# Fruit peels as biofertilizers and biopesticides for sustainable agriculture and horticulture: A review

## Abstract

The annual increase in global population of 1.1% necessitates increased agricultural yields to provide a sustainable food supply, which necessitates the extensive use of chemical fertiliser and pesticide. This practise, however, causes a number of environmental and health issues, which ultimately drives the creation of safer organic fertilisers and bio-pesticides. Organic fertiliser comprises various antioxidants and carbonaceous matter, which are inexpensive and safe elements utilised for plant growth. While inorganic fertiliser is typically made entirely, such as sulphate of ammonia, they may also be processed from quarries. One must need to develop other sustainable alternativeto meet the demand of world's expanding population, thereby meeting the SDGs of poverty eradication, zero hunger, and climate action.One possible technique is to use fruit peels as biofertilizers and bio pesticides. Fruit peels are often discarded in the garbage and taken to a solid waste dumping facility. Because of the breakdown of peel material at the disposal location, this generates an odour problem. Ergothis is critical for establishing the peel as a significant bio resource in worldwide organic agriculture development, reducing solid waste accumulation in the environment with its attendant public health threat, and documenting a long-term management technique. Fruit peels are high in nutrients such as potassium, calcium, iron, zinc,calcium, citrate content, and other minerals.

## Introduction

In general, fertiliser is applied to crops to increase production, whereas pesticides protect crops from pests and hazardous illnesses (Kumar 2013). However, the continued and excessive use of contemporary synthetic fertilisers and pesticides in agriculture has harmed the environment by contaminating surface and ground water and causing a drop in beneficial soil microbes that are essential for soil fertility. Apart from having an impact on the environment, chemical fertilisers and pesticides may also have serious health consequences for humans through the ingestion of food containing harmful pesticide residue (Aktar*et al*. 2009).Aside from the high costs of procurement, shipping, transportation, and distribution logistics, inorganic fertilisers and pesticides pose major hazards to the environment with their attendant tendencies to reduce soil integrity, cause environmental degradation, pose risks to biodiversity, substantially contribute to an algal bloom, and have the potential to make soil heavy metals laden. However, the situation can be improved by adopting and continuing to employ organic preparations, such as digestate organic fertiliser made from renewable and locally available bioresources. Agricultural biomass might be a tremendous help because it is a rich source of nutrients that can be used in a variety of applications if managed appropriately. They can be treated to remove pathogens before being used as a source of high-quality organic matter in the soil (Dimkpa, 2016).

Given the foregoing, anaerobic digestate like inorganic fertilisers and peat has proven to be a slow-release fertiliser providing essential nutrients such as nitrogen, phosphorous, and potassium (NPK) as well as other essential plant macronutrients required for crop plant growth, health, and wellbeing. Crop digestate is most typically utilised as soil conditioners and organic fertilisers in the agricultural and horticulture industries due to its high nutritional content and soil viable microorganisms. Furthermore, crop digestates, when used as organic fertilisers, reinforce and remodel soil structures while also increasing soil nutrient status and enhancing a load of beneficial microorganisms for special activities, particularly in marginal or nutrient-depleted soils. In a comparable manner digestates are useful in substituting for the significant use of peat, which has special properties that make it critical for large-scale application as a growth substrate in horticulture. Besides, crop digestates contain varying concentrations of nutrients, particularly NPK, and thus their use is of enormous benefit to agriculturists because these nutrients are naturally scarce, particularly phosphorus, which is typically obtained through mining at high costs and energy expenditure, in addition to the serious health hazards posed by its mining.

Humic Acid (HA) derived from palm oil Empty Fruit Bunch (EFB) vermicompost, a natural plant growth booster found in organic compost, might be used as an environmentally benign fertiliser as well as an insect control agent. Several studies have been performed to develop natural pest control agents generated from plants or organic resources. Garlic, for example, has been extensively studied for its antibacterial qualities and has been used as an insect repellent on a small basis. However, due to its low efficacy, garlic extract (GE) has not been effectively commercialised as an agricultural pesticide (Valencia and Luis 2010).It has been shown to be more effective when a combination of HA and GE is employed.On the other hand, statements have been made about the potential use of HA alone as a natural pest control agent. According to (Pathma and Sakthivel, 2012), the uptake of phenolic compounds present in HA makes plant tissue unpleasant to consume, hence inhibiting pest attack on plant and affecting insect reproduction rates and survival.Citrus peels are frequently dumped as garbage. Citrus peels are high in essential oils and are harmful to a variety of bug species. Essential oils are also an environmentally beneficial solution for insect pest control. Citrus maxima peel essential oil (CMEO), a waste product, was characterised and its potential for insect pest management was assessed. Limonene and -Pinene are the main terpenoids found in CMEO. The CMEO proved the ability to reduce insect pests via contact and fumigant toxicity. Citrus peel essential oils can be commercially formulated using nanotechnology. One tonne of C. maxima peels yields 5.8 litres of essential oil, according to research. The output of CMEO increases its potential for commercial use as a biopesticide. The essential oil yield produced from C. maxima peels in several tests ranged from 0.29-14.25%, according to scientists. The bulk of the bioactive compounds discovered in essential oils were found to have substantial effects on non-target fishes, including fishes, as well as human health and the environment. Because of their eco-friendliness, these essential oils have a higher efficiency and could be used as biopesticides in the future, as well as superior instruments for integrated pest control.

***Anaerobic Digestate-** is a material that remains after the anaerobic breakdown (decomposition under low oxygen conditions) of a biodegradable substrate like as solid waste streams, plant biomass, crop residues and animal manure, municipal and domestic wastes.

## Why are biofertilizers and biopesticides required for sustainable agriculture and horticulture?

Biofertilizers are also known as living fertilisers because, unlike chemical fertilisers, they contain a variety of helpful microbes such as bacteria and fungi (Thomas and Singh, 2019, Alori*et al*., 2017). Biofertilizers can also refer to any organic plant growth resource that is made available for plant development through microbial community linkages or interactions (Mcik*et al*., 2020, Mahanty*et al*., 2017, Bhardwaj*et al*., 2014). Microbes are extremely small but quite beneficial (Soumare*et al*., 2020; Nath*et al*., 2018). Microorganisms can supply all 16 necessary components required by plants for optimal growth and development. All of these elements, particularly nitrogen, phosphorus, and potassium, can be supplied by microbes found in biofertilizers. These elements are abundant in soil or the environment, but in an inaccessible form. Microbial activity converts these useless components into a form that plants may use (Mcik*et al*., 2020; Kuan*et al*., 2016). The use of biofertilizers will increase biodiversity, which includes a variety of beneficial bacteria and fungus (Prasad *et al*., 2017; Ritika and Utpal, 2014). These microbial communities help plants grow (Kour*et al*., 2020; Yadav and Sarkar, 2019). Adding beneficial PGPM to agricultural activities started around 60 years ago. It is now clear that beneficial bacterium can boost plant tolerance to unfavourable environmental changes such water and nutrient scarcity, as well as heavy metal contamination (Mendoza-Arroyo *et al*., 2020; Ritika and Utpal, 2014). Such potentially beneficial biological fertilisers will have a considerable impact on soil biodiversity and productivity. Producing chemical fertilisers is exceedingly expensive and difficult to meet current demand. As a result, the development of biofertilizers as a potential replacement for chemical fertilisers became necessary. Biofertilizers will also safeguard the ecosystem in the interests of the farmers' community as an environmentally sustainable and improved economic output (Qu*et al*., 2019).

Biopesticides have a variety of modes of action, including growth regulators, gastrointestinal disruptors, metabolic poisons, neuromuscular toxins, and non-specific multi-site inhibitors (Sparks and Nauen, 2015;Dar *et al*., 2021). These numerous modalities of action against specific pests eliminate the possibility of resistance, which is typical with chemical pesticides. The long-term use of conventional pesticides in industrial-scale farming, particularly during the Green Revolution, created challenges such as pesticide-related pollution, post-harvest chemical consumption via bioaccumulation, biodiversity losses, secondary pest resurgence, and elimination of natural/beneficial enemies. These adverse effects are unrelated to the usage of biopesticides. As a result, costly limits on synthetic pesticides are constantly implemented in order to reduce their quantities over time. For example, the number of active chemicals in conventional pesticides decreased from over 1,000 in 2001 to 250 in 2009, while the number of new conventional pesticides introduced onto the market decreased from 70 in 2000 to 28 in 2012 (McDougall, 2013). The growing need for biopesticides is a direct outcome of the falling quantity of traditional pesticides for a variety of reasons. These advantages include, but are not limited to, changing the course of pest resistance, low toxicity properties, complementary input to synthetic pesticides, eco-friendliness, specificity (having little or no negative impact on non-target organisms and humans), biodegradability, and little or no post-harvest contamination, stability against abiotic stress (Deravel*et al*., 2014; Kalpana and Anil, 2021), and compatibility in integrated pest management (IPM).

## Reasons why fruit peels have a high potential for biofertilizer and pesticide production

Fruit peels are high in cellulose, hemicellulose, phenolic chemicals, and terpenes. Aside from that, fruit peels contain a plethora of bioactive compounds such as phenols, flavonoids, tannins, triterpenoids, steroids, glycosides, carotenoids, anthocyanins, ellagitannins, vitamin C, and essential oils, which are generally discarded as a byproduct or waste by the fruit processing industry. Fruit peels are often discarded in the garbage and taken to a solid waste dumping facility. Because of the breakdown of peel material at the disposal location, this generates an odour problem. Banana, pomegranate, orange, mango, pineapple, apple, and guava are among the fruits grown throughout the country. These fruits are generally consumed fresh, but they are also extensively used in food processing industries to make juice desserts, jams, jellies, salads, fruit cocktail, pickles, and so on. The "fruit peel" is often regarded as an environmental burden and waste after the edible portion of the fruit has been consumed. As a result, they have the potential to be a novel renewable, sustainable, and low-cost raw material (source) for the production of a variety of value-added products based on waste hierarchy framework and concepts such as biofertilizers, biopesticides, dietary fibre, animal feed, industrial enzymes, substrate for the production of bioactive compounds, synthesis of nanomaterials, and clean energy (from residual biomass).

## Fruit peels biofertilizers andbiopesticides

### 1. Empty fruit bunches (EFB)biofertilizer

EFB is lignocellulosic biomass that is created when oil palm fruits are separated from FFB during the palm oil production process. EFB accounts for 20-22 percent of solid by-products created during palm oil extraction, making it the most visible waste produced by the oil palm industry (Tahir*et al*., 2019, Han and Kim, 2018, Samiran*et al*., 2015). Previously, EFB was used as a fuel source in oil palm mills to generate steam, resulting in greenhouse gas emissions. Although, due to its high moisture content, employing EFB as boiler fuel is less viable (Ahmad *et al*., 2019). It was occasionally returned to the crop area to decompose organically and prevent soil erosion. Because EFB is produced in vast amounts in oil palm mills, it is an excellent residue for recycling as a biofertilizer.

Conversion of empty fruit bunches into biofertilizers

Biocomposting is an aerobic process that relies on a varied microbial community to break down the organic components of EFB, release nutrients, and remove pathogens. The aerobic thermophilic bacteria naturally present in biomass break down lignocellulosic components during biocomposting to produce nutrient-rich humus-like materials (biofertilizer). High-rate composting, stabilisation, and maturation are the three steps of the biocomposting process (Meyer-Kohlstock*et al*., 2013).

Majority of the literature stated that the composting process for EFB biomass takes about 2-3 months. Siddiquee*et al*. (2017), on the other hand, reported a 30-day composting technique that drastically decreases the EFB composting time.To decompose the EFB biomass, two strains of Trichoderma were used. The same researchers discovered that EFB compost contains a high concentration of macronutrients (N, P, and K), which enhances soil acidity and electrical conductivity. Lim *et al*. (2015a) revealed the impacts of microbial inoculation additive to improve the efficiency of EFB decomposition and, at the end of the composting process, lower C:N ratio, increase pH value (8), microbial population, and organic acid degradation in a separate paper. Lim *et al*. (2015b) evaluated the physicochemical parameters of EFB compost inoculated with efficient bacteria in another investigation.It was documented that the process of composting EFB took about two months. The mineral content (Mg, Ca, B, and K) of the microbial-treated EFB compost increased, whereas the pH (8) and total organic carbon (10.8%) decreased. They concluded that the addition of efficient microbes accelerates the composting of EFB.

Wei *et al*. (2016) evaluated how varied temperatures, aeration rates, and response time during the composting process affected the final quality of EFB compost. The scientists combined urea as a nitrogen source and fresh compost as an inoculum with EFB samples and composted them for 42 days. Aeration intensity, reaction time, and the temperature-reaction-time connection all had an effect on nitrogen content.Total ion changes over time demonstrated a strong relationship with conductivity (Pearson correlation coefficient of 0.853), with the largest significant decrease in C/N ratio (from 30.2:1 to 17.6:1) obtained at 40 °C with 0.4 L/min kg aeration. Tahir*et al*. (2019) stated that including competent lignocellulolytic fungus in the composting process, in conjunction with an adequate EFB composting method, is one of the options for quick composting. NahrulHayawin and colleagues (2010) reported that EFB vermicomposting is a viable technology for converting oil palm trash into value-added vermicompost. During the phase, the overall organic carbon, C/N ratio, and pH value declined, while the N, P, and K proportions improved. Furthermore, the level of heavy metals in the vermicompost increased but did not exceed the nutritional range.

Table 1.The lignocellulosic content of empty oil palm fruit bunches.

| Lignocellulosic content (%) based on the dry weight | | | |
|---|---|---|---|
| Cellulose (%) | Hemicellulose (%) | Lignin (%) | References (%) |
| 44.2 | 33.5 | 20.4 | Rosli*et al*., 2017 |

| Lignocellulosic content (%) based on the dry weight | | | |
|---|---|---|---|
| Cellulose (%) | Hemicellulose (%) | Lignin (%) | References (%) |
| 40–50 | 20–30 | 20–30 | Alizadeh*et al*., 2014 |
| 50 | 30 | 20 | Loh, 2017 |

Table 2.The macronutrient composition of empty oil palm fruit bunches.

| Macronutrient content (%) based on the dry weight | | | | | | |
|---|---|---|---|---|---|---|
| C (%) | H (%) | N (%) | S (%) | O (%) | P (%) | References |
| 45.00 | 6.40 | 0.25 | 1.06 | 47.30 | – | Samiran*et al*. (2015) |
| 48.79 | 7.33 | 0.70 | – | 0.68 | – | Hamzah (2008) |
| 47.65 | 3.2 | 1.82 | 0.36 | 44.97 | – | Idris*et al*. (2012) |
| 48.72 | 7.86 | 0.25 | 2.21 | 48.18 | 2.03 | Loh (2017) |

Table 3. The micronutrients content in empty fruit bunches of oil palm.

| Micronutrient's content (%) based on the dry weight | | | | | |
|---|---|---|---|---|---|
| Cu (mg/kg) | B (mg/kg) | Zn (mg/kg) | Mn (mg/kg) | Fe (mg/kg) | References |
| 23 | 10 | 51 | 48 | 473 | Hayawin*et al*. (2014) |
| 26 | – | 71 | 88 | 210 | Gandahi and Hanafi (2014) |

Table 4.(Barker and Pilbeam, 2015) Nutrient type, percentage of elements accessible in empty fruit bunches, and major roles in plants.

| Nutrient Category | Nutrient | Percentage of plant | Major function in plants |
|---|---|---|---|
| Macronutrient | Carbon (C) | 45 | Plant structures. |
| | Hydrogen (H) | 6 | pH regulation, water retention, synthesis of carbohydrates. |
| | Nitrogen (N) | 1.75 | Protein/amino acids, chlorophyll, cell formation. |
| | Sulphur (S) | 0.03 | Protein, amino acid, vitamin, and oil formation. |
| | Oxygen (0) | 45 | Respiration, energy production, plant structures. |
| | Phosphorous (P) | 0.25 | Cell formation, protein synthesis, fat, and carbohydrate metabolism. |
| Micronutrient | Copper (Cu) | 0.0001 | Enzyme activity. |
| | Boron (B) | 0.0001 | Enzyme activity. |
| | Zine (Zn) | 0.002 | Enzyme activity. |
| | Manganese (Mn) | 0.005 | Enzyme activity and pigmentation. |

| Nutrient Category | Nutrient | Percentage of plant | Major function in plants |
|---|---|---|---|
| | Iron (Fe) | 0.01 | Enzyme development and activity. |

## 2. Papaya peelbiofertilizers

Conversion method

The papaya fruit peel because of its high lignin and cellulose content, papaya fruit peel required pre-treatment to make it easily biodegradable and to avoid the usual rate-limiting occurrence, particularly during the hydrolysis stage of digestion. It was documented that three alternative pre-treatment procedures, namely mechanical, thermal, and alkaline (NaOH), were used by the scientists. Crushed peels of 20mm pieces were employed as raw material by the researchers, but then subjected them to an $80^{o}$C thermal treatment in a water bath (CLIFTON, Nickel-Electro Ltd., England). It was documented that the temperature was chosen based on previous research indicating that it was the best for lignocellulosicpretreatment. The alkaline pretreatment approach was claimed to be carried out at 55° C for 24 hours, using 3 g NaOH/100 g TS, and NaOH was chosen due to its past performance as a suitable alkali for lignocellulosic biomasspretreatment.

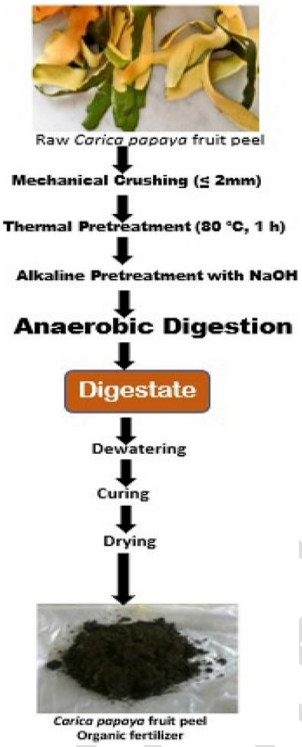

Fig. 1llustration of the organic fertiliser development process.

### Procedures for developing organic fertilisers

The majority of researchers reported that the digestates that were carefully retrieved from the reactor at the end of the AD were used to extract the sample for analysis before being placed into sterile sacks to drain. The dewatered digestates were cured in sterile bags for 20 days prior to physiological and nutritional delivery in field trials, resulting in a solid preparation that was stored in dry forms.

### Microbiological tests

#### Aerobic and anaerobic bacteria and fungus characterization and enumeration

The scientists studied that the aerobic bacteria in the fermenting material; inoculum, digestate, and solid organic fertiliser were analysed using the conventional method for total aerobic plate count using nutrition agar, eosin methylene blue (EMB) agar, peptone water, and MacConkey agar. As reported by other researchers, all samples were collected aseptically and in triplicates, while presumptive isolates were characterised by phenotypic methods and the probable ones were further identified using appropriate fast API kits (BioMerieux, France).

Methanogen (archaea) enumeration

Based on earlier studies on the characterization and identification of methanogens, the majority of scientists concluded that a mineral-rich basal medium, which had been shown to be particularly efficient, was utilised. The medium was used to characterise the methanogens in a sample of fermenting material, inoculum, digestate, and solid organic fertiliser.

### 3. Pesticide (Humic acid) generated from palm oil Empty Fruit Bunch (EFB) vermicompost

It was documented that for the production of HA, the vermicomposts were made utilising EFB, a byproduct of the palm oil mill, as the basic material and underutilised organic wastes (fishmeal, bonemeal, and bunch ash) as additions to boost the macronutrients of the vermicomposts. It was reported that for 52 days of composting, earthworms were used as composting agents. Alkaline extraction followed by precipitation in strong acid was used to extract humic acid (HA) from developed vermicomposts (Lamar *et al*. 2014). Ai May *et al*., (2020) in an experiment, a mixture of dried vermicompost (200gm) and sodium hydroxide (1 L of 0.1 M) were employed to extract HA, which was discovered dissolving in a beaker after 6 hours of stirring. They later the mixture was then centrifuged at 4000 rpm for 10 minutes and collected the dissolved HA-containing supernatant for alkaline precipitation after removing the humic substance-containing solid pellet. Then continually added a 6M hydrochloric acid to the supernatant which was later stirred until it reached pH 1 and HA precipitated out of the mixture. It was then centrifuged at 4000 rpm for 10 minutes to extract the HA from the pellet, while the fulvic acid-containing supernatant was discarded. The HA pellet was washed with distilled water before being neutralised to pH 7 using 6 M NaOH and 6 M HCl. Then they collected the dried HA after slurry was oven dried overnight at 105 °C. Equation given below was used to compute the HA yield from 200 g of vermicompost.

Where mHA is the mass (g) of dried HA collected.

Humic acid verification

The scientists confirmed the HA extracted from vermicomposts was determined by analysing FTIR spectra obtained with a Spectrum 1000 spectrophotometer (Perkin Elmer) at a resolution of 2 cm1 in the 500-4000 cm1 range. 1 mg of HA was blended with high purity infrared grade KBr powder and compacted into tiny pellets for measurement.

### 4. Essential oils (EOs) from Pomelo (Citrus maxima) fruit peels as biopesticides

EOs extracted from citrus fruit has been used in many industrial applications, such as perfumery, pharmacology, food industry and fine chemistry. Citrus EOs has been tested as pesticides against a number of pests.

Many researchers discovered that essential oils derived from citrus peels were efficient in treating a variety of insect pests. It was noted that washed peels stored in sterile ziplock bags at 4 °C were utilised as source material for hydro-distillation of fresh peels (300 g) for essential oil extraction utilising a modified Clevenger method. The hydro-distillation procedure took 5 hours (100 °C). To eliminate the water content, the CMEO was processed through sodium sulphate (AR). The oil yield was calculated on a fresh weight basis using the formula yield (%, v/w):

$$\text{Yield (\%, v/w)} = \text{VEO}/\text{WF} \times 100$$

where VEO is the dry essential oil volume, and WF is the weight of pomelo peels used for essential oil extraction.

## Effects of biofertilizers and biopesticides in plant growth

Dahunsi*et al.* (2021) discovered that when papaya fruit peel fertilisers were given to maize plants, the field assessment results outperformed those of the NPK 15-15-15 inorganic fertiliser and the control, particularly at medium to high organic fertiliser application rates (30 to 60 kg N/ha). The organic fertiliser also increased crop growth and improved soil fertility. When the values from the organic fertiliser field experiments were compared to the controls, the organic fertiliser performed better in all parameters such as the number of leaves, leaf area, plant height, stem girth, total shoot and root biomass, and root length.However, in the average highest size of the maize ear, the chemical fertiliser surpassed all organic fertiliser applied rates by 1.4%. After harvesting, all experimental soils had higher values of all nutritional components than the control, with the maximum value in the experiment being 60 kg N/ha. Nitrogen, phosphorus, and potassium grew by 28, 40, and 22%, respectively, in the 60 kg N/ha soil over the inorganic fertiliser application experiment, whereas other elements increased at varying rates in all treatments. Thus, organic fertiliser made from papaya fruit peel is a rich source of crop plant nutrients and soil beneficial bacteria, both of which are required to maintain soil balance, improve plant development and wellness, and raise food production and ultimately ensure food security.

Ai May *et al.* (2019) investigated that the efficiency of HA derived from vermicompost of Palm Oil Empty Fruit Bunches (EFB) as a biopesticide in a study. They discovered that crickets chose void (soil bedding) alone over Humic Acid, garlic extract, or a combination of the two. Test (4) showed a comparison of HA and GE, demonstrating that HA is a more effective insect repellent agent than GE. This could be because HA contains phenolic and carboxyl functional groups (Seenivasan and Senthilnathan 2018). The combination of HA and GE (87% GE+ 13% HA) was discovered to be the most efficient insect repellent agent, with the number of insects remaining in vessel D consistently lower than in vessels B and C. These data suggest that crickets prefer the combination of HA and GE over HA and GE alone. This is because GE is an active repellent chemical, whereas HA diluent can improve GE absorption, resulting in a stronger pesticidal impact (Valencia and Luis 2010). Overall, it is established that 87% GE + 13% HA is the most efficient insect repellent agent, followed by 100% Humic Acid and finally 100% garlic extract.

Halpatrao*et al*. (2019)evaluated the effect of applying several fruit peel compositions such as apple, banana, pineapple, and sweetlime as a natural fertiliser. In the study, he and his colleagues discovered that growing plantlets in soil containing apple peel powder increased the concentration of proteins in the plantlets, whereas growing plantlets in soil containing pineapple peel powder increased the concentration of carbohydrates in the plantlets. They discovered that using fruit peel decoction increased plant length by 7.2cm. Plant length for plants cultivated in distilled water (control) was 52.3 cm. Adding Banana peel extract increased shoot length while adding Sweet lime peel extract increased root length. Similarly, when they reproduced the shoots in vitro, they found that apple peel powder had the greatest effect on shoot length (8.52cm) and root length (7.14cm).

Jariwala and Syed (2017) explored the use of fruit peels for optimal plant growth and increased production, focusing mostly on Nitrogen, Phosphorous, and Potassium. Fruit peels from Pomegranate, Orange, Sweet lime, and Banana were used. According to the findings, Citric Peel powder has more nitrogen (9.1 mg/g), but Alkaline Peel powder contains more phosphorus (4.2 mg/g) and potassium (2.1 mg/g). This demonstrates that the powder can be used as a soil fertiliser, pH regulator (to improve soil morphology), micronutrient supplement (zinc, iron, calcium), and horticulturally. Both types of peels are used to regulate soil pH. Whereas citrate peel powder is used to lower soil pH and alkaline peel powder is used to raise soil pH.

Visakh*et al*. (2022)confirmed that *T. castaneum* and *C. maculatus* adults were strongly repulsed by CMEO ($p > 0.05$). At the lowest concentration (0.5 mg/cm2 dose), mean PR values for *T. castaneum* were greater than 50% (Class III) 2 hours to 24 hours after exposure. They also observed that notably, at 2 h to 24 h post-exposure, CMEO at the lowest concentration (0.5 mg/cm2) caused repellence of only 23.90% (Class II) in *C. maculatus* adults while CMEO repelled *T. castaneum* with a mean PR of 78.7% (Class IV) at higher concentrations (5 mg/cm2). At the highest applied concentration (5 mg/cm2), the mean PR value with C. maculatus adults was 69.30% (Class IV). They concluded from the overall findings that CMEOs were moderately repellent (Class II-IV) to *C. maculatus* adults at 2 h to 24 h.They also discovered that CMEO has a higher fumigant activity against *C. maculatus* adults than *T. castanaeum* adults. They discovered that lethal dosages of 4.95 mg/L and 4.13 mg/L resulted in 50% mortality (24 h and 48 h) in *T. castanaeum* adults based on probit analysis. Similarly, *C. maculatus* individuals died at lethal quantities of 3.38 mg/L air and 1.34 mg/L air (during 24 and 48 hours, respectively). They eventually found that the lethal concentration decreased with increasing exposure time and that *C. maculatus* adults were more vulnerable to CMEO than *T. castaneum* adults.

Campolo*et al.* (2017).highlighted the good insecticidal activity of the citrus peel essential oils against the tomato borer T. absoluta.They discovered that the application rate (F = 24.534; df = 4; p 0.001) had the greatest influence on egg mortality, whereas no significant differences were found when comparing the formulation (i.e., EO emulsion and EO-NP: F = 1.628; df = 1; p = 0.203) and the different EOs (F = 1.468; df = 2; p 0.232). The sweet orange EO emulsion treatment had the highest mortality after 24 hours (Table 2) and at the highest application rate. The maximum mortality was recorded in the sweet orange EO-NP treatment at the maximum application rate (40 mg mL1) in the second sampling (72 h after the treatment).They also discovered that when they evaluated sweet orange EO emulsion on translaminar Toxicity on Larvae (TTL) in the first sampling (24 hours after the treatment), it was the most effective in killing the moth's larvae. In all situations, EO emulsions were more efficacious than EO-NPs (F = 49.568; df = 1; p 0.001) (Table 3). The death rate of T. absoluta larvae rose in all treatments in the second sampling (72 h), and it nearly doubled in the sweet orange EO-NP compared to the first sampling. The number of adults that emerged following EO administration was substantially higher in EO-NP treated larvae than in EO emulsion treated larvae.In contrast to the TTL experiment results, they reported that the EO-NP formulations killed more larvae (F = 29.106; df = 1; p 0.001) than the EO emulsions. Throughout the testing, the mandarin EO-NP formulation was the most efficient against the wandering larvae (max mortality = 94 4%), but the lemon EO emulsion could only kill 38.3% of the exposed larvae.

## Conclusion

Chemical fertilisers have been shown to be effective and convenient for raising agricultural productivity and managing disease, but they also pose a significant risk to public health and the environment. There is currently a severe supply-demand imbalance for chemical fertilisers and pesticides. In terms of cost, environmental friendliness, and profitability, converting plant waste biomass into biofertilizers and biopesticides for agricultural use will be a more sustainable solution for modern agriculture. The use of biofertilizers has enhanced plant health, growth, and yield dramatically. In addition, the development of biofertilizers and biopesticides will have a long-term impact on the country's agricultural economic development. It will also aid in environmental and public health protection. As a result, the use of organic fertiliser and pesticides is a medium for promoting organic agriculture and a true means of overcoming the obstacles given by the high rate of inorganic fertilisers.

## References

Ahmad, F.B., Zhang, Z., Doherty, W.O.S., O'Hara, I.M. (2019). The outlook of the production of advanced fuels and chemicals from integrated oil palm biomass biorefinery Renew. Sustain. Energy Rev., 109, pp. 386-411.

Ai May, A.K., Shamsuddin, R., Hau, L.J., Aqsha, A., Mansor, N., Mustapa, N.I. and Narasimha, M. (2020). Investigation of pesticidal ability of humic acid derived from palm oil Empty Fruit Bunch (EFB) vermicompost. Int. J. Recycl. Organ.Waste Agric., 9 (3), pp. 237-247F.

Aktar, M.W., Sengupta, D. and Chowdhary, A. (2009).Impact of pesticides use in agriculture: their benefits and hazards.*Interdiscip.Toxicol*.,2(1):1-12.

Alizadeh, Jannesar, R., Khodavandi, A., Sadri,A. and Keshavarz, E.S.(2014). Inoculation Technology for Trichoderma harzianum during Interaction with Oil Palm ElaeisguineensisJacq.*J. Pure Appl. Microbiol.*, 8 (6), pp. 4541-4547.

Alori, E.T., Glick, B.R. and Babalola, O.O.(2017).Microbial phosphorus solubilization and its potential for use in sustainable agriculture.*Front. Microbiol*., 8, p. 971.

Barker, A.V. and Pilbeam, D.J.(Eds.)(2015). Handbook of plant nutrition, CRC Press.

Bhardwaj, D., Ansari, M.W., Sahoo, R.K. and Tuteja, N.(2014).Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microb. Cell Fact*., 13 (1), pp. 1-10.

Campolo, O., Cherif, A. and Ricupero, M. (2017).Citrus peel essential oil nanoformulations to control the tomato borer, Tutaabsoluta: chemical properties and biological activity. *Sci. Rep.*, 7, 13036.

Dahunsi, S.O., Oranusi, S., Efeovbokhan, V.E. et al. Crop performance and soil fertility improvement using organic fertilizer produced from valorization of Carica papaya fruit peel. *Sci Rep* 11, 4696.

Dar, S. A., Wani, S. H., Mir, S. H., Showkat, A., Dolkar, T., and Dawa, T. (2021). Biopesticides: mode of action, efficacy and scope in pest management. *J. Adv. Res. Biochem. Pharmacol*. 4, 1–8.

Deravel, J., Krier, F., and Jacques, P. (2014). Biopesticides, a complementary and alternative approach to the use of agrochemicals.A review.*Biotech. Agro Soc. Environ*. 18, 220–232.

Dimkpa.C.(2016.) Microbial siderophores: Production, detection and application in agriculture and environment. *Endocytobiosis Cell Res*., 27 (2).

Gandahi, A.W. and Hanafi, M.M. (2014). Bio-composting oil palm waste for improvement of soil fertility, Springer, Cham, pp. 209-243.

Halpatrao, A., Sonawane, A., Chavan, A., Mansoori, I., Kasurde, N., Kondkar, N., Sayyad, R. and Durve-Gupta, A. (2019). Application of Different Fruit Peels Formulations as a Natural Fertilizer for Plant Growth.*JETIR*, 6(5): 2349-5162.

Hamzah, M.M. (2008). The production of ecofiber from palm oil empty fruit bunch (EFB) (Doctoral dissertation, UMP).

Han, J. and Kim, J.(2018).Process simulation and optimization of 10-MW EFB power plant. In Computer Aided Chemical Engineering, Elsevier, 43, pp. 723-729).

Hayawin, Z.N. Astimar, A.A, Ibrahim, M.H., Abdul Khalil, H.P.S, Syirat, Z.B. and Menon, N.R. (2014).The growth and reproduction of Eiseniafetida and Eudriluseugeniae in mixtures of empty fruit bunch and palm oil mill effluentCompost.*Sci. Utiliz*., 22 (1), pp. 40-46.

Idris, S.S, Rahman, N.A. and Ismail, K. (2012).Combustion characteristics of Malaysian oil palm biomass, sub-bituminous coal and their respective blends via thermogravimetric analysis (TGA)*Bioresour. Technol*., 123, pp. 581-591.

Jariwala, H.J. and Syed, H.S. (2017). Study on Use of Fruit Peels Powder as a Fertilizer. Conference paper: https://www.researchgate.net/publication/319329572.

Kalpana, T., and Anil, K. (2021).A review of biopesticides and their plant phytochemicals information.*Ann. Romanian Soc. Cell Biol*. 25, 3576–3588.

Kour, D., Rana, K.L., Yadav, A.J.,Yadav, N., Kumar, M., Kumar, V.,Vyas, P.,Dhaliwal, H.S. and Anil Kumar Saxena, A.K.(2020).Microbial biofertilizers: Bioresources and eco-friendly technologies for agricultural and environmental sustainability. *Biocatal. Agric. Biotechnol*., 23, p. 101487.

Kuan, K.B., Othman, R., Rahim, K.R., Zulkifli, H. and Aroca, R.R. (2016).Plant growth-promoting rhizobacteria inoculation to enhance vegetative growth, nitrogen fixation and nitrogen remobilisation of maize under greenhouse conditions.PLoS ONE, 11 (3), p. e0152478.

Kumar, S. (2013).Use of pesticides in agriculture and livestock animals and its impact onenvironment of India.*A. J. Environ. Sci*., 8(1), 51–57.

Lamar, R.T., Olk, D.C., Mayhew, L. and Bloom, P.R. (2014). A new standardized. method for quantification of humic and fulvic acids in humicores and commercial products. *J AOAC Int.*, 97:721-730.

Lim, P.N., Wu, T.Y., Clarke, C. and Nik-Daud, N.N.(2015a).A potential bioconversion of empty fruit bunches into organic fertilizer using Eudriluseugeniae. *Int. J. Environ. Sci. Technol*., 12 (8), pp. 2533-2544.

Lim, L.Y., Chua, L.S. and Lee, C.T.(2015b). Effects of microbial additive on the physiochemical and biological properties of oil palm empty fruit bunches compost. *J. Eng. Sci. Technol*., 5(1), pp. 10-18.

Mącik, M., Gryta, A. and Frąc, M.(2020).Biofertilizers in agriculture: An overview on concepts, strategies and effects on soil microorganisms. *Adv. Agron*., 162, pp. 31-87.

Mahanty, T., Bhattacharjee, S., Goswami, M., Bhattacharyya,P., Das, B., Ghosh, A. and Tribedi, P.(2017).Biofertilizers: a potential approach for sustainable agriculture development. *Environ. Sci. Pollut. Res*., 24 (4), pp. 3315-3335.

McDougall, P. (2013). R&D Trends for Chemical Crop Protection Products and the Position of the European Market.A Consultancy Study Undertaken for ECPA. Available online at: https://croplifeeurope.eu/information-page/regulatory-affairs/publications-regulatory-affairs

Mendoza-Arroyo.G.E., Chan-Bacab, M.J., Aguila-Ramírez, R.N., Ortega-Morales, B.O.,CanchéSolís, R.E., Chab-Ruiz, A.O. and Camacho-Chab, J.C.(2020).Inorganic phosphate solubilization by a novel isolated bacterial strain Enterobacter sp. ITCB-09 and its application potential as biofertilizers Agriculture, 10 (9), p. 383.

Meyer-Kohlstock, D., Hädrich, G., Bidlingmaier, W.,and Kraft, E. (2013).The value of composting in Germany-Economy, ecology, and legislation.*Waste Manage*., 33 (3), pp. 536-539.

Mercy, S., MuchiraBanu, S. and Jenifer, I. (2014).“Application of different fruit peel formulation as a natural fertilizer for plant growth” *IJSTR*, pp.301-302.

NahrulHayawin, Z., Abdul Khalil, H.P.S., Jawaid, M., Hakimi Ibrahim, M. andAstimar, A.A.(2010).Exploring chemical analysis of vermicompost of various oil palm fibre wastes.Environmentalist, 30 (3), pp. 273-278

Nath, M., Bhatt, D., Bhatt, M.D., Prasad, R. andTuteja, N.(2018).Microbe-mediated enhancement of nitrogen and phosphorus content for crop improvement.Crop Improvement through Microbial Biotechnology, Elsevier, pp. 293-304.

Pathma, J. and Sakthivel, N. (2012).Microbial diversity of vermicompost.bacteria that exhibit useful agricultural traits and waste management potential. Springerplus, 1:26-26.

Prasad, H., Sajwan, P., Kumari, M.,andSolanki, S.P.S. (2017).Effect of organic manures and biofertilizer on plant growth, yield and quality of horticultural crop: A review.*Int. J. Chem. Stud.*, 5 (1), pp. 217-221.

Rosli, N.S., Harun, S., Jahim, J.M.and Othaman, R.(2017).Chemical and physical characterization of oil palm empty fruit bunch.*Malaysian J. Anal. Sci*., 21 (1), pp. 188-196

Loh, S.K.(2017). The potential of the Malaysian oil palm biomass as a renewable energy source*Energy Convers.Manage*., 141, pp. 285-298.

Samiran, N.A., Jaafar, M.N.M., Chong, C.T. and Jo-Han, N.(2015).A review of palm oil biomass as a feedstock for syngas fuel technology.*Jurnalteknologi*, 72 (5).

Soumare, A., Boubekri, K., Lyamlouli, K., Hafidi, M., Ouhdouch, Y. and Kouisni.L.(2020). From isolation of phosphate solubilizing microbes to their formulation and use as biofertilizers: status and needs.*Front. Bioeng.Biotechnol*., 7, p. 425.

Sparks, T. C., and Nauen, R. (2015). IRAC: Mode of action classification and insecticide resistance management. *Pest.Biochem. Physiol*. 121, 122–128.

Tahir, P.M.,Winnie-Pui-PuiLiew, Lee, S.Y., Ang, A.F., Lee, S.H., Mohamed, R. and Halis, R.(2019). Diversity and characterization of lignocellulolytic fungi isolated from oil palm empty fruit bunch, and identification of influencing factors of natural composting process. *Waste Manage*., 100, pp. 128-137.

Ritika, B. and Utpal, D. (2014).Biofertilizer, a way towards organic agriculture: A review.*Afr. J. Microbiol. Res.*, 8 (24), pp. 2332-2343.

Siddiquee, S., Shafawati, S.N. and Naher, L.(2017).Effective composting of empty fruit bunches using potential Trichoderma strains. *Biotechnol. Rep*., 13, pp. 1-7

Thomas, L. and Singh, I.(2019).Microbial biofertilizers: types and applications Biofertilizers for Sustainable Agriculture and Environment, *Springer, Cham*, pp. 1-19.

Qu,K., Guo, F., Liu, X., Lin, Y.and Zou, Q.(2019).Application of machine learning in microbiology Front. *Microbiol.*, 10, p. 827.

Valencia, M. and Luis, J, (2010). Botanical repellent composition containing allium sativum and humic acid and intended for pest insect control, method for producing same, and uses thereof. French Patent.

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Visakh, N.U.,Pathrose, B.,Narayanankutty, A.,Alfarhan, A.and Visakh, V.R. (2022).Utilization of Pomelo (*Citrus maxima*) Peel Waste into Bioactive Essential Oils: Chemical Composition and Insecticidal Properties.*Insects*, 13(5), 480.

Wei, V.S.J., Bing, C.H., Saptoroand, A. and Nandong, J.(2016).Effects of temperature, aeration rate and reaction time on composting of empty fruit bunches of oil-palm. *Iranica J. Energy Environ.*, 7 (2), pp. 156-162.

Yadav, K.K. and Sarkar, S.(2019). Biofertilizers, impact on soil fertility and crop productivity under sustainable agriculture. *Environ. Ecol*., 37 (1), pp. 89-9.3