical pesticides developed and registered against different insect pests in Canada, China, and Greece. Analysis of these botanical pesticidal products has shown about 16 plant species used as active ingredients of green pesticides for controlling various insect pests in agriculture, household, personal, urban and veterinary sectors. Products based on lemon-scented gum tree *Corymbia citriodora* (66%), garlic *Allium sativum* (6%), pyrethrum *Chrysanthemum cinerariaefolium* (6%) and camphor tree *Cinnamomum camphora* (5%) are the most common among total 161 products being manufactured and marketed by 76 companies in above mentioned three countries. All the listed products are currently registered by their respective national ministries. Insect pests belonging to 23 families of orders Diptera, Phthiraptera, Lepidoptera, and Siphonaptera are the major targets of these botanical pesticidal products. Similarly, two technical grade active ingredients and 16 formulation types were identified among these products. The most common formulation types are the any other liquid (AL) (36.02%) and vaporizing products (VP) (11.18%). In Pakistan, there should be more focus on the green pesticidal research and development and the Government should support such initiatives by taking all the stockholders onboard in order to promote organic plant protection strategies as biorational alternatives of hazardous synthetic pesticides.

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Introduction

Plants have existed for over 400 million years and they have developed different defensive

mechanisms, such as repellency and even insecticidal properties to shield themselves from insect attack. The use of plants as insecticides dates back at least as far as the Roman Empire. For instance, during the reign

of the Persian King Xerxes in 400 B.C., a powder obtained from the dry flowers of a plant known as pyrethrum (*Chrysanthemum cinerariaefolium*) was used to delouse children (Dodia *et al.*, 2010). This practical implication motivated researchers to investigate the insecticidal activities of other plants. Consequently, Canada, China and Greece have leapt on the botanical usage because former is more conservative about pesticide registration (Isman, 2006) whereas, the latter two countries have been using botanical insecticides for 2 millennia (Thacker, 2002). However, unfortunately, Pakistan is way behind in the race of research and registration of different botanical pesticides although many local and exotic flora have been evaluated for their insecticidal and other anti-insect potential (Majeed *et al.*, 2020; Ghafoor *et al.*, 2020; Ahmed *et al.*, 2022; Ismail *et al.*, 2022; Majeed *et al.*, 2021; Tayyab *et al.*, 2022).

The term green pesticides refers to organic materials that can suppress the pest population (Mossa, 2016; Nollet and Rathore, 2019; Fenibo *et al.*, 2022; Subhash *et al.*, 2022). It is widely recognized among the public; however, it is also a subject of controversy. This term encompasses a variety of concepts and alternative names, including eco-friendly agrochemicals, ecological pesticides, and risk-reduced pesticides, each reflecting different perspectives within the discourse (Qian *et al.*, 2010; Karunamoorthi, 2012; Ataei *et al.*, 2021). Globally, the registered green or botanical pesticides constitute of only 1.0% of the pesticide market (Rozman *et al.*, 2007) because most plant active materials are being used commercially in cosmetic and pharmaceutical industries (Peeyush *et al.*, 2011; Sparagano *et al.*, 2013). Approximately, 17,500 plant species having aromaticity are being cultivated worldwide and more than 3,000 active constituents have been characterized from them (Maddocks-Jennings *et al.*, 2005).

In recent years, research and development efforts have been increased significantly, and a substantial number of green pesticides are registered as agricultural, household, personal, urban and veterinary protectants in Canada, China and Greece but Pakistan did not list even a single registered botanical pesticidal product to date (Ali, 2018). The only patent in Pakistan named as Bioman having active material from neem (*Azadirachta indica*) is being used as household protectant against insect pests but it has not been registered yet.

Many scientists have explored green pesticides tremendously but Murray B. Isman's contributions are remarkable about discussing the effectiveness of green pesticides and their future trends along with their registration for practical use (Isman, 2006, 2017, 2020). The main objective of this review is to compile a complete collection of Canadian, Chinese, Greek and Pakistani green pesticides. Fortunately, we have attained the complete list of products from Canada and Greece but along with this on the other hand we could not access to the complete list of green pesticides from China and virtually no product was found from Pakistan. Furthermore, we have tried to analyze the formulations of green pesticides in different sectors and according to different insect pest families and orders as de Faria and Wraight (2007) described different formulations of mycoinsecticides and mycoacaricides from worldwide.

This review aimed to document a comparative database of plant-based green pesticidal products developed and registered in different countries. Although, Pakistan is far behind in this regard, a substantial number of green pesticides have been developed in other countries. Here we present a comprehensive list of these phyto-products developed and registered in Canada, China and Greece. This review is based on information of green pesticides products retrieved from different online databases of Canada, China and Greece.

Products and formulations

A list of green pesticides fully from Canada, Greece and partially from China was drawn up on the basis of literature gathered from legitimate governmental databases. To this end, we accessed different official blogs from September, 2021 and January, 2022.

Green pesticide products

Green pesticides contain organic content extracted from various parts of different plant species used against insect pests. Based on information obtained from specific blogs, a complete list of licensed and registered green pesticides from Canada, China and Greece are prepared with their manufacturing details. Information on target insect pests is also gathered and summarized at order and family level.

Formulations for the green pesticides

The labeled formulation types of green pesticides are identified from the catalogue of the CropLife International coding system for pesticides (CropLife

International, 2017). The catalogue defines approximately 95 different formulation types. More than one formulation type is also existed in a single product. For the better understanding of the defined formulations of green pesticides, we have also consulted the manual of FAO/WHO specifications for pesticides (WHO, 2016).

Overview of Green Pesticides

Database of all green pesticidal databases have shown that sixteen plant species, including two hybrids, are used in green pesticides as active ingredients. These have been described alphabetically in Table 1. The highest number of products (106) are derived from lemon-scented gum tree *Corymbia citriodora* (family Myrtaceae) since it is the most commonly planted genus in the world, comprising around 900 species and sub-species (Gilles *et al.*, 2010). Citronellal and geraniol are the main bioconstituents of *C. citriodora*, exhibiting effectiveness against different insect pests including green peach aphids and thrips (Costa *et al.*, 2015). Approximately, 76 companies have developed 161 products of green pesticidal products (Smith *et al.*, 2021). All these products enlisted here are being actively utilized by the consumers (Supplementary Table 1).

Table 1: Plant species developed as green pesticides and their commercial status.

Plant species	No. of products*	Percentage
<i>Allium sativum</i> L.	9	6
<i>Brassica juncea</i> L. Czern.	1	1
<i>Brassica napus</i> L.	1	1
<i>Celastrus angulatus</i> Maxim	3	2
<i>Chrysanthemum cinerariaefolium</i> Vis.	10	6
<i>Cinnamomum camphora</i> (L.) Presl	8	5
<i>Citrus limon</i> L.	4	2
<i>Corymbia citriodora</i> Hook.	106	66
<i>Cymbopogon nardus</i> L.	2	1
<i>Eucalyptus</i> Genus	2	1
<i>Lavandula × intermedia</i>	1	1
<i>Lonchocarpus</i> Genus	3	2
<i>Mentha × piperita</i>	1	1
<i>Pelargonium graveolens</i> L.	1	1
<i>Pinus sylvestris</i> L.	1	1
<i>Sophora</i> Genus	2	1
<i>Stellera chamaejasme</i> L.	3	2
<i>Veratrum nigrum</i> L.	3	2
Total	161	100

*All products are active for their commercial use.

The presented data summarizes the commercial status of various plant species developed as green pesticides, detailing the number of products derived from each species and their corresponding percentages. The data reveals that *Corymbia citriodora* (commonly known as lemon eucalyptus) dominates the landscape with a remarkable 106 products, accounting for 66% of the total. This indicates its significant role in the development of eco-friendly pest control solutions. Other significant contributors are *Chrysanthemum cinerariaefolium* (10 products, 6%) and *Allium sativum* (9 products, 6%), both known for their insecticidal properties. A few species, such as *Cinnamomum camphora* and *Celastrus angulatus*, also show a modest presence with 8 and 3 products, respectively. Many other plant species, including *citrus lemon*, *eucalyptus*, and *lavandula × intermedia*, contribute minimal numbers, each represented by one to four products. Overall, we have tabulated the growing trend of utilizing botanical resources in pesticide development, with a total of 161 products identified, reflecting the increasing interest in sustainable agricultural practices and the potential of natural compounds in pest management (Supplementary Table 1).

The data claimed a comprehensive overview of various personal and veterinary insect repellents sourced from Greece, Canada, and China, highlighting their active ingredients, application types, and target insect families. Notably, many of these products utilize plant extracts, reflecting a trend towards natural insect repellents. *Eucalyptus* species, and *Lavandula × intermedia* (Lavender), indicating their effectiveness against Diptera, particularly mosquitoes from families like Culicidae and Anisopodidae. The formulations vary in concentration, with some products containing up to 30% active ingredients, optimizing their efficacy. Additionally, veterinary protectants like Citrobug for dogs and horses demonstrate the cross-application of these natural compounds in human and animal products. This diversity in formulations and target pests underscores the potential for utilizing plant-based compounds in developing effective repellents, aligning with growing consumer demand for eco-friendly alternatives.

According to the data developed for green pesticides from the three countries, the Greece developed more products (69.56%) than Canada (16.15%) and China (14.29%), respectively. Formulation types could not be determined for 20.49% of all listed products and despite

some conflicting data and lack of standardization among different sources, two technical products, i.e., technical material (TC) and technical concentrate (TK), and sixteen different formulation types were identified. The most common types were the any other liquid (AL) (36.02%) which is not defined and vapor releasing products (11.18%). The remaining types included technical material (3.73%), aerosol dispenser (3.11%), emulsifiable concentrate (3.11%), emulsion (3.11%), Micro-emulsion (3.11%), cream (2.48%),

milk (2.48%), soluble concentrate (2.48%), tablet for direct application (1.86%), suspension concentrate (1.86%), technical concentrate (1.86%), contact liquid (0.62%), fine granule (0.62%), smoke generator (0.62%), vaporizing mat (0.62%) and stick (0.62%).

Table 2 shows the distribution of green pesticides as per their target insect orders and families, showing how different pesticide types are associated with specific insect orders and families. It includes the total

Table 2: Number of green pesticides as per target insect orders and families.

Orders and families	Plant species																			Total	%
	As	Bj	Bn	Ca	Cci	Cca	Cl	Ccit	Cn	Eg	Lxi	Lg	Mxp	Pg	Ps	Sg	Sc	Vn			
Blattodea					1		2												3	1.86	
Blaberidae					1		2												3	1.86	
Blattidae					1		2												3	1.86	
Corydiidae					1		2												3	1.86	
Cryptocercidae					1		2												3	1.86	
Ectobiidae					1		2												3	1.86	
Lamproblattidae					1		2												3	1.86	
Nocticolidae					1		2												3	1.86	
Tryonicidae					1		2												3	1.86	
Coleoptera						7													7	4.35	
Dermestidae						7													7	4.35	
Dermaptera							2												2	1.24	
Forficulidae							2												2	1.24	
Diptera	9				9	1	1	91	2		1		1	1	1				117	72.67	
Anisopodidae					6			22					1						29	18.01	
Culicidae	9				9	1	1	91			1		1	1	1				115	71.43	
Muscidae	3					1	1	4						1	1				11	6.83	
Mycetophilidae					6			22					1						29	18.01	
Sciaridae					6			22					1						29	18.01	
Tabanidae	1					1	1	7					1	1	1				13	8.07	
Hemiptera							1			2		3						3	9	5.59	
Aleyrodidae							1												1	0.62	
Aphididae							1			2		3						3	9	5.59	
Hymenoptera					1		2												3	1.86	
Formicidae					1		2												3	1.86	
Lepidoptera				3												2	3	3	11	6.83	
Pieridae				3												2	3	3	11	6.83	
Phthiraptera								18											18	11.18	
Pediculidae								18											18	11.18	
Siphonaptera							2	9											11	6.83	
Pulicidae							2	9											11	6.83	
Thysanura							2												2	1.24	
Lepismatidae							2												2	1.24	

As, *Allium sativum*; Bj, *Brassica juncea*; Bn, *Brassica napus*; Ca, *Celastrus angulatus*; Cci, *Chrysanthemum cinerariaefolium*; Cca, *Cinnamomum camphora*; Cl, *Citrus limon*; Ccit, *Corymbia citriodora*; Cn, *Cymbopogon nardus*; Eg, *Eucalyptus* Genus; Lxi, *Lavandula x intermedia*; Lg, *Lonchocarpus* Genus; Mxp, *Mentha x piperita*; Pg, *Pelargonium graveolens*; Ps, *Pinus sylvestris*; Sg, *Sophora* Genus; Sc, *Stellera chamaejasme*; Vn, *Veratrum nigrum*. Percentages calculated by dividing the number of products per order/family by the total number of products (161).

Table 3: Number of green pesticides per different target sectors.

Sectors	Plant species ^a																			
	As	Bj	Bn	Ca	Cci	Cca	Cl	Ccit	Cn	Eg	Lxi	Lg	M×p	Pg	Ps	Sg	Sc	Vn	Total	%
Agricultural protectant			1	3			1			2		3				2	3	3	18	11.18
Household protectant					1	7	2												10	6.21
Personal protectant	7				9			94	2		1								113	70.19
Urban protectant	2				2														4	2.48
Veterinary protectant						1	1	13					1	1	1				18	11.18

a: As, *Allium sativum*; Bj, *Brassica juncea*; Bn, *Brassica napus*; Ca, *Celastrus angulatus*; Cci, *Chrysanthemum cinerariaefolium*; Cca, *Cinnamomum camphora*; Cl, *Citrus limon*; Ccit, *Corymbia citriodora*; Cn, *Cymbopogon nardus*; Eg, *Eucalyptus* Genus; Lxi, *Lavandula x intermedia*; Lg, *Lonchocarpus* Genus; Mxp, *Mentha x piperita*; Pg, *Pelargonium graveolens*; Ps, *Pinus sylvestris*; Sg, *Sophora* Genus; Sc, *Stellera chamaejasme*; Vn, *Veratrum nigrum* b: Percentages calculated by dividing the number of products per sector by the total number of products (161).

number of green pesticides used for each order/family and their respective percentage contributions to the total. The targets are distributed across 10 insect orders: Diptera (72.67%), Phthiraptera (11.18%), Lepidoptera (6.83%), Siphonaptera (6.83%), Hemiptera (5.59%), Coleoptera (4.35%), Blattodea (1.86%), Hymenoptera (1.86%), Dermeptera (1.24%), and Thysanura (1.24%). The products listed are reported to be effective against insects from at least 23 different families, with the Culicidae, Anisopodidae, Mycetophilidae, and Sciaridae families being among the most commonly targeted.

Overall, this data (Table 2) reflects the prioritization of pest control efforts using green pesticides. The data indicates that the most common use of green pesticides is in controlling mosquito populations (Culicidae), with a notable emphasis on controlling lice (Pediculidae), and some additional pest groups in the Diptera order. Meanwhile, orders like Coleopteran and Dermaptera see relatively low pesticide usage, reflecting either lesser pest impacts or alternate management methods. This trend could guide future research or policy on pesticide use and environmental impacts, highlighting areas where green pesticide alternatives are most necessary.

This breakdown shows how the distributions of green pesticides vary across different insect families, illustrating which pests are of greater concern and the level of interventions needed in pest management.

On the other hand, Table 3 shows the distribution of green pesticides across various target sectors. The sectors covered include the agricultural protectant, household protectant, personal protectant, urban protectant, and veterinary protectants. But the

green pesticides are used in personal protectant with significant contribution from plants like *Corymbia citriodora* and *Mentha x piperita*. The majority of green pesticides are developed for personal protectant (70.19 %), followed by agricultural protectants (11.18%), veterinary protectants (11.18 %), households protectants (6.21%), and urban protectants (2.48%). The agricultural sectors and veterinary sectors also play an important role, while the urban protectants and household protectants sectors account for the smaller portion of the total. The distribution across these sectors shows how various plant species are utilized based on their specific pesticidal property, and the data indicates a strong preference for certain species in key target markets, especially in personal care and agriculture (Table 3).

There is a major downside of having an incomplete products' list just for China for the development of this literature. The collection of items provided in this literature, would serve as a resourceful database which can be revised and updated regularly.

Conclusions and Recommendations

Overall literature review reveals a substantial research and commercialization of different plant based products as green or botanical pesticides by China, Greece and Canada. Lemon-scented gum tree (*C. citriodora*), garlic (*A. sativum*), pyrethrum (*C. cinerariaefolium*) and camphor tree (*C. camphora*) are the most researched and commercialized plant species in this regard with maximum registered green pesticidal products. However, Pakistan is still far behind in this regard most probably because of the inadequate research capacities and priorities, and because of the lack of suitable registration regulations

for botanical insecticidal products. There should be more focus on the green pesticidal research and development in the country and the Government should support such initiatives by taking all stockholders onboard in order to promote organic plant protection strategies as biorational alternatives of hazardous synthetic chemicals and pesticides. Our Ministry of Agriculture should maintain such database and blogs of registered green pesticides as being done by the Ministry of Rural Development and Food, Greece and by the Ministry of Agriculture, China.

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Novelty Statement

The review paper presents a comprehensive review analysis and a consolidated database of the botanical insecticidal products manufactured in developed countries (Canada and China) and compared it with the progress made in Pakistan.

Author's Contribution

Muhammad Zeeshan Majeed: Conceived the idea and supervised the work.

Kanwer Shahzad Ahmad: Conducted literature review and wrote first draft.

Umar Farooq and Kaneez Fatima: Data analysis and preparation of result tables.

Huda Aitzaz and Murtajiz Abbas: Helped in data recording, tabulation and discussion.

Muhammad Asam Riaz: Proofread the draft technically and grammatically.

Supplementary Material

There is supplementary material associated with this article. Access the material online at <http://dx.doi.org/10.17582/journal.sja/.....>

Conflict of interest

The authors have declared no conflict of interest.

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