IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

# BIOWASTE TO BIO-REPELLENT: A STUDY ON THE INSECTICIDAL EFFICACY OF CITRUS MAXIMA PEELS

[1] **Jeeva Raj[1],**[1]Student,Bsc Microbiology, [1]St.Mary's College Thrissur, Kerala ,India

***Abstract:*** Mosquito-borne diseases continue to pose significant global health challenges, particularly in tropical regions. Conventional synthetic repellents, while effective, are often associated with environmental and health concerns. This study explores the potential of Citrus maxima (pomelo) peel waste as a natural source of mosquito-repelling compounds. Citrus peels are rich in bioactive constituents such as limonene, flavonoids, and essential oils, which exhibit strong insect-repellent properties. The extraction of these compounds through eco-friendly methods aims to promote the utilization of agricultural waste while offering a safer alternative to chemical repellents. Preliminary analysis suggests that these phytochemicals disrupt mosquito sensory mechanisms, reducing their ability to detect human hosts. This approach not only addresses the issue of fruit waste management but also supports the development of sustainable, plant-based mosquito repellents with potential applications in public health and household care. Further research is proposed to validate the efficacy through laboratory bioassays and formulation trials.

***Index Terms -*** Pomelo peels, *Citrus maxima*, Bio-waste, Mosquito Repellent, Valorization, Value addition

## I. Introduction

India is the largest producer of fruits globally and contributes significantly to the world's total fruit output. With this high level of production comes the challenge of managing an enormous volume of organic waste, estimated at 25 to 57 million tons annually, of which around 15 to 60 percent consists of fruit peels (Malpani et al., 2024). This waste originates mainly from domestic kitchens and food processing industries. As the demand for fruit-based products grows due to population expansion and changing dietary trends, the generation of peel waste continues to rise (Kumar et al., 2020).

Although often regarded as a by-product, fruit peels possess substantial nutritional and industrial value. When not properly managed, they contribute significantly to municipal solid waste, creating environmental and sanitation challenges, especially in developing regions (Rathnakumar et al., 2017). Municipal solid waste includes organic matter such as citrus peel residues, which degrade rapidly due to their high moisture content and acidity. This decomposition lowers oxygen levels in water bodies and leads to unpleasant odors and pollution (Ruiz et al., 2014).

Citrus fruits such as oranges, lemons, grapefruits, and pomelos (Citrus grandis) are among the most widely cultivated and consumed globally. However, their processing yields a large amount of waste. During juice extraction, only about 45 percent of the fruit is used, while the remaining 27 percent of peel, 26 percent of pulp, and 2 percent of seeds are typically discarded (Leporini et al., 2009). Improper disposal methods such as landfilling and incineration add to environmental degradation and resource loss (Siles et al., 2016).

Citrus peels are rich in compounds such as polyphenols (including naringin, hesperidin, and tangeretin), carotenoids (like beta-carotene, lutein, and lycopene), pectin, essential oils (particularly D-limonene), dietary fibers, prebiotics, and enzymes (Wang et al., 2014; Foti et al., 2021; Maoka et al., 2009). These bioactive substances have found applications in food, pharmaceutical, cosmetic, agricultural, and environmental industries. Products developed from citrus waste include edible films, biofertilizers,biopolymers, food preservatives, and pest control agents.

### 1.1 Citrus peel as a natural insect repellent

One promising and sustainable application of citrus peel is in the production of natural insect repellents, particularly for controlling mosquito populations. Mosquito-borne diseases such as dengue fever, malaria, Zika virus, and chikungunya remain critical public health concerns, especially in tropical and subtropical regions. Commercial repellents often contain synthetic chemicals like DEET, which can cause health risks, environmental contamination, and insect resistance over prolonged use (Pandey et al., 2023).

Pomelo peels are a good source of essential oils and limonoids, such as D-limonene, which have demonstrated larvicidal and insecticidal activities. These substances interfere with the insect nervous system, reduce feeding behavior, and can lead to larval mortality. Studies have shown that extracts from *Citrus latifolia* can achieve complete mosquito larval mortality under laboratory conditions, highlighting the effectiveness of citrus-based solutions (Obembe et al., 2022).

In addition to insect control, limonoids like limonin exhibit antimicrobial, anticancer, antioxidant, and pesticidal properties (Gualdani et al., 2016). Research also supports the use of essential oils from citrus peels as safer alternatives to synthetic pesticides, with lower toxicity to humans and the environment (El Asbahani et al., 2015; Golmakani et al., 2016).

Fermented citrus peels produce citrus bioenzymes, which are used as eco-friendly household agents for cleaning and disinfection. These bioenzymes serve as multi-functional products, offering insect-repelling properties while contributing to a non-toxic, sustainable living environment. Their use in wastewater or greywater management systems provides the additional benefit of pest deterrence without polluting water bodies or harming beneficial microbes (Mukherjee et al., 2020).

In the face of growing ecological concerns, the emergence of pesticide resistance, and a global push toward sustainable alternatives, converting citrus peel waste into mosquito repellents is an efficient and environmentally responsible strategy. Utilizing *Citrus grandis* (pomelo) peels for this purpose supports waste valorization, promotes public health, and aligns with the principles of a circular economy. This study aims to investigate the formulation and efficacy of mosquito repellents derived from pomelo peel extracts, contributing to the advancement of sustainable pest management technologies.

## 1.2 VALORIZATION

Citrus peel waste, especially from fruits like *Citrus maxima* (pomelo), is often discarded despite being rich in bioactive compounds such as flavonoids, carotenoids, essential oils, and dietary fiber. With growing interest in sustainable practices and circular economy, researchers are exploring these peels for their potential in food, pharmaceutical, agricultural, and environmental applications. This paper highlights the key bioactive constituents in citrus peels and their diverse industrial uses, from natural antioxidants and food additives to eco-friendly insect repellents and biofertilizers.

### 1.2.1 Polyphenols

Citrus peels are rich in diverse polyphenolic compounds, including flavonoids such as flavonols, flavanones, flavones, isoflavones, and anthocyanidins. These phenolics are secondary metabolites involved in plant defense mechanisms and possess antioxidant properties (Beckman et al., 2000). In food systems, they influence taste, color, aroma, and oxidative stability. Recent research emphasizes the efficiency of green extraction techniques over conventional methods for isolating polyphenols from citrus waste (Nipornram et al., 2018). Epidemiological studies highlight their role in reducing the risk of chronic diseases like cancer, cardiovascular disorders, diabetes, and neurodegenerative conditions (Graf et al., 2005; Arts et al., 2005).

### 1.2.2 Carotenoids

Carotenoids, responsible for the vivid yellow to red hues in fruits, are widely distributed tetraterpenes. They include carotenes (e.g., β-carotene, lycopene) and xanthophylls (e.g., lutein, zeaxanthin) and are essential for human nutrition and health (Britton et al., 2004; Maoka et al., 2009). These pigments are not only vital antioxidants but also serve as precursors for vitamin A. The structural diversity of carotenoids extends to over 800 identified compounds, including higher (C45–C50) and apocarotenoids (C30–C35), contributing to their biological functionality.

### 1.2.3 Pectin

Citrus peel is a major industrial source of pectin, a gelling agent widely used in jam and jelly production. Fresh peels yield 1.5–3% pectin, while dried peels contain 9–18% (Berk, 2016b). Advanced extraction methods such as microwave-assisted techniques have significantly enhanced pectin recovery, with yields reaching up to 28% (Maran et al., 2014; Su et al., 2019; Yousuf, 2019). These methods make citrus pectin a valuable ingredient in functional food and pharmaceutical applications.

### 1.2.4 Essential Oils

Essential oils in citrus peels, rich in compounds like D-limonene, are extensively used in flavoring and fragrance industries (El Asbahani et al., 2015; Berk, 2016). Their composition varies with the extraction method. Techniques like solvent-free microwave and supercritical $CO_2$ extraction have proven effective, achieving limonene yields as high as 30.65% (Golmakani et al., 2016; Lopresto et al., 2019; Safranko et al., 2021). Despite their high efficiency, these methods require costly equipment.

### 1.2.5 Dietary Fibre

Citrus peel is a potent source of both soluble and insoluble dietary fibers, offering numerous health benefits. Techniques such as acid-alkali treatment, enzymatic hydrolysis, and steam explosion have improved fiber yields significantly (Yang et al., 2017; Wang et al., 2015). These fibers enhance gastrointestinal health and are increasingly used in health-focused food formulations.

### 1.2.6 Food Additives

Citrus peel is widely applied as a natural food additive, enhancing flavor, color, and nutrition. Bioactive compounds from fruit processing waste are explored as antioxidant-rich alternatives to synthetic additives (Zhu et al., 2020). European Union regulations define food additives as substances added for technological functions, and citrus peels are commonly used in candied bakery items due to their unique organoleptic qualities (Saltmarsh, 2020).

### 1.2.7 Prebiotics

Citrus pectin, especially in its oligosaccharide form, has demonstrated prebiotic potential. These compounds selectively enhance the growth of beneficial gut microbes (Davani-Davari et al., 2019). Enzymatically derived pectic oligosaccharides from citrus peel have shown higher prebiotic activity than commercial pectin (Foti et al., 2021; Miguez et al., 2016). Certain pectic polysaccharides from citrus also exhibit anti-tumor properties (Lee et al., 2014).

### 1.2.8 Bioenzyme Cleaner

Bioenzymes, produced by fermenting citrus peels, serve as natural cleaning agents. They are biodegradable, chemical-free alternatives to synthetic detergents and can be used for washing dishes, clothes, fruits, vegetables, and as insect repellents and surface cleaners (Mukherjee et al., 2020). Bioenzymes are eco-friendly and do not pollute water systems, making them suitable for domestic and agricultural applications.

### 1.2.9 Biopolymer

Biopolymers from citrus peels offer promising applications in biomedicine and materials science. They are naturally occurring macromolecules such as polysaccharides and proteins—used in drug delivery and tissue engineering (Stryer, 2003; Ezeoha et al., 2013; Gullapalli et al., 2011). Innovations include polylactic acid and polyhydroxyalkanoates synthesized through microbial fermentation (Baranwal et al., 2022). These biopolymers are eco-friendly alternatives to synthetic plastics.

### 1.2.10 Biofertilizer

Citrus peel-based biofertilizers are rich in essential minerals and possess antimicrobial properties. They can detoxify heavy metals in the soil, enhance soil structure, and improve crop productivity (Zema et al., 2018; Okram et al., 2003). The transformation of citrus waste into biofertilizers represents a sustainable agricultural practice with both ecological and economic benefits.

**1.2..11 Insect Repellent**

Citrus limonoids primarily limonin and its derivatives are potent insecticidal agents found in citrus peel, pulp, and seeds. These compounds exhibit broad-spectrum biological activities including antioxidant, antimicrobial, and insecticidal effects (Gualdani et al., 2016). Studies show that extracts from Citrus latifolia and other citrus species can induce 100% mosquito larval mortality (Obembe et al., 2022). Essential oils also offer a safer alternative to synthetic insecticides due to their reduced toxicity and environmental impact (Pandey et al., 2023).

## II. REVIEW OF LITERATURE

Mosquito-borne diseases such as dengue, malaria, chikungunya, and Zika virus continue to pose serious health challenges globally, especially in tropical and subtropical regions (Benelli & Mehlhorn, 2016). Although synthetic repellents like DEET have been widely used due to their efficacy, concerns regarding their toxicity, skin irritation, and environmental persistence have driven interest toward natural alternatives (Fradin & Day, 2002).

Citrus fruits, particularly their peels, have emerged as potential sources of mosquito-repelling agents. These peels are often discarded as waste but are rich in essential oils, flavonoids, and phenolic compounds known for their bioactivity against insects (Boussaada et al., 2008). Studies have highlighted that the essential oils obtained from citrus peels can act as effective natural repellents and larvicides (Giatropoulos et al., 2018).

Among citrus varieties, *Citrus maxima* (pomelo) stands out due to its high content of limonene, citral, linalool, and β-pinene—volatile compounds shown to interfere with mosquito olfaction and reduce host attraction (Isman, 2020). Limonene, in particular, disrupts neural function in insects, while linalool and citral contribute to repellency through their sensory-disrupting properties (Oyedele et al., 2002).

Pomelo peels also contain significant levels of flavonoids such as naringin, hesperidin, and quercetin. These compounds have been associated with insecticidal and growth-regulating effects in mosquitoes (Albuquerque et al., 2022). Naringin has shown inhibitory effects on mosquito larval development, while quercetin interferes with metabolic and hormonal pathways in insects (Sultana et al., 2012).Citrus-based repellents have been tested against mosquito species such as *Aedes aegypti* and *Anopheles stephensi*, with some studies showing comparable efficacy to low concentrations of DEET (Maia & Moore, 2011). Additionally, nanoemulsion-based formulations incorporating citrus oils have demonstrated extended protection time, increased bioavailability, and reduced irritation risks (Souza et al., 2020).

The method of extraction plays a critical role in determining the composition and effectiveness of the repellent compounds. Green extraction technologies such as microwave-assisted extraction, ultrasound-assisted extraction, and supercritical $CO_2$ extraction have proven more efficient than traditional methods like steam distillation, producing higher yields of bioactive components while minimizing environmental harm (Nipornram et al., 2018).

Beyond public health applications, the valorization of citrus waste aligns with sustainable development goals. Utilizing citrus peels as raw material for mosquito repellent products promotes circular economy principles and helps reduce agro-industrial waste (Saini et al., 2022).

In summary, the literature indicates that *Citrus maxima* peels are a rich source of natural mosquito-repelling compounds. Their integration into eco-friendly formulations holds promise for both personal care and public health, though further research is necessary to ensure consistency, safety, and large-scale applicability.

## III. MATERIALS AND METHODS

This section outlines the process undertaken to develop a natural mosquito repellent formulation utilizing citrus peel waste. The primary ingredient, *Citrus maxima* (pomelo) peel powder, was selected for its known bioactive properties, particularly the presence of essential oils and flavonoids with insect-repelling activity. To enhance the structural integrity and spreadability of the formulation, activated charcoal and corn flour were incorporated in optimized proportions. Charcoal served as a filler and absorbent, while corn flour functioned as a natural binder. A small amount of distilled water was used to achieve a smooth, paste-like consistency suitable for topical or surface application. The preparation aimed to produce a stable, eco-friendly product using low-cost, biodegradable materials.

### 3.1 Collection and Preparation of Citrus Peel

Fresh *Citrus maxima* (pomelo) fruits were sourced from local markets. The peels were carefully separated, washed thoroughly to remove dirt and residues, and air-dried under shade for 5–7 days to preserve the bioactive compounds. Once dried, the peels were crushed and powdered using a mechanical grinder and stored in airtight containers at room temperature for further extraction.

### 3.2 Ingredient Weighing and Proportions

The raw materials were carefully selected based on their natural properties *Citrus maxima* peel powder for its mosquito-repelling bioactives, activated charcoal for its absorbent and stabilizing qualities, and corn flour for its natural binding ability ensuring the formulation remained eco-friendly, cost-effective, and safe for topical application.

A 50-gram batch of the mosquito repellent formulation was prepared using the following composition:

| Ingredient | Function | Amount (g) |
|---|---|---|
| Powdered *Citrus maxima* (Pomelo) Peel | Active mosquito repellent | 26 g |
| Corn Flour | Binder and texture stabilizer | 7 g |
| Activated Charcoal | Filler, odour absorber | 12 g |
| Water / Natural Base | Blending medium | 5 g |

All ingredients were weighed using a digital balance to ensure precision.

### 3.3 Formulation Process

- In a clean mixing bowl, the pomelo peel powder and charcoal were combined and mixed thoroughly to achieve a uniform blend.
- Corn flour was gradually added to the mixture and stirred until evenly incorporated.
- Distilled water was added slowly in small amounts while continuously mixing to form a smooth, semi-solid paste.
- The resulting mixture was kneaded lightly to remove any lumps and ensure consistent texture throughout .
- Solid forms were prepared using different moulds followed by drying in sunlight in 3 days.

Figure 1 : Mosquito Repellent

## IV. LARVEL EXPOSURE EXPERIMENT

Larvae of *Aedes aegypti* were collected from stagnant water sources and identified based on morphological characteristics. For the bioassay, approximately five larvae were individually transferred into three separate 200 mL glass beakers, labeled as A, B, and C.

- **Beaker A** was treated with crushed mosquito repellent solid formulated from *Citrus maxima* peel-based ingredients.
- **Beaker B** was treated with fine dried powder of *Citrus maxima* (pomelo) peel.
- **Beaker C** contained only fresh distilled water and served as the control.

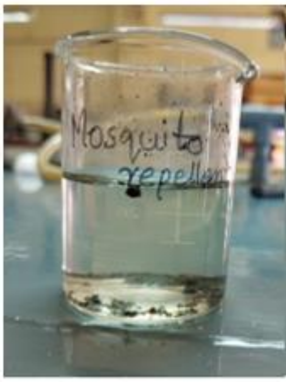


Figure 2: Beaker A

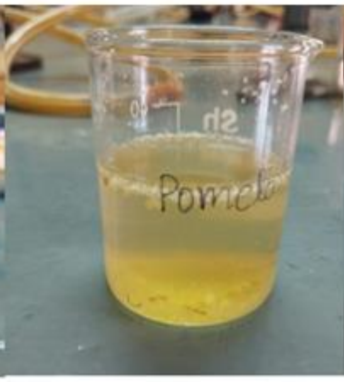


Figure 3 Beaker: B

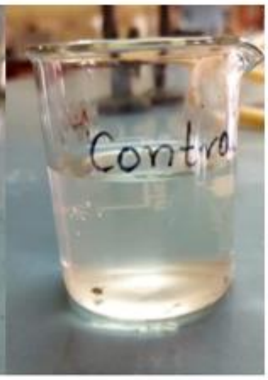

Figure 4 : Beaker C

All beakers were maintained at room temperature and observed at regular intervals to assess larval mortality, behavioral changes, and repellency effects. The experiment was conducted in triplicate to ensure reproducibility and reliability of the results.

## V. RESULTS AND DISCUSSIONS

Results showed a clear variation in larval mortality among the three setups:

- **Beaker B** (dried peel powder) exhibited the highest larvicidal activity. All larvae were found dead within 2 hours of exposure, indicating a rapid and potent effect.

- **Beaker A** (crushed peel-based repellent) showed slightly lower efficacy. Complete larval mortality was observed at approximately 3.5 hours.

- **Beaker C** (control) showed no signs of larval mortality or behavioural changes, confirming that the observed effects in Beakers A and B were due to the bioactive components of the *Citrus maxima* peels.

These findings suggest that the dried peel powder was more effective than the crushed formulation. This could be attributed to a higher concentration or better release of bioactive compounds such as limonene, linalool, naringenin, and other flavonoids found in dried citrus peels, which are known to possess insecticidal and larvicidal properties. Drying may enhance the stability and bioavailability of these compounds, thereby increasing their efficacy.

The absence of mortality in the control group eliminates environmental factors as a cause and reinforces the effectiveness of *C. maxima*-based treatments. This preliminary evidence supports the potential of citrus peel waste as a natural and eco-friendly alternative to chemical larvicides in mosquito control strategies.

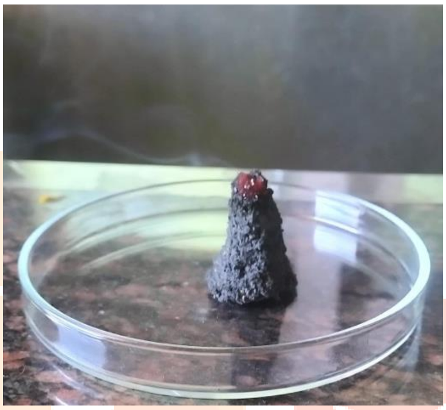

Figure 5: Fumigation Test

The mosquito repellent formulated from *Citrus maxima* peels was tested by applying it in a confined space , where it effectively repelled mosquitoes for up to 2 hours with minimal landing or biting observed. This indicates its strong repellent activity, likely due to the presence of bioactive compounds such as flavonoids and essential oils.

## VI. CONCLUSION

The present study demonstrates the promising potential of *Citrus maxima* (pomelo) peel waste as a natural, sustainable, and eco-friendly alternative for mosquito control. The larvicidal tests revealed that dried peel powder exhibited rapid and effective action against *Aedes aegypti* larvae, achieving 100% mortality within 2 hours, while the crushed formulation also showed significant activity. Fumigation tests using smoke from the dried peel powder further validated its insecticidal efficacy, causing complete knockdown of adult mosquitoes within 1 hour of exposure, with no mortality observed in the control group. The formulated mosquito repellent provided notable protection by repelling mosquitoes for over 2 hours, reducing landing and biting activity.

The effectiveness of these treatments can be attributed to the presence of bioactive compounds such as limonene, linalool, β-pinene, naringenin, and various flavonoids and polyphenols, which are known for their insecticidal and repellent properties. These findings underscore the dual benefit of this approach: utilizing agro-industrial citrus waste that would otherwise contribute to environmental burden, and developing cost-effective, biodegradable alternatives to harmful synthetic mosquito repellents.

Overall, this study advocates for further research into the standardization and formulation of citrus peel-based mosquito control products. With additional validation and safety assessments, *Citrus maxima* peels could be developed into commercial larvicides, fumigants, and repellents that contribute to vector control and environmental sustainability.

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