

From Peel to Product: A Review of Banana Peel Waste Valorization as Organic Fertilizer for Sustainable Crop Production and Soil Health

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ABSTRACT

Banana peels account for 30 to 40 percent of the fresh weight of the banana fruit and are generated in quantities large enough to constitute a serious solid waste management problem in producing regions. At the same time, the peels are rich in potassium and other mineral and organic constituents that make them a promising raw material for organic fertilizer. This review synthesizes the peer-reviewed literature on the use of banana peel as an organic fertilizer, covering the composition of the peel, the principal preparation methods (composting, dried and powdered peel, liquid organic fertilizer, biochar, nano-fertilizer, and blended formulations), the documented effects on soil physical and chemical properties, and the reported responses of horticultural and field crops. Across the studies reviewed, banana peel-based fertilizers generally improved soil organic carbon, porosity, and nutrient availability, and

supported plant growth and yield at levels comparable to inorganic fertilizer in several trials, although nutrient concentration in the finished product varies widely and some treatments produced no significant advantage over mineral fertilizer. The review concludes that banana peel fertilizer is a viable component of sustainable nutrient management, and identifies standardization of production protocols, field scale validation beyond the seedling stage, and economic evaluation as priority areas for future research.

Keywords: *banana peel, organic fertilizer, biofertilizer, compost, liquid organic fertilizer, potassium, soil health, waste valorization*

INTRODUCTION

Banana is one of the most widely produced and consumed fruits in the world, and its processing and consumption generate a corresponding stream of lignocellulosic waste. Banana peels alone make up 30 to 40 percent of the fresh weight of a banana fruit, which poses a major challenge for the safe disposal of solid waste (Bishnoi et al., 2023). In the past, open burning and landfilling were the most commonly used methods of disposing of this material, but both practices have negative environmental impacts and unprocessed peels that rot in dumping sites produce unpleasant odors and disrupt the cleanliness of the surrounding environment (Bishnoi et al., 2023; La Andi et al., 2023).

At the same time that banana peel presents a disposal problem, it also presents an opportunity. The peel is rich in potassium and contains a range of mineral nutrients, organic matter, and bioactive compounds, and it has long been used informally by farmers to replenish soil nutrients (Bhavani et al., 2023; Khanyile et al., 2024). Converting this waste stream into fertilizer addresses two problems simultaneously: it reduces the environmental burden of peel disposal, and it substitutes a low cost, renewable input for synthetic fertilizer, whose excessive use can degrade soil quality and reduce long term productivity (Aditia et al., 2026).

The scientific literature on banana peel fertilizer has grown rapidly, but it is scattered across journals, crops, and preparation methods, and no early synthesis tied the methods to their agronomic outcomes. Khanyile et al. (2024) provided the first dedicated review of banana peel fertilizer preparation methods, and a growing number of primary studies have since tested specific formulations on specific crops. The objective of this review is to synthesize this body of work into a coherent picture for researchers and practitioners. Specifically, the review (a) summarizes the composition of banana peel that underpins its fertilizer value, (b) describes the principal preparation methods reported in the literature, (c) examines the documented effects of banana peel fertilizers on soil properties and on crop growth and yield, (d) compares their performance with inorganic fertilizers, and (e) identifies the limitations of the current evidence base and the priorities for future research.

Literature Review

Composition of banana peel and the basis of its fertilizer value

The fertilizer value of banana peel rests on its mineral and organic composition. Analytical work has consistently identified potassium as the dominant mineral element in the peel. Aboul-Enein et al. (2016) reported that potassium was the major element in banana peel at 9.39 percent of dry weight, followed by magnesium, calcium, sodium, and phosphorus at 0.71, 0.44, 0.18, and 0.09 percent of dry weight, respectively, with microelements including iron, manganese, zinc, and copper also present. Hassan et al. (2018) similarly quantified appreciable phosphorus (211.30 mg per 100 g), iron (47.00 mg per 100 g), calcium (59.10 mg per 100 g), magnesium (44.50 mg per 100 g), and sodium (115.10 mg per 100 g) in banana peel, alongside crude protein, crude fat, crude fiber, and carbohydrate fractions.

These nutrients map directly onto plant requirements. Potassium regulates water relations, enzyme activation, and fruit development; phosphorus supports root establishment and energy transfer; and the secondary and microelements contribute to a range of physiological functions. The organic fraction of the peel, which includes cellulose, hemicellulose, lignin, pectin, and fiber, decomposes into soil organic matter, improving soil structure, water holding capacity, and cation exchange capacity (Bhavani et al., 2023; La Andi et al., 2023). Bhavani et al. (2023) note that in agricultural sectors banana peel can be used as fertilizer to enhance soil physical properties, crop quality, and yield precisely because of its potassium content and organic matter. Two compositional caveats matter for fertilizer use. First, the nutrient content of the peel varies with cultivar, maturity stage, and processing, so a fertilizer made from peels is not a standardized product unless it is analyzed and adjusted. Second, the carbon to nitrogen ratio of raw banana residue can be high; Ultra et al. (2005) measured a C/N ratio of 68 in uncomposted banana residue, which is high enough to cause net nitrogen immobilization in soil during the early period after incorporation. This underlines the importance of the decomposition and blending steps described below.

Preparation methods for banana peel fertilizer

Khanyile et al. (2024) reviewed and analyzed the methods used to prepare fertilizer from banana peels and found that a composite of banana and orange peels emerged as the most favored and widely used approach, closely followed by dried banana peels. The preparation method matters: the same review highlighted the substantial impact of fertilizer application methods such as top dressing and basal dressing, and found that for biochar the difference in plant height between treatments was not significant, further emphasizing the importance of the application method used (Khanyile et al., 2024). The principal preparation routes reported in the literature are described below.

Composting and bokashi

Composting is the most established route. Ultra et al. (2005) studied ten formulations of banana residue-based compost combined with leguminous plants (*Sesbania rostrata*, *Flemingia macrophylla*, and *Arachis hypogea*) and chicken manure over a 16-week composting period. Combinations of banana residues with chicken manure or leguminous plants were highly decomposed compared with untreated banana residue, and the use of legumes or chicken manure enhanced the composting process significantly. The compost piles showed increases in pH, total nitrogen, and total phosphorus, and decreases in total potassium, total carbon, and the C/N ratio over time; banana residue with chicken manure reached a C/N ratio of 15 at four weeks, while blends with leguminous materials reached that level at eight to sixteen weeks (Ultra et al., 2005).

Bio activators can accelerate and enrich the compost. Juliastuti et al. (2017) composted a mixture of bioethanol solid waste, corn agricultural waste, and banana peel waste at a ratio of 1:2:3 in a rotary drum composter with the bio activators EM4 and *Aspergillus niger*, and found that the EM4 to *A. niger* ratio of 2:3 raised the potassium content of the finished organic fertilizer to 0.43 percent, with all variables meeting Indonesian national standard requirements for nitrogen and phosphorus content. In Costa Rica, Formowitz et al. (2007) examined bokashi, a compost produced from banana residues with effective microorganisms, and found that the effect of the microorganisms on the mineralization of banana material was negligible: dry matter losses of about 78 percent over five weeks were similar across treatments. All bokashi variants nevertheless increased the shoot growth of young banana plants in the greenhouse compared with unamended soil (Formowitz et al., 2007).

Kadir et al. (2016) used banana peel as the fermentation liquid in food waste composting, with soil and coconut husk as the composting medium. The finished compost contained nitrogen in the range of 35,325 to 78,775 mg per liter, phosphorus of 195.83 to 471 mg per liter, and potassium of 422.3 to 2,046 mg per liter, values the authors judged sufficient for agricultural use and only slightly different from commercially available organic compost (Kadir et al., 2016).

Dried and powdered peel

A simpler approach is to dry and grind the peels. Nasir (2021) used grinded banana and orange peels as an organic fertilizer and, in an incubation experiment, recorded increases in soil nitrogen content of 16 to 31 percent and in potassium of 12 to 24 percent compared with a commercial compost treatment. La Andi et al. (2023) applied raw banana peel waste directly at rates of 10 to 40 tonnes per hectare to an Inceptisol and measured the resulting changes in soil physical properties. Bomisso et al. (2019) formulated dried and ground plantain peel, alone and in mixtures with chicken dung compost, into nursery fertilizers for plantain plantlets.

Liquid organic fertilizer

Liquid organic fertilizer (LOF) from banana peel is produced by fermentation of the peels, typically in water with or without an added decomposer. Hariyono et al. (2021) prepared banana peel liquid organic fertilizer as a potassium source for eggplant; Anatolana et al. (2024) prepared liquid organic fertilizer from Kepok banana peel waste for sweet corn; Sari et al. (2020) tested concentrations of 0, 5, 10, 15, and 20 percent Kepok banana peel liquid fertilizer on strawberry; Manis et al. (2018) fermented banana peel waste into liquid fertilizer and measured a total nitrogen content of 0.032 percent; and Aditia et al. (2026) combined Kepok banana peel liquid organic fertilizer with reduced rates of NPK fertilizer on pakchoy. Anugrah and Prastamay (2022) applied Kepok banana peel liquid organic fertilizer at weekly rates of 10 to 100 mL to pakcoy grown in a greenhouse.

Biochar

Pyrolysis converts the peel into a potassium rich, carbon sequestering amendment. Islam et al. (2019) produced banana peel biochar through slow pyrolysis under limited oxygen, heating the peels at about 400 degrees Celsius for two hours, grinding and sieving the charred material, and incorporating it into agricultural soil at rates of 1, 2, and 3 percent. The resulting biochar was found to be rich in potassium and was evaluated as an alternative potassium source to potassium chloride in pot experiments.

Nano-fertilizer

At the most technologically refined end of the spectrum, Hussein et al. (2019) extracted a mixed nano bio stimulant fertilizer from banana peels, with constituent particle sizes ranging from 19 to 55 nm and a major fraction of 40 nm particles. The synthesized nano fertilizer contained chelated potassium, chelated iron, tryptophan, urea, amino acids, protein, and citric acid, and was tested on tomato and fenugreek.

Blended and co-composted formulations

Several studies blend banana peel with other organic materials to balance nutrients and improve decomposition. Bomisso et al. (2019) blended dried ground plantain peel with poultry litter compost; Ultra et al. (2005) co-composted banana residue with leguminous plants and chicken manure; Juliastuti et al. (2017) mixed the peel with bioethanol solid waste and corn waste; and the banana and orange peel composite identified by Khanyile et al. (2024) as the most widely used formulation exhibits what those authors describe as outstanding fertilizer properties.

METHODS

Review Design

This study employed a narrative literature review design. Published peer-reviewed studies on the use of banana peel as organic fertilizer were identified, screened, and synthesized thematically. The review is organized around four themes derived from the research objective: the composition of banana peel, the methods used to prepare banana peel fertilizer, the effects of the fertilizer on soil properties and crop growth and yield, and the comparative performance of banana peel fertilizer against inorganic fertilizer.

Search Strategy and Sources

Relevant studies were retrieved from scholarly databases and academic indexes using combinations of the keywords banana peel, banana peel waste, organic fertilizer, biofertilizer, compost, liquid organic fertilizer, biochar, potassium, and soil health. Reference lists of retrieved reviews, particularly the dedicated review of banana peel biofertilizer preparation methods by Khanyile et al. (2024), were examined for additional primary studies.

Selection of Studies

Studies were included when they (a) used banana peel or banana plant residue as the primary or co-primary raw material of a fertilizer or soil amendment, (b) reported either a chemical characterization of the product or a measured plant or soil response, and (c) were published in a peer-reviewed journal or peer-reviewed conference proceedings. Review articles and analytical characterization studies were retained where they support the interpretation of the primary agronomic evidence. Studies in which banana peel appeared only as an incidental ingredient were excluded. This procedure yielded the 26 sources cited in this review, spanning studies published between 2005 and 2026.

Data Analysis

The retrieved studies were read in full and analyzed thematically. Reported preparation methods were grouped into six categories (composting and bokashi, dried and powdered peel, liquid organic fertilizer, biochar, nano-fertilizer, and blended formulations), and reported outcomes were synthesized by theme: soil physical and chemical properties, crop growth and yield, and comparison with inorganic fertilizers. Quantitative results are reported as they appear in the original studies, and the limitations of the evidence base are assessed collectively in the discussion.

RESULTS AND DISCUSSION

Effects on Soil Properties

The most direct evidence that banana peel fertilizer improves soil condition comes from La Andi et al. (2023), who applied banana peel waste at 10, 20, 30, and 40 tonnes per hectare to Inceptisol soil in a randomized block design. The application of organic fertilizer from banana peel waste changed several physical properties of the soil, including soil volume weight (bulk density), soil porosity, soil organic carbon, percent soil water content, soil permeability, and the stability of soil aggregates (La Andi et al., 2023). These are the physical attributes that govern root penetration, aeration, and water storage, and their improvement is the signature of a well-functioning organic amendment.

Chemical improvements are equally well documented. Teshome (2022) characterized soil amended with banana peel compost at rates of 10, 20, and 30 g per pot and found progressive enrichment: nitrogen rose from 0.46 percent in unamended soil to 1.54, 1.93, and 2.58 percent; phosphorus from 1.51 to between 5.77 and 5.91 mg per kg; potassium from 11.82 to between 41.28 and 42.34 mg per kg; and organic carbon from 1.31 percent to as much as 25.50 percent. Soil pH shifted from 6.34 toward 7.30, cation exchange capacity increased from 21.08 to as much as 36.94 cmol per kg, and electrical conductivity rose from 0.11 to 4.09 dS per cm (Teshome, 2022). In the incubation and field experiments of Nasir (2021), grinded banana and orange peels increased soil nitrogen by 16 to 31 percent and potassium by 12 to 24 percent relative to a commercial compost, and the soil fertilized with the peel mixture held a higher potassium concentration than soil fertilized with mineral fertilizer.

Nutrient availability, however, depends on how the material is prepared. Ultra et al. (2005) showed in a 24-week greenhouse incubation that net nitrogen mineralization occurred in soils amended with banana residue co-composted with chicken manure or leguminous materials, whose C/N ratios ranged from 12 to 16, whereas uncomposted banana residue with a C/N ratio of 68 caused net nitrogen immobilization in the earlier period. An abrupt increase in exchangeable potassium was observed in all treatments two weeks after incorporation, and the higher available potassium in pure banana residue treatments reflects the inherently high potassium content of banana residues (Ultra et al., 2005). Juliastuti et al. (2017) reached a similar conclusion from the production side, showing that the bio activator blend used in composting can raise the potassium content of the finished fertilizer to 0.43 percent.

Effects on Crop Growth and Yield

Primary studies have tested banana peel fertilizers on a wide range of crops, from leafy vegetables and fruit vegetables to staple and horticultural crops. Table 1 summarizes representative studies, and the following subsections group the findings by fertilizer form.

Table 1. *Representative Studies on Banana Peel as Organic Fertilizer*

Study	Fertilizer Form	Crop or System	Reported Outcome
Ultra et al. (2005)	Co-composted banana residue	Clay soils, incubation	Net N mineralization in blends; higher exchangeable K in pure banana residue
Formowitz et al. (2007)	Bokashi compost	Young banana plants	Shoot growth increased over unamended control
Juliastuti et al. (2017)	Compost with EM4 and <i>A. niger</i>	Chilli and eggplant	K content raised to 0.43%; fruit quality standards met
Nasir (2021)	Dried powdered peel blend	Tomato (field)	N and K status comparable to mineral fertilizer
Islam et al. (2019)	Biochar (2 to 3%)	Water spinach and pumpkin	No K deficiency; biomass numerically higher
Hussein et al. (2019)	Nano-fertilizer extract	Tomato and fenugreek	Germination rose to 97% and 93.1%
Manis et al. (2018)	Liquid organic fertilizer	Water spinach	40 mL rate gave best height and wet weight

Hariyono et al. (2021)	Liquid organic fertilizer	Eggplant	Growth and yield similar to KCl fertilizer
Sari et al. (2020)	Liquid organic fertilizer (10%)	Strawberry	Improved growth and earlier flowering
Anatolana et al. (2024)	Liquid organic fertilizer (100 mL/L)	Sweet corn	Best height, cobs, and cob weight
Teshome (2022)	Peel compost (10 to 30 g)	Swiss chard (pot)	All rates improved growth and yield over control
Aditia et al. (2026)	Liquid organic fertilizer + 50% NPK	Pakchoy	Performance maintained with half the NPK dose
La Andi et al. (2023)	Raw peel waste (10 to 40 t/ha)	Inceptisol soil	Improved porosity, organic C, water content, aggregate stability

Legend: The table lists representative peer-reviewed studies, the form of banana peel fertilizer they tested, the crop or soil system studied, and the principal reported outcome.

Compost, Bokashi, and Solid Formulations

Composted banana residues and bokashi consistently support plant growth. In the study of Formowitz et al. (2007), application of all bokashi variants significantly increased the shoot growth of young banana plants compared with plants grown in control soil without amendments. Juliastuti et al. (2017) tested their banana peel containing compost on chilli and eggplant and found that the treatment with the EM4 to *A. niger* ratio of 2:3 produced the greatest chilli weight at 0.95 g and, in another variable, a threefold increase in the number of chilli fruits, while the 2:3 ratio produced eggplant fruit weighing 24.01 g per harvest. Memon (2012), comparing banana waste compost with farmyard manure and pressmud in a pot experiment with maize, found highly significant increases in plant height, dry matter yield, and NPK content with the application of composted fertilizers, although maize response was better with pressmud, followed by farmyard manure and banana waste. In nursery culture, Bomisso et al. (2019) showed that dried ground plantain peel, applied alone or blended with chicken dung compost, induced harmonious growth of plantain plantlets, with plants reaching a height of 13.77 cm and a pseudostem circumference of 2.93 cm, compared with 8.45 cm and 1.55 cm in the unfertilized control and 6 cm and negative growth relative to baseline under mineral NPK fertilizer, leading the authors to recommend the peel formulation as an alternative to chemical fertilizers.

Solid peel compost has also proven effective on vegetables. Teshome (2022) found that all rates of banana peel compost enhanced and improved Swiss chard growth performance and yield relative to the no compost control, with the 30 g rate producing the tallest plants at 26.33 cm and the greatest leaf width at 12.77 cm. Simbolon et al. (2026) reported that banana peel liquid organic fertilizer significantly increased the number of branches and the weight of 100 seeds of soybean grown in Andisol soil, while chicken manure significantly increased stem diameter, number of branches, number of pods, and weight of 100 seeds.

Liquid Organic Fertilizer

Liquid formulations have produced consistently positive, dose dependent responses across crops. On sweet corn, Anatolana et al. (2024) found that concentrations of Kepok banana peel liquid organic fertilizer had a significant effect on plant height, leaf count, stem diameter, cob length without husk, cob diameter without husk, and cob weight without husk, with the concentration of 100 mL per liter of water yielding the best results across all measured parameters. On strawberry, Sari et al. (2020) demonstrated that 10 percent liquid organic fertilizer of banana peels increased the growth of strawberry plants and shortened the time to flowering. On water spinach, Manis et al. (2018) found that the application of banana peel liquid fertilizer influenced plant height and wet weight, with the 40 mL treatment showing the best results for average plant height, number of leaves, and wet weight. Anugrah and Prastamay (2022) reported that Kepok banana peel liquid organic fertilizer affected the growth of pakcoy, with the 25 mL treatment producing the greatest plant height of 21.7 cm, 12.6 leaves, and a wet weight of 17.62 g. On eggplant, Hariyono et al. (2021) found that the comparison of banana peel liquid organic

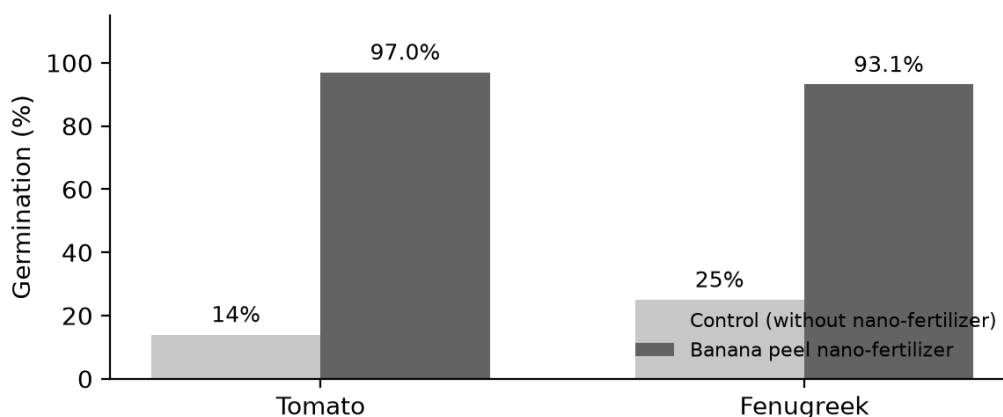
fertilizer application gave similar results to the growth and yield of eggplant across all proportions of substitution for potassium chloride fertilizer, meaning the liquid fertilizer alone matched the conventional potassium source.

Biochar and Nano-Fertilizer

The biochar route converts the peel into a slow-release potassium source. Islam et al. (2019) found that plant productivity and above ground biomass were reduced at the 1 percent biochar rate but increased at the 2 and 3 percent rates compared with the control, although the differences were statistically insignificant at the 5 percent level. In their second experiment, potassium deficiency symptoms appeared in pumpkin seedlings grown without potassium, whereas no deficiency symptoms were noticed in plants supplied with potassium from either potassium chloride or banana peel biochar, and the plants grown with the biochar were healthy, stronger, and greener in appearance (Islam et al., 2019).

The nano formulation produced striking germination responses. Hussein et al. (2019) reported that the germination percentage of tomato increased from 14 percent in the control without nano fertilizer to 97 percent after 7 days of plantation, and the germination percentage of fenugreek was enhanced from 25 percent to 93.14 percent, with germination increasing with the dose of banana peel extract in both crops. Figure 1 illustrates these responses.

Figure 1. *Germination Percentage of Tomato and Fenugreek Seeds with and Without Banana Peel Nano-Fertilizer*



Legend: The figure compares germination percentage under the control treatment without nano-fertilizer against the banana peel nano-fertilizer treatment reported by Hussein et al. (2019).

Comparison with Inorganic Fertilizers

A recurring question in this literature is whether banana peel fertilizer can substitute for, or complement, inorganic fertilizer. The direct comparisons generally support at least partial substitution. Hariyono et al. (2021) tested six proportions of banana peel liquid organic fertilizer and potassium chloride on eggplant and found that the comparison of the two sources gave similar results for the growth and yield of eggplant. Nasir (2021) found in a field experiment that the concentration of nitrogen and potassium at different plant growth stages, whether in soil or plant, did not differ significantly between plots fertilized with mineral fertilizer and plots fertilized with the banana and orange peel mixture; indeed, the potassium concentration was higher in the soil fertilized with the organic mixture, and the tomato fruits showed no clear significant differences in nitrogen and potassium ratio, weight, size, or density, except that total salts percentage was lower in the fruits from the peel treatment (Nasir, 2021). Aditia et al. (2026) showed that 100 mL of Kepok banana peel liquid organic fertilizer combined with 50 percent NPK produced the highest number of leaves and a shoot weight statistically comparable to the highest fertilizer rate, a treatment that reduced the NPK fertilizer dose by 50 percent while maintaining strong vegetative performance.

The comparative evidence is not uniformly favorable. Elfarisna et al. (2024) found that the application of Kepok banana peel liquid organic fertilizer did not affect the growth and production of okra plants compared with inorganic fertilizer, attributing the result to the low nutrient content in the banana peel liquid fertilizer. In the biochar trials of Islam et al. (2019), the increases in plant productivity at the 2 and 3 percent rates were statistically insignificant. Memon (2012) found that composted banana waste improved maize growth relative to the control but underperformed pressmud and farmyard manure, and that un-decomposed banana waste actually depressed plant growth and dry matter yield. On balance, the literature supports banana peel fertilizer as a complement to, and partial substitute for, inorganic fertilizer rather than a drop-in replacement, with performance depending on the formulation, the rate, and the nutrient demands of the crop.

Limitations and Future Directions

Several limitations qualify the positive findings reviewed above. First, the nutrient concentration of banana peel fertilizer is variable and often low. Manis et al. (2018) measured a total nitrogen content of only 0.032 percent in their liquid fertilizer, and Elfarisna et al. (2024) attributed the poor performance of their liquid fertilizer on okra to its low nutrient content. Hussein et al. (2019) and Juliastuti et al. (2017) achieved better nutrient profiles, but through enrichment or blending, suggesting that the concentration step is decisive rather than optional.

Second, raw or insufficiently decomposed peel can harm crops. Memon (2012) showed that un-decomposed banana waste generally depressed plant growth and dry matter yields compared with the control, and Ultra et al. (2005) showed that uncomposted banana residue immobilized nitrogen during the early incubation period because of its high C/N ratio. Composting or other stabilization is therefore not an optional refinement but a prerequisite.

Third, not all amendments perform equally across application methods. Khanyile et al. (2024) found that plant height was not significantly different between biochar treatments, emphasizing the importance of the application method used, and Formowitz et al. (2007) found that the effective microorganisms added no measurable benefit over ordinary bokashi except for increasing the potassium concentration in the leaves of young banana plants.

Fourth, the evidence base has structural gaps. Khanyile et al. (2024) concluded that more new studies should go beyond the seedling stage, especially to harvest, to give more information on the performance and viability of banana peel fertilizers. Many of the primary studies reviewed here were conducted in pots, greenhouses, or polybags over one or two growing cycles, on a single soil type, with limited replication. Abubakar et al. (2026), comparing banana peel and eggshell liquid bio-fertilizers on onion and fluted pumpkin, found that most measured growth and yield parameters showed no statistically significant differences among treatments, and cautioned that further field-based studies with larger sample sizes and diverse environmental conditions are required before recommending widespread agricultural use.

Finally, safety must be documented rather than assumed. da Costa et al. (2025) characterized a banana peel flour biofertilizer and found no toxicity at the low concentrations tested, up to 10,000 micrograms per milliliter, in an *Artemia salina* model, while confirming the presence of the macronutrient's nitrogen, phosphorus, and potassium, with low nitrogen and high phosphorus and potassium content that explains the alkalizing effect on pH. Systematic ecotoxicological and heavy metal screening of this kind should accompany any move toward commercial formulation.

The literature points to a clear agenda. First, crop response studies must extend beyond the seedling stage to harvest, since most current evidence covers early growth only (Khanyile et al., 2024). Second, the most promising formulations, particularly the banana and orange peel composite and biochar applied through appropriate methods, should be validated at field scale across multiple seasons, soil types, and climates, with the comprehensive soil characterization, nutrient uptake measurement, and economic evaluation that Simbolon et al. (2026) recommend. Third, production protocols need standardization: the dose response studies reviewed here identified optimal rates that range from 10 percent solutions for strawberry (Sari et al., 2020) to 100 mL per liter for sweet corn (Anatolana et al., 2024) and 10 to 40 tonnes per hectare for raw peel on soil (La Andi et al., 2023),

and these optima are not yet connected by a common framework of nutrient analysis. Fourth, enrichment strategies, including co-composting with manures and legumes (Ultra et al., 2005; Juliastuti et al., 2017), bio activator selection (Juliastuti et al., 2017), and nano formulation (Hussein et al., 2019), deserve systematic comparison so that practitioners can match the formulation to the nutrient gap they need to fill. Finally, integration studies that position banana peel fertilizer within circular bioeconomy systems for the banana value chain would connect the agronomic evidence with waste management policy (Bishnoi et al., 2023).

CONCLUSION

The peer reviewed literature reviewed here supports a clear conclusion: banana peel is a legitimate raw material for organic fertilizer. Its high potassium content and organic matter improve soil physical and chemical properties, including porosity, organic carbon, water content, and aggregate stability (La Andi et al., 2023; Teshome, 2022), and its use as compost, dried powder, liquid organic fertilizer, biochar, or nano fertilizer has supported the growth and yield of sweet corn, strawberry, eggplant, tomato, pakchoy, soybean, Swiss chard, water spinach, and banana plantlets, in several cases at levels statistically comparable to inorganic fertilizer (Anatolana et al., 2024; Hariyono et al., 2021; Nasir, 2021). The technology is accessible, ranging from simple drying and fermentation to pyrolysis and nano extraction, which allows adoption at scales from household gardens to commercial fields.

At the same time, the evidence base is not yet strong enough for unqualified recommendation. Nutrient concentration in finished products varies widely, raw peel can immobilize nitrogen and depress growth, and most trials stop at the seedling stage under controlled conditions (Elfarisna et al., 2024; Khanyile et al., 2024; Memon, 2012; Ultra et al., 2005). The realistic current position is that banana peel fertilizer is a proven complement to inorganic fertilizer and a promising partial substitute whose full potential awaits standardized production protocols, harvest stage field validation, and economic assessment. Given the scale of banana peel generation and the environmental cost of its disposal, closing those gaps is a research priority worth pursuing.

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