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Utilization of Fruit Peels as Sustainable Organic Fertilizers: A Comprehensive Review

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ABSTRACT
The detrimental effects of conventional farming on the environment and public health have increased the demand for sustainable agricultural methods. Organic farming, which emphasizes natural inputs and environmentally friendly practices, has emerged as a competitive alternative. To increase soil health, lessen environmental pollution, and support sustainable agriculture, organic fertilizers are essential. Contrarily, traditional synthetic fertilizers have several disadvantages and environmental problems, such as soil deterioration, water pollution, and nutrient imbalances. This in-depth analysis looks at the use of fruit peels as organic fertilizers that are sustainable. Fruit peels, such as those from citrus, bananas, and mangoes, are a valuable source of nutrients that are available to plants and support the growth of healthy plants and increase crop yields. Additionally, using them as organic fertilizers offers a long-term solution for handling organic waste, helping to promote recycling, waste reduction, and environmental sustainability. Fruit peel-based organic fertilizers' slow-release properties reduce nutrient runoff and leaching, protecting aquatic ecosystems and water quality. Additionally, they encourage the accumulation of organic matter in the soil, lower atmospheric carbon dioxide levels, and mitigate climate change, all of which contribute to carbon sequestration. Fruit peels have many benefits, but there are also drawbacks to consider, such as nutrient imbalances, nutrient content variability, and proper application techniques. To maximize the health benefits of fruit peels while reducing potential risks, proper preparation and nutrient management are required. The distinct benefits and drawbacks of using fruit peels as fertilizers are revealed by comparison to other organic fertilizers like compost, manure, and biofertilizers. While compost and biofertilizers offer a more balanced nutrient profile and boost microbial activity, fruit peels offer specialized nutrients and improve soil structure. The effectiveness of fruit peel-based organic fertilizers depends on proper nutrient management, knowledge of crop and soil requirements, and the use of the right fertilizers. Fruit peels have a lot of potentials as organic fertilizers that are sustainable, increase plant growth, and support sustainable agricultural practices. For broader adoption in practical settings, more study is required to assess economic and environmental factors, optimize application rates, investigate synergistic effects with other organic amendments, and optimize application rates.
Keywords: Organic Fertilizer, Fruit peel, Biofertilizer, Plant growth, Nutrients

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INTRODUCTION
The negative effects of conventional farming practices on the environment and human health have increased the demand for sustainable agricultural practices. Organic farming has gained popularity as a practical substitute because it places an emphasis on using natural inputs and environmentally friendly practices. To improve soil health, reduce environmental pollution, and ensure sustainable agricultural practices, organic fertilizers are essential. Conventional synthetic fertilizers, however, have several drawbacks and environmental issues. Some of the major problems include nutrient imbalances, soil deterioration, and water pollution.
The lack of vital micronutrients in synthetic fertilizers frequently leaves crops with nutrient deficiencies and reduces soil fertility. Synthetic fertilizers frequently only supply macronutrients. Continuous use of

synthetic fertilizers can compromise soil structure and nutrient-holding capacity by reducing organic matter, decreasing microbial activity, and raising soil acidity. Furthermore, overuse of synthetic fertilizers can cause nutrient runoff into water bodies, which can wreak havoc on aquatic ecosystems by causing eutrophication and harmful algal blooms. A powerful greenhouse gas that contributes to climate change, nitrous oxide, is also released during the production, transportation, and use of synthetic fertilizers [1, 2].

In addition to offering many advantages for sustainable agriculture, organic fertilizers are a sustainable substitute for synthetic fertilizers. They improve soil structure, moisture retention, and microbial activity by enhancing it with important macronutrients, micronutrients, and organic matter. This increases the long-term fertility and productivity of the soil. Slow nutrient release from organic fertilizers lowers the chance of nutrient runoff and leaching, prevents water pollution, safeguards aquatic ecosystems, and preserves water quality. By encouraging the buildup of organic matter in the soil, enhancing soil carbon storage, and preventing climate change by lowering atmospheric carbon dioxide levels, organic fertilizers also aid in carbon sequestration. All things considered; organic fertilizers present a promising way to achieve sustainable agriculture [3, 4].

Large-scale production of Fruit Peel waste in the food processing and agricultural sectors has raised serious environmental concerns. A million tons of fruit waste is produced annually in India, which is also the world's second-largest producer and consumer of fruits. Due to their decomposition in landfills and release of harmful greenhouse gases, these enormous quantities of waste food products also contribute to enormous environmental issues. Fruit and vegetable processing facilities frequently emit the most waste into the environment, followed by household garbage [5].

Nutrient Content and Composition of Fruit Peels

In a study conducted by Romelle et al. [6] to analyze the chemical composition of fruit peels of Pawpaw, pineapple, mango, apple, banana, orange, pomegranate, and watermelon, It was observed that the yield of peel ranged from 6.44 ± 0.02 to 33.81 ± 0.56%. eight fruit peels were examined for their protein content; apple peels had the least amount and pawpaw peels had the most. Pawpaw peels had a higher protein content than Solo pawpaw peels, whereas mango peels had protein levels like those of crude proteins. Pomegranate peels had the lowest lipid content (3.36±0.37%) and watermelon peels had the highest (12.61±0.63%), respectively. Apple, pawpaw, orange, and mango peels all had lipid contents that were comparable to those found in apple star peel (8.94%), pawpaw peel (5.78%), orange peel (9.52%), and mango peels (4.80%). Banana peels had a lipid content of 8.40 ±1.15%, which was like the 7.9% found by Munguti et al. [7] but less than 13.1 ± 0.2 % discovered by Wachirasiri *et al.* [8]. Apple peels had an ash content of 1.39 ± 0.14% and banana peels had 12.45 ± 0.38%. Crude fibers content ranged from 11.81 ± 0.06 to 26.31 ± 0.01%, and crude carbohydrate content ranged from 32.16 ± 1.22 to 63.80 ± 0.16%, respectively. While the amount of carbohydrates in pomegranate peels was less than 78.67%, the level of crude fibers was comparable to the content found in white pomegranate peels. These variations might result from geographical factors or variations in cultivar varieties.

Minerals are essential to the body's building and regulating processes as well as other physiological processes. Fruits are thought to be an excellent source of dietary minerals [9]. The range of calcium content in fruit peels is 8.30 ± 0.54 to 162.03 ± 7.54 mg/100 g, with pineapple peels having the lowest and orange peels having the highest levels. Apple peels contain less calcium than banana peels. Variations in the contents of minerals and trace elements can result from factors like variety, ripeness, soil type, and irrigation schedule. Zinc is necessary for immune system development and cellular replication. Zinc levels in fruit peels range from 0.66 0.06 to 6.84 ± 0.55 mg/100g, with mango peels having the lowest levels and orange peels having the highest levels. Pomegranate peels have the lowest levels of iron and manganese in fruit peels, which range from 9.22 ± 0.63 to 45.58 ± 2.37 mg/100g and 0.52 ± 0.10 to 9.05 ± 0.34 mg/100g, respectively, Iron and manganese levels in banana peels are lower than those discovered by Anhwange et al., though [10].

Calcium can become bound to oxalates in fruit peels, rendering it useless for its usual physiological and biochemical functions. The amount of oxalates in eight different fruit peels ranged from 41.02 mg/100 g to 2,283.77 mg/100 g, with pawpaw peels having the lowest amount and pomegranate peels having the highest amount. Pomegranate and banana peels had the lowest concentrations of hydrogen cyanide, whereas watermelon and banana peels had the highest concentrations. Fruit peels contained fewer alkaloids than Irish potatoes, which had an alkaloid content of 29.5%. The range of phytates in fresh fruit peels was 0.70 ± 0.17 to 6.02 ± 0.61%, with banana peels having the highest concentration and watermelon peels having the lowest. Fruit peels were found to contain phenolics in amounts ranging from 0.91 ± 0.06 to 24.06 ± 0.89%, with mango and watermelon peels having the lowest and highest phenolic contents, respectively.

Effect of Fruit Peels on Soil Fertility

Fruit peels are a natural way to amend the soil and help it retain more organic matter. Structure, water-holding capacity, and nutrient retention in the soil are all improved by organic matter. Additionally, it provides food for helpful soil microorganisms, fostering their development and activity [4]. Fruit peels contain vital nutrients like potassium, phosphorus, calcium, and micronutrients that can help boost the levels of nutrients in the soil. These nutrients are gradually released into the soil after being incorporated, improving soil fertility. Organic amendments' slow-release properties ensure that plants receive a steady supply of nutrients and help prevent nutrient leaching [11]. Fruit peels are rich in organic matter which acts as a substrate for beneficial soil microorganisms. This encourages the growth of these organisms. These microbes are essential to the decomposition of organic matter, the control of plant diseases, and the cycling of nutrients. Fruit peels enhance soil fertility and health by creating an environment that is conducive to microbial activity [12]. A slight acidification of the soil may result from some fruit peels, such as citrus peels, due to the organic acids found in them. In soils with high pH levels, this can be advantageous because it contributes to the creation of a pH range that is better suited for the availability and uptake of nutrients by plants.

Fruit peels can help the soil retain more water when they are incorporated into the soil. Organic matter contributes to the soil's increased porosity, which improves water infiltration and retention. As a result, plants can absorb more soil moisture and crops experience less water stress [13]. It's important to remember that the efficiency of fruit peels as soil amendments may vary depending on elements like their rate of decomposition, the way they are applied, and the type of soil. Fruit peels' nutrient availability and overall benefits to soil fertility can also be improved by composting or vermicomposting them prior to application.

Impact of Fruit Peels on Plant Growth and Yield

The findings of Nossier [14] show that mineral fertilizers can be replaced with organic fertilizers. These findings were based on the use of banana and orange peels, where it was observed that the results were converging and that there were no significant differences when using banana and orange scales or the standard mineral fertilizer. Instead, there was an increase in the potassium ratio at each stage of tomato plant growth when using organic fertilizers. The quality of tomato fruits fertilized with banana and orange peel was found to be higher than that of the control, particularly in terms of the proportions of total salts and acidity, which were lower. However, there were no discernible differences between tomato plant's fruits according to either method of fertilization. The reason is that during its various stages of development, banana, and orange peel are rich in many plant nutrients. Numerous studies have attested to the abundance of nutrients in fruits and vegetables.

Both have been explained (Mercy et al.; Tsay et al.)[15,16], and it has recently become common practice to use fruits and vegetable peels as fertilizer for the soil. This is because using various formulations of organic fertilizers with fruit peels has increased the efficiency and fertility of the soil and increased the diversity of microorganisms that are necessary for plant growth. These crusts are abundant in the elements needed for plant growth and the soil, which is why it has been observed that the earth's elemental content has increased. The fruit peels of bananas, sweet lemons, oranges, and pomegranates are particularly rich in iron, potassium, zinc, and many other elements that increase soil fertility, which in turn increases plant growth and health, Mercy et al. [15] emphasized in their research. Hiral et al. [17] have confirmed in their research that the use of powdered fruit peels such as bananas, oranges, and others can be used as fertilizer for the ground, regulating pH and supplementing some nutrients such as zinc, iron, and calcium.They also stressed that the use of these peels in fertilization does not require a high cost and therefore it also helps in converting waste into usable materials.

Environmental Benefits and Challenges

Fruit peels can be used as organic fertilizers to help lessen the need for synthetic fertilizers, reducing chemical runoff. Organic fertilizers made from fruit peels release nutrients gradually and are less prone to leaching and runoff than synthetic fertilizers. As a result, there is less chance of nutrient pollution of water bodies, which lessens the harm to aquatic ecosystems [18]. Reduced Greenhouse Gas Emissions: Synthetic fertilizers, in particular nitrous oxide ($N2O$) and carbon dioxide ($CO2$), are produced, transported, and used in ways that increase greenhouse gas emissions. By reducing reliance on energy-intensive synthetic fertilizer production and reducing the use of chemical fertilizers, organic fertilizers made from fruit peels have the potential to lower these emissions [19].

Fruit consumption habits in the area and seasonal variations, for example, can have an impact on the availability of fruit peels to produce organic fertilizer. To guarantee a steady supply of fruit peels throughout the year, it might be necessary to set up efficient collection and storage systems. Fruit peels are perishable and vulnerable to microbial deterioration if improperly stored. Fruit peels must be properly stored and preserved before being used as organic fertilizers to maintain their nutrient content and quality, such as through drying or composting. Application Methods and Rates: To ensure effective nutrient uptake by plants, the right application method and rate of fruit peel-based organic fertilizers must be carefully determined. Nutrient imbalances, soil compaction, or ineffective nutrient uptake may result from improper application, which will impact plant growth and yield [20]. Excessive use without proper nutrient management can result in nutrient imbalances or accumulation in the soil, even though fruit peel-based organic fertilizers can aid plant growth. To prevent potential risks like nutrient leaching, groundwater contamination, or environmental degradation, it is essential to monitor soil nutrient levels and adopt appropriate application rates and timing [21].

Understanding the nutrients in fruit peels, optimizing application rates, and incorporating them into a thorough nutrient management plan are all examples of good management practices that can help maximize the advantages of using fruit peels as organic fertilizers while lowering any risks or potential drawbacks.

Comparative Analysis with Other Organic Fertilizers

Fruit peels are rich in nutrients like potassium, phosphorus, and micronutrients. Examples include citrus peels, banana peels, and mango peels. For instance, citrus peels are known to have high potassium levels, which are crucial for plant development and fruit development. These nutrients offer an excellent source of nutrients that are available to plants, promoting wholesome plant growth and raising crop yields [22]. Waste Utilization: A sustainable method of handling organic waste is to use fruit peels as organic fertilizers. Peels should be turned into organic fertilizers rather than discarded as waste to encourage waste minimization, recycling, and environmental sustainability. By reusing organic materials that would otherwise end up in landfills, it helps to promote the circular economy by lowering greenhouse gas emissions and environmental pollution [23]. Slow-Release Nutrients: Fruit peels slowly release nutrients over time, giving plants a steady supply of nutrients. This slow-release property is advantageous because it lowers the possibility of nutrient leaching and increases the effectiveness of nutrient uptake. The gradual nutrient release coincides with the needs of the plant for growth, promoting balanced nutrient uptake and reducing nutrient loss from the soil [24].

Fruit peels may not contain an ideal balance of nutrients for optimum plant growth.Utilizing only fruit peels as fertilizer could cause the soil to become unbalanced in nutrients, which would affect plant nutrition and yield. Adding additional organic fertilizers or soil amendments to fruit peels might be necessary to provide a more complete nutrient profile. It is crucial to note that while fruit and vegetable by-products contain various ingredients, not all of them are desirable for developing a cost-effective and sustainable biorefinery process. The concentration of the ingredients in the fruit or vegetable byproduct, the market value of the ingredients that were extracted, the extraction yields, and the costs of their ingredients should all be considered before deciding [25]. It can be difficult in practice to apply organic fertilizers made from fruit peels. Fruit peels must be properly prepared before decomposing and releasing nutrients, such as by composting or grinding. Nutrient availability and application uniformity can be impacted by inconsistent particle size or inadequate preparation. To maximize their efficacy, proper application methods must be used, such as incorporating fruit peels into the soil or using them as mulch [25].

Compost provides a more well-balanced nutrient profile, enhanced soil structure, and increased water-holding capacity when compared to fruit peels. Additionally, compost improves soil fertility and fosters long-term soil health by supplying the soil with advantageous microorganisms [23]. However, the creation of compost necessitates more time and careful decomposition management, which includes routine turning and temperature and moisture monitoring. Products called biofertilizers contain helpful microorganisms that improve nutrient availability and plant growth. Biofertilizers, as opposed to fruit peels, provide microbial populations that enhance disease resistance, enhance nutrient cycling, and foster plant growth. Biofertilizers increase crop productivity, decrease the need for chemical fertilizers, and improve soil fertility over the long term. But to guarantee microbial viability and efficiency, biofertilizers need handling and application techniques [26].

FUTURE PERSPECTIVES

To optimize fruit peel-based organic fertilizer application rates for various crops and soil types, more research is required. Farmers will be able to apply the proper amount of organic fertilizer to maximize plant growth without causing nutrient imbalances or environmental concerns if they have a thorough understanding of the nutrient needs of crops and the nutrient-release dynamics of fruit peels. This study could concentrate on figuring out the nutrient requirements for a given crop and fine-tuning application rates based on the traits of the fruit peel and the soil. Developing precise and effective nutrient management strategies will be made easier with an understanding of nutrient release dynamics under various environmental conditions. Fruit peel-based organic fertilizers can improve soil fertility and plant productivity when combined with other organic amendments like compost or biofertilizers [27]. Finding complementary interactions that enhance nutrient cycling and enhance overall soil health will be made possible by research in this area. Sustainable soil management strategies require an understanding of how fruit peel-based organic fertilizers affect the microbial communities in the soil [28]. Field-scale studies are necessary to confirm the efficacy of these fertilizers in practical settings, assessing their effects on crop yield, nutrient use effectiveness, soil health, and sustainability in general. Considerations such as production costs, yield enhancements, and potential cost savings in comparison to conventional fertilization techniques highlight the importance of economic viability [29]. To calculate reductions in greenhouse gas emissions, energy use, and water pollution when compared to conventional synthetic fertilizers, thorough environmental assessments are required.The development of organic fertilizers made from fruit peels holds great promise for sustainable agriculture. The best use of these organic fertilizers in enhancing soil fertility, enhancing crop productivity, and promoting sustainable agricultural practices requires optimizing application rates, understanding nutrient release dynamics, exploring synergistic effects with other organic amendments, conducting field-scale studies, and conducting economic and environmental assessments.

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