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The potential of ginger (*Zingiber officinale* Rosc.) extracts as a bio-pesticide

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Abstract
Excessive and widespread use of commercially available synthetic pesticides against phytophagous insects in various agroecosystems has led to their successive bioaccumulation in the surrounding environment. This phenomenon diminishes biodiversity, increases insect resistance, and negatively impacts non-target species, including human health and the ecosystem. To combat this, safer and environmentally friendly alternatives to chemical pesticides are needed. One such alternative is plant-derived extracts, which have shown potential effectiveness in pest control. Ginger has been recognized as a promising natural pest-controlling agent with high efficiency and low toxicity in plant pest and disease management systems. Zingiberene, shogaol, and gingerol are the active components of ginger that give it its potent biocidal qualities. These active constituents interfere with some insect metabolic procedures, such as chitin synthesis, respiratory systems, central nervous systems, ATP synthesis, protein synthesis, impaired sexual communication, and antifeedant. This review demonstrates different varieties of ginger found in India and its efficacy as a pest-controlling agent and an alternative to conventional pesticides. It also aims to gather all the available scientific data regarding the extraction of different ginger plant parts, their application, and the mode of action in pest disease control of plants.

Keywords: Bio-pesticide, pest control, ginger extract, mode of action

1. Introduction

Ginger, originating from southeastern Asia, holds significant importance as a spice crop due to its ethnomedicinal and nutritional properties [1, 2]. All over tropical countries, about 50 genera and 1200 species of Ginger (*Zingiber officinale* Rosc) belong to the Zingiberaceae family [3]. This plant is a perennial herb with rhizomes. Rhizomes are thick-lobed, aromatic, and yellow-brown. Ginger is a commercial crop [4]. India holds the top position as the world's largest producer of ginger. India contributes to nearly 30-40 percent of the global production of ginger. In India, Karnataka, Kerela, Meghalaya, Mizoram, Arunachal Pradesh, Nagaland, Sikkim, West Bengal, Orissa, etc., are the central ginger-growing states [1].

Ginger is used in every household as a spice; it also has anti-vomiting, anti-emetic, anti-flatulent, anti-nausea, and analgesic effects. Crude extract of ginger rhizomes has an immense impact on gastrointestinal tract diseases, blood purification, sex stimulants, aphrodisiacs, and respiratory infections [5]. The bioactive constituents of ginger exhibit antioxidant properties and can regulate apoptosis, inhibit vascular endothelial growth factors, and reduce inflammatory reactions [6].

Ginger has a pungent smell due to 1-3% of volatile oils such as sesquiterpene, zingerone, kaempferol, and zingiberene [7]. Numerous reports have been found supporting that crude extract of ginger has insecticidal properties.

In the present scenario, the extraction processes to obtain the desired bioactive components that can serve as biopesticides are crucial. Several extraction processes are available, such as cold extraction, maceration, Soxhlet, subcritical fluid extraction, and microwave extraction. The effectiveness of extracting components from ginger depends significantly on key factors such as optimal temperature, the nature of the solvent used, particle size, and the duration of extraction.

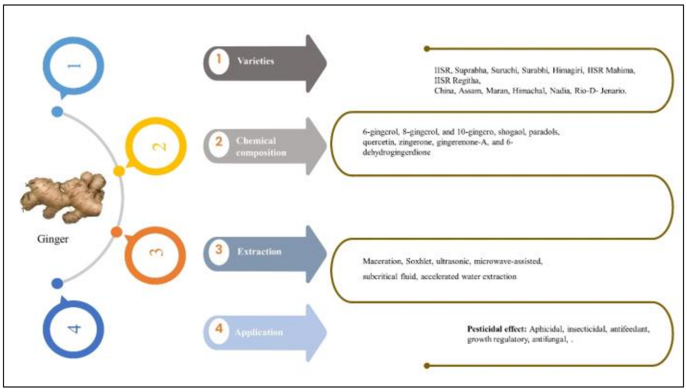
Synthetic pesticides are effective against various pest species of crops, and they are currently the principal method of insect control. Farmers often resort to chemical control methods in pursuit of greater profits.

However, their indiscriminate application has resulted in a multitude of detrimental consequences. Overreliance on chemical control exacerbates issues such as pest resurgence, pest resistance, depletion of beneficial organisms, environmental contamination, human toxicity, the presence of pesticide residues in food, and depletion of natural predators. It also disrupts crop pollination due to declines in honey bee populations, poisoning of domestic animals, contamination of livestock products, loss of aquatic and terrestrial wildlife, as well as pollution of underground water sources and rivers. Additionally, chemical pesticides entail considerable expenses [8]. Therefore, an alternate control technique will be highly desired in light of the foregoing issues. Natural pesticides are less harmful to humans than synthetic counterparts and are easily degradable. They also exhibit various advantageous properties, such as antifeedant effects, pest repellence, growth regulation activity, and insect toxicity [9]. Thus, natural pesticides are gaining traction in agricultural protection. Consequently, research into their utilization is expanding significantly.

Plant-based insecticides help to control pest populations at various developmental stages of their growth. Plant species, such as culinary spices or medicinal herbs, are most commonly used for biopesticide preparation. It helps balance the environment and agricultural production with every safety concern [10].

In a nutshell, plant-derived secondary components such as flavonoids, alkaloids, terpenoids, and phenols effectively control the pest population by disrupting their metabolic pathways and triggering rapid mortality [11]. The pungent scent, aroma, and flavor of ginger are attributed to a combination of volatile oils such as gingerols and shogaols [12]. Ginger has advantageous characteristics that help battle plant disease [13] symptoms and works as insecticidal [14], aphicidal [15], ovicidal, and antifeedant [16] on pest populations. Active compounds like gingerol, zingiberene, and shogaol in ginger influence insect metabolic processes, including chitin synthesis, respiratory systems, central nervous systems [17], sexual communication, shrinkage of larvae [16], and ultimately insect death.

In this review paper, we have incorporated articles regarding the different varieties of ginger, their chemical components, the potential of ginger crude extract-derived bioactive components, and their mode of action as a natural pesticide.



2. The systematic position of the ginger plant [18]

Kingdom - Plantae
Phylum - Spermatophyta
Subphylum - Angiosperms
Class - Monocotyledon
Order - Zingiberales
Family - Zingiberacea
Genus - Ginger
Species - *Zingiber officinale*

3. Ginger varieties of India (Directorate of Arecanut and Spice Development, Ministry of Agriculture and Farmers Welfare and TNAU Agritech portal, Horticulture)

Due to the unconscious assortment and natural hybridization of ginger clones, numerous varieties have grown. Indian types show substantial variation in rhizome yield, dry weight, extractive amount, fiber, and volatile oils. Agroclimatic conditions and natural mutants by selection are the primary reasons for the different varieties of ginger crops in our country [19]. Table 1. shows the different varieties of ginger.

Table 1: Ginger varieties

The chosen cultivars					
Varieties	**Yield t/ha**	**Maturity (days)**	**Dry potential yield (%)**	**Fiber (%)**	**Oleoresin**
Himagiri	13.50	230	20.60	6.40	4.30
Suprabha	16.60	229	20.50	4.40	8.90
IISR Regitha	22.40	200	19.00	4.00	6.30
Surabhi	17.50	225	23.50	4.00	10.20
IISR Mahima	23.20	200	23.00	3.26	4.48
Suruchi	11.60	218	23.50	3.80	10.00
IISR	22.60	200	20.70	4.50	6.70
Local cultivars					
China	9.50	200	21.00	3.40	7.00
Himachal	7.27	200	22.10	3.80	5.30
Maran	25.21	200	20.00	6.10	10.00
Assam	11.78	210	18.00	5.80	7.90
Rio-D-Jenario	17.65	190	20.00	5.60	10.50
Nadia	28.55	200	22.60	3.90	5.40

4. Chemical composition of ginger extracts through chemical analysis

There are about 400 different components present in ginger. Chemical component examination of ginger rhizomes reveals that the primary constituents include carbohydrates (50%-70%), lipids (3%-8%), as well as phenolic and terpene constituents [12]. The primary phenolic constituents in fresh ginger primarily consist of gingerols, paradols, and shogaols. Gingerols are most prominent in fresh ginger. However, shogaols are found in trace amounts. In fresh ginger, the hydroxyl group at the C-5 position of gingerols may be removed due to heat treatments or extended storage duration [20]. Consequently, shogaols undergo double bond formation between the C-4 & C-5 positions. So, 6-shogaol was abundant in dried gingers, followed by 8-shogaol and 10-shogaol [21]. The fragrance is attributed to bisabolene and zingiberene. The pungent fragrance of ginger is due to the presence of gingerols and shogaols. Table 2. shows the various bioactive components of ginger.

Table 2: Different forms of ginger and its bioactive constituents

Bioactive components	Phenolic	Terpenes	Others	Ref.
Fresh ginger	Gingerol (6, 8, 10-gingerol), paradols, shogaol, 6-dehydrogingerdione quercetin, zingerone, and gingerenone-A,	β-bisabolene, α-farnesene, zingiberene, α-curcumene, and β-sesquiphellandrene	Polysaccharides, raw fibers, lipids, and organic acids	[20]
Dried ginger	Shogaol (6,8,10-shogaol) and gingerol			[21]
Ginger powder	gingerol,paradols, and shogaol	ingiberene, β-sesquiphellandrene, β-bisabolene, α-curcumene,and α-farnesene,	amino acids, protein, raw fiber, ash, vitamins, and phytosterols,	[12]

5. The different extraction methods of ginger

Various amino acids, essential oils, fiber, acids, gingerol, and shogaols are the major constituents of *Zingiber officinale* Roscoe extraction. There are many ways of the extraction process depending on the desired result. To get essential oil, steam distillation is used, and a solvent extraction method is followed for oleoresins. For thermolabile bioactive components, cold extraction is used. Here are some major extraction processes are listed below in Table 3.

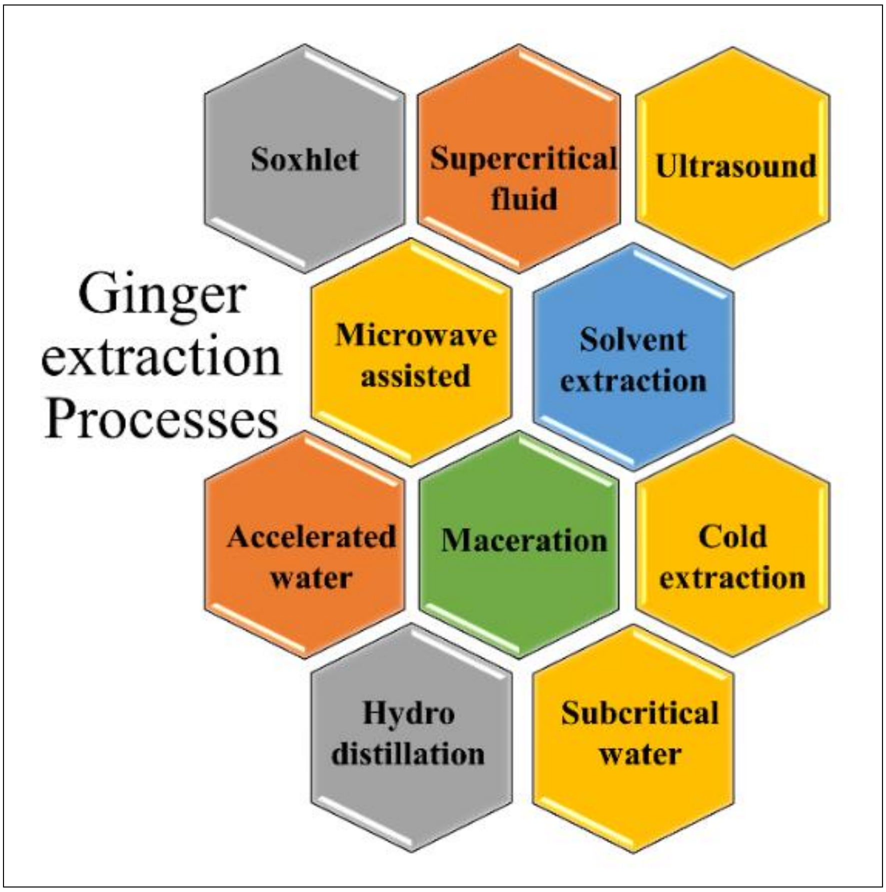


Fig 1: Various ginger extraction processes

Table 3: The primary extraction process of ginger

Sl no.	Extraction procedure	Solvents	Phytochemicals	Extraction duration	Extraction temperature	Production rate	Ref.
1	Cold extraction.	absolute methanol		4 days	30 °C	10.79±0.03%	[6]
2	Steam distillation	water	Linalool, borneol, and geraniol, xhantorrhizol and n-hexadecanoic acid	7.5 hrs	214 °C	2.43% oil	[22]
3	Maceration Soxhlet ultrasonic	Ethanol		maceration -72 hrs Soxhlet -12 hrs ultrasonic-30 min	maceration - Soxhlet -78.4 °C ultrasonic-15 °C		[23]
4	Subcritical Fluid Extraction	water	zingiberene, gingerol, paradol, and shogaol	20 mins extraction time, 9 mins aging time	125 °C,	0.036%	[24]
5	Ultrasound extraction process	Ethanol	zingerone	frequency of 42 kHz	60 °C		[25]
6	Solvent-free microwave extraction	No solvent	essential oil	30 mins	microwave power level 640 watts	0.25% of ginger oil	[26]
7	Hot water extraction; high-pressure homogenization; ultrasonication	water		60 mins 15mins	55 °C 62 °C 52 °C		[27]
8	Microwave-assisted extraction (MAE)	ethanol	6-gingerol	10 mins	70 °C, 400 W	26%	[28]
9	Soxhlet Extraction, autoclave agitator, and ultrasound-assisted extraction	Soxhlet- acetone (best), methanol, ethanol, water, n-hexane		4 hrs	80 °C	57%	[29]
10	Maceration process	ethanol	Gingerol, oleoresins				[30]
11	Solvent extraction	CO2, EtOH, IsoC3	a-zingiberene, gingerols and shogaols	11hrs	25 and 35 °C		[31]
12	Microwave extraction	water	zingiberene, β-sesquiphellandrene, β-phelladrene and cineol.	1 hr	800 W		[32]
13	Soxhlet, Accelerated Water Extraction (ASE)	Soxhlet- ethanol ASE- water	Gingerols (6,8,10-gingerol) and 6-shogaol	Soxhlet-12hrs ASE-30 mins	Soxhlet-78.1 °C ASE-140 °C	13.948, 7.12, 10.312 and 2.306 mg/g,	[33]
14	Soxhlet	acetone, methanol, n-hexane, water, ethanol		60 min	80°C	Acetone-57% (highest)	[29]
15	Subcritical water extraction	water	gingerol	20 mins	130-140 °C	5%	[34]
16	Supercritical Fluid Extraction SFE	CO2	curcumene, zingiberene, and β - sesquipellandrene	4 hrs	40 °C	2.9%	[35]
17	Supercritical fluid extraction (SFE), hydrodistillation (HD) techniques, and steam distillation (SD)	SFE-CO2 SD-water HD-water	geranial and α-zingiberene, β-sesquiphellandrene,		SFE-40 °C HD-100 °C SD-133 °C	SFE-19.34% SD-28.9% HD-15.70%	[36]
18	Subcritical water extraction (SWE)	(SWE)-water Co-solvent-ethanol	gingerols and shogaol	30 mins	130 °C	2990.55 µg /g	[37]

5.1 Subcritical Fluid Extraction

In 2019, Vita *et al*. reported a ginger extraction method utilizing subcritical fluid extraction. In this process, 0.036% zingiberene was obtained. The complete extraction procedure was conducted at 125 °C, with a ginger-to-solvent ratio of 0.08, an extraction duration of 20 minutes, utilizing water as the environment-friendly solvent, followed by a 9-minute aging period [24]. Another study of ginger extract was reported where gingerol was the active component. The experiment was carried out with 100 g of grounded ginger powder at 130 °C, 3 bar pressure, and for 20 minutes. A total of 5% gingerol was obtained through this method [35]. Amiri *et al*. developed a water-based method for the green extraction of ginger. The grounded ginger powder had a particle size of 1mm, and other optimized conditions were 130 °C and 20 bar for 30 min. Gingerols and shogoals were the active components of ginger extract [37].

5.2 Soxhlet and accelerated water extraction

Kanadea and Bhatkhandeb, 2016 reported in their study about ginger extraction with the Soxhlet extraction process with various solvents (methanol, n-hexane, acetone, water, ethanol). 50 g of ginger powder and 200 ml of solvent at 80 °C for 4 hrs were used. The results showed that with increasing pressure and temperature, yield reduces [29]. Azian *et al*. 2014, reported another ginger extraction process that compares Soxhlet and accelerated water extraction methods. In Soxhlet extraction, 20 grams of dried and ground ginger were utilized with 200 milliliters of ethanol at 78.1 °C for a duration of 12 hours. On the other hand, the Accelerated solvent extractor (ASE) was worked at 140 °C and 1500 psi pressure with various purging times in one cycle. The maximum yields of 6-, 8-, and 10-gingerols, as well as 6-shogaol in Soxhlet extraction, were found to be 13.948, 7.12, 10.312, and 2.306 mg/g, respectively. In ASE, the yields were 68.97±3.95 mg/g at 3 minutes, 18.98±3.04 mg/g at 5 minutes, 5.167±2.35 mg/g at 3 minutes, and 14.57±6.27 mg/g at 3 minutes, respectively [33].

5.3 Cold extraction
Gautam *et al*. 2019, reported an extraction process where thermolabile bioactive constituents of the ginger extract could be procured without any alteration. For the extraction process, 10 grams of different plant parts of ginger powder were combined with 250 milliliters of methanol and subjected to a shaker incubator for a duration of 4 days at 30 °C, with a speed of 160 rounds per minute. The yield of ginger rhizome (R), ginger leaves (L), packaged ginger powder (P), and ginger rhizome juice were 10.79±0.03%, 8.17±0.07%, 9.76±0.16%, and 16.8±1.98% respectively [6].

5.4 Supercritical fluid extraction (SFE)
Fitriady *et al*. 2017, described an extraction method with varying temperatures and time and CO_2 as a solvent system. Results showed that to get the highest yield (2.9%), the optimum temperature was 40 °C with 4500 psi for 4 hrs. Reason behind the experiment was to observe the changes in solvent and vapor pressure, as well as the total yield and composition of the extract. Zingiberene, β- sesquipellandrene, and curcumene were the major constituents of extraction procedure [35].

5.5 Microwave-assisted extraction (MAE)
Another study reported the MAE of ginger to get the maximum yield of 6-gingerol. Optimized conditions were 100 g of ginger powder, 400 W, and 70 °C for 10 min. The yield was 21.15±0.13 mg/g in fresh ginger and 18.81±0.15 mg/g in dried ginger [28]. Compared to other conventional extraction methods, this process showed higher antioxidant activity.

6. Pesticidal effects and mode of action of ginger
Ginger extract-derived bioactive constituents affect feeding, behavior, growth, development, reproduction, nervous system, respiratory systems, and metamorphosis in diverse insect taxa. The chemosensory and central nervous systems regulate plant selection, feeding behavior, and molting in phytophagous insect hosts, which are disrupted due to the use of ginger extract as a biopesticide. The efficacy and mode of action of ginger's active components on insects are listed below in Table 4.

Table 4: Pesticidal Effects of Ginger and its Mode of Action

Sl no	Mode of action	Major components	Target pest	Dosage	Exposure time	Ref
1	Aphicidal	6-Gingerol, quercetin-3-O-rutinoside	sorghum aphid (*Melanaphis sorghi*)	contact toxicity- 10 mg/ml growth inhibition- 5, 10, and 15 mg/ml	12 hrs, 24 hrs	[38]
2	Insecticide	crude extract	cabbage looper (*Trichoplusia binotalis*)	3%	7 days	[39]
3	Insecticide	Crude extract	*Sitophilus oryzae* L.	1%, 2%, 5% and 10%	4 weeks	[40]
4	Insecticide	α-zingiberene-16.98% and 13.74% α-farnesene -12.57% and 10.64% α-curcumene-8.75% and 8.03% β-sesquiohellandrene-8.02%, 8.23% citral-7.66%, 1.60%	cockroaches	IC50- 16.0% IC90- 28.0%	48 hrs	[41]
5	Insecticide	fractions of ginger	okra flea beetles and cowpea bruchid	20%, 25%, and 30%	21 days	[8]
6	Insect growth regulatory (IGR) and antifeedant activity against-*Spilosoma obliqua*, antifungal activity against-*Rhizoctonia solani*.	zingiberene, [6]-gingerol, [6]-dehydroshogaol	*Spilosoma obliqua, Rhizoctonia solani.*	[6]-dehydroshogaol-EC50 3.55mg/ml dehydrozingerone EC50 86.49mg /liter	24 hrs	[16]
7	Insecticide	isopropyl myristate -16.41% tetratetracontane-13.16% 17-pentatriacontene-10.68% celidoniol deoxy-4.47% a-zingiberene -12.26% Eucalyptol-4.5%	*Spodoptera littoralis*	LC50-4330 µg/ml LC90-10369 µg/ml	48hrs	[11]
8	Insecticide	terpenoid	*Aedes aegypti*	LC50 - 2.409%.	60min	[17]
9	Insecticide	crude extract	*Culex theileri*	45% insecticidal and 61% repellent activity	30 mins	[42]
10	Aphicidal	crude extract	black bean aphid (*Aphis fabae Scop*)	20 mg/ml mortality-70%	48hrs	[15]
11	Insecticide	crude extract	cabbage looper (*Trichoplusia binotalis*)	20ml/l	7 days	[39]

6.1 Aphicidal
Among different plant-based natural pesticides, the effect of ginger plant parts is immensurable. Liu *et al*. 2022, reported ginger shoot extract's aphicidal and growth regulatory effects against sorghum aphids (*Melanaphis sorghi*). The study showed that the significant constituents of ginger extracts were quercetin-3-O-rutinoside and 6-gingerol, which act as the main aphicidal components. The actions of pepsin, α-amylase, and lipase of aphids were inhibited, although the action of superoxide dismutase (SOD) was suggestively stimulated. The activity of acetylcholinesterase (AChE) was also repressed. Overall, the findings showed that the mortality rate increased and the litter size, aphid molting, and longevity decreased as the concentration of ginger extract increased [38].

6.2 Insecticidal
Madreseh-Ghahfarokhi *et al*. 2018, reported that the essential oils derived from *Zingiber officinale* exhibit pesticidal and repellent properties for *Culex theileri* Theobald, 1903. Essential oils with different concentrations of 250 µl/ml, 500 µl/ml, 750 µl/ml, 1 were prepared, and a Y-tube olfactometer bioassay was performed against the mosquitoes. Results showed 5% insecticidal and 61% repellent efficiency of ginger essential oil [42]. Another study also demonstrated the effective use of ginger extract as an insecticide against the adult beetle Oryzaephilus surinamensis (a pest associated with dates). It showed an LC50 value of 0.14 mg/g through contact toxicity. Insect protein configuration changes by increasing protein subfractions due to using ginger as a pesticide [43]. Singh *et al*., 2012 reported the insecticidal effects of ginger on *Spodoptera litura* F. and *Plutella xylostella saunders* in cabbage [44]. Another report showed insecticidal effects on *Rhaffella germanium*, *Diphtheria spp*, *Aedes spp*, and brown plant hoppers [10].

6.3 Nematocidal
The ginger plant extract has a nematocidal effect. It induces behavioral changes by modifying nematodes' host recognition ability [45].

6.4 Antimicrobial
Research findings indicate that α-zingiberene, arcurcumene, β-sesquiphellandrene, geranial, α-farnesene, and β-bisabolene, which are components of ginger essential oil, exhibit antimicrobial properties. They demonstrate a notable inhibition zone diameter against bacteria such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Listeria monocytogenes* [5].

6.5 Zingiberene
It acts as an antifeedant. Zingiberene attacks insects' central nervous system (CNS) and turns off sensory organs. Thus, the insects are unable to smell and recognize adjacent food items. Eventually, it damages the gastrointestinal tract and inhibits the activity of the olfactory organs, and as a result, the larva stops eating and dies due to weakness [17].

6.6 Kaempferol
It impairs olfactory organs, resulting in respiratory issues in insects. Additionally, it exhibits larvicidal effects by interfering with the larval respiratory system and impairing mitochondrial function. This disruption ultimately affects the electron transport system, leading to a reduction in ATP production. Consequently, the larva experiences a decline in energy levels, eventually leading to its demise [17].

6.7 Gingerols, dehydroshogaol
These components derived from ginger exhibit insect growth regulatory (IGR) and antifeedant properties. They disrupt membrane metabolism within the gut epithelium of target insects and generate oxygen radicals through oxidation. Moreover, gingerols and dehydroshogaol distress P450-dependent ecdysone 20-monooxygenase activity, leading to the interruption of juvenile hormone (JH) levels, ecdysteroid levels, chitin synthesis, endocrine function, and antioxidant enzyme systems [16].

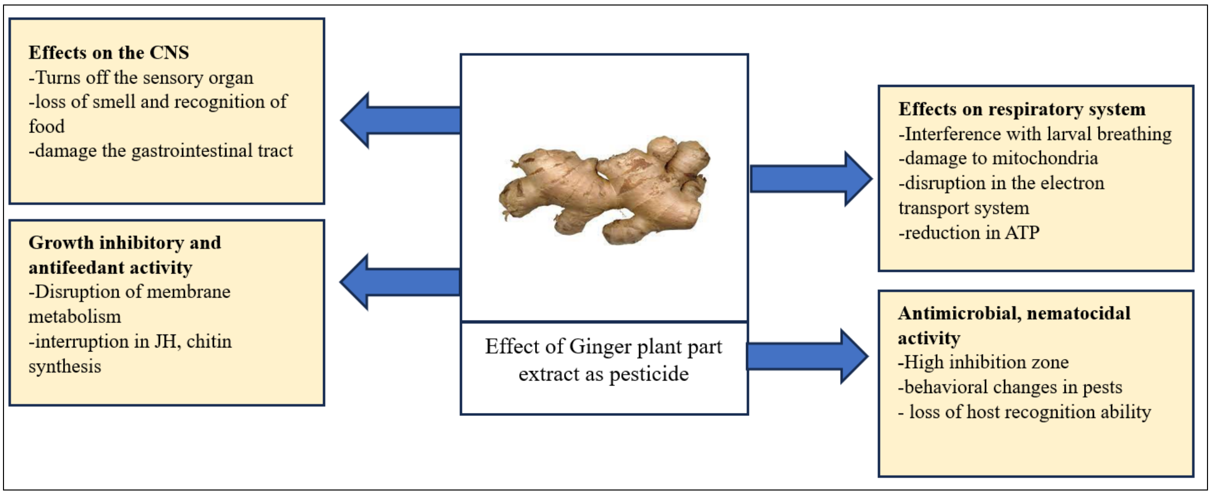


Fig 2: Various pesticidal effects of Ginger (*Zingiber officinalis*

7. Discussion
In this review paper, we tried to accumulate different extraction processes of ginger, their different varieties, active components, and, most importantly, their mode of action on insect pests as a natural pesticide. The extraction efficiency depends on various factors such as the optimized sample, the particle size of the sample, temperature, reaction time, solvent type, solvent-to-solute ratio, pressure, and yield. Ginger extraction can be conducted through various methods, including autoclave agitation, ultrasound-assisted extraction, Soxhlet extraction, microwave extraction, solvent-based extraction, solvent-free extraction, and more.

After comparing various extraction processes, Soxhlet extraction emanated as a proficient technique. It is a simple process with high recovery and thermal stability, is economically viable, has low energy consumption, and, most importantly, is environment-friendly. Although concerning duration, Soxhlet extraction takes an enormous time for each complete cycle. Microwave-assisted extraction takes only 10 mins, followed by ultrasonication extraction, which takes 15 mins, and subcritical fluid extraction, which takes 20 mins. Considering solvent usage, a few methods use a green solvent, such as water or no solvent. In conclusion, the extraction process may differ in order to get the desired yield and active components.

Across different extraction techniques, such as Soxhlet extraction, microwave-assisted extraction, supercritical fluid extraction, ultrasonic, and accelerated solvent extraction, the yield remains more or less consistent. The most prominent benefit of Soxhlet extraction is that there is no filtration requirement. The sample phase constantly comes into contact with a fresh portion of solvent, which causes the analyte to move from the matrix.

The extraction rate using ultrasound-assisted extraction was approximately 1.75 times faster than that of a traditional Soxhlet-based extraction method. Ultrasonic-assisted extraction technique displayed the maximum polyphenol recovery compared to hot water extraction and high-pressure homogenization.

A notable drawback involves manually extracting solvents after microwave-assisted extraction (MAE). Extended cooling periods of MAE can elevate contaminant levels and raise the risk of analyte loss.

Various bioactive constituents of ginger and its derivatives have biological activity. Alteration of the alkyl or alkenyl side chain, derivatization of the OH group, and exchange in the aromatic nucleus are the most probable reasons for ginger extract's profound pest control ability.

The ginger extract reduces pest populations and acts as an insecticide, larvicide, aphicide, repellent activity, and nematicide. It also has antibacterial properties. Due to ginger-derived active constituents, insects lost their ability to smell and could not find food. Respiratory problems, contact toxicity, food aversion, cytoplasmic membrane leakage, hormonal work disruption, ATP production decrease, etc., occur due to ginger-derived active components in insects. Thus, ginger-derived active ingredients could easily replace chemical pesticides to decrease the adverse effects on the environment.

8. Conclusion

Studies suggest that the duration of the extraction process holds the utmost influence on achieving optimal extraction, followed by temperature, pressure, choice of solvent, particle size, and the type of sample used. Gingerol is the most abundant constituent of ginger extract, although due to high temperature and long duration, it is converted to shogaol. Therefore, extraction with dried ginger at high temperature showed a higher shogaol quantity in the extract. Ginger crude extract is useful in controlling pest infestation by disrupting essential metabolic pathways such as chitin synthesis, respiratory systems, ATP synthesis, and central nervous system. It is safe for the environment, easily degradable, less dangerous for human health, and, most importantly, has minimum consequences on natural enemies. However, the mode of action of the respective ginger chemical constituent is still indistinguishable. Each constituent has a unique function, an area of concern for future research.

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10. Author Contributions

Nitu Sinha drafted the manuscript and Dr. Sonali Ray conceived the article along with final drafting. The authors read and approved on the final version of the manuscript.

11. Disclosure statement

There is no conflict of interest among the authors regarding the publication of the manuscript.

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