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Review

The Potential of Fermented Food from Southeast Asia as Biofertiliser

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Abstract: The intensive amount of chemical usage in agricultural practices could contribute to a significant impact on food safety issues and environmental health. Over-usage of chemical fertilisers may alter soil characteristics and contaminate water sources, leading to several human and animal health issues. Recently, there have been efforts to use microbial biofertilisers as a more sustainable and environmentally friendly agricultural practice in the common household of Southeast Asia. Traditionally, this method tends to utilise leftover food materials and readily available bacterial cultures, such as yoghurt drinks, and ferment them under a specific period in either solid or liquid form. So far, most of the testimonial-based feedbacks from local communities have been positive, but only limited information is available in the literature regarding the usage of biofertiliser fermented food (BFF). Previously, raw food waste has been used in the agriculture system to promote plant growth, however, the functional role of fermented food in enhancing plant growth have yet to be discovered. An understanding of the symbiotic relationship between fermented food and plants could be exploited to improve agricultural plant production more sustainably. Fermented food is known to be rich in good microbial flora (especially lactic acid bacteria (LAB)). LAB exist in different sources of fermented food and can act as a plant growth-promoting agent, improving the nutrient availability of food waste and other organic materials. Therefore, in this review, the potential use of seafood-based, plant-based, and animal-based fermented food as biofertiliser, especially from Southeast Asia, will be discussed based on their types and microbial and nutritional contents. The different types of fermented food provide a wide range of microbial flora for the enrichment of proteins, amino acids, vitamins, and minerals content in enhancing plant growth and overall development of the plant. The current advances of biofertiliser and practices of BFF will also be discussed in this review.

Keywords: fermented food; microorganisms; biofertilizer; agricultural; Southeast Asia

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1. Introduction

Currently, conventional farming employs the use of chemical fertilizers (also called inorganic, synthetic, artificial, or manufactured fertilizers) with defined chemical constituents as their main farming method. Chemical fertilizers usually consist of synthetic components of phosphorous, potassium and nitrogen to enhance plant yield and protection from diseases [1]. This type of fertiliser is often sourced from petroleum products, rocks, or certain organic sources and mixed with chemical fillers according to specific formulations. As it is in its pure form, the nutrients can be rapidly released into the plants only days after application. Due to its mass production from cheap sources, they are widely available at a minimal cost. However, the excessive use of chemical fertilisers is often associated with negative side effects, especially when used in excess. Overuse may lead to long term damage to the physicochemical characteristics of the soil [2], soil acidification [3], and groundwater contamination [4]. Additionally, rain may cause the nutrients to be washed away to other water sources, resulting in algal blooms (eutrophication). Moreover, reports have shown that mishandling of chemical fertilisers can jeopardise the quality of health among farmers [5] and consumers [6–8]. In terms of emission, chemical fertilisers are the significant contributor of greenhouse gases in agriculture [9], which could be offset by the use of biofertiliser [10].

Biofertilisers can be defined as a substance that contains different microorganisms which can break down organic waste into usable, beneficial soluble substances such as amino acids, sugars, alcohols and hormones [11]. Despite the lower cost and uniformity of using chemical fertilisers, biofertilisers are much better at retaining or enriching the soil, and reducing water pollution [12–16]. Additionally, the application of a biofertiliser can help to maintain the natural habitat of the soil, protect against soil-borne disease, and improve crop yields by up to 30% [17,18]. However, standardised inoculation techniques are one of the major constraints, as there is no uniform technique for the production of biofertilisers. This is due to the fact that their quality differs in effectiveness when applied in field and laboratories [19]. Unpredictable environmental conditions, inconsistent performance, plant species, soil type, inoculum density, and native microbial flora can also influence the performance of biofertiliser [20]. Fertigation using biofertiliser fermented food (BFF) has also been trialled in modern agriculture systems such as soilless farms, glasshouse production, and hydroponics [21].

Recently, there has been a trend in typical Southeast Asian households to develop their BFF. This practice is mostly pioneered by the Thai people, who for decades, have fermented food wastes such as eggshell, onion skin, and banana skin after washing the leaves, seeds, roots and soil of their plant with encouraging results [22]. This practice is similar to composting except that the food materials are degraded in either solid or liquid form, meaning its application can occur by both soil or foliar feeding [23]. According to Sairi et al.and Man et al., these practices have proven to be effective, and thus there are possibilities that traditional fermented foods which are rich in microorganisms could confer similar effects on the growth of plants [24,25]. Other studies have also demonstrated the positive growth effect of BFF on vegetables such as *Phaseolus radiatus* L. (mung bean) [26], *Lactuca sativa* L. (lettuce) [27], *Brassica rapa* (mustard) [28] and *Ipomoea reptans Poir* (water spinach) [29]. This is due to the fact that a wide range of microorganisms have the ability to enhance growth, resource acquisition, immunity, and overall development [17,30–32]. Furthermore, as the substrate of BFF typically involves rich carbon, nitrogen, and micronutrient sources, these properties could provide additional nutrients to the plant and soil (Figure 1).

BFF is not restricted to southeast Asia only but can be implemented in other parts of the world due to the easy availability of fermented food everywhere. Fermented food which is mainly composed of good microbial flora helps in promoting plant growth or seed germination [32,33]. Different countries have different varieties of fermented food that can be utilized as BFF. For instance, there are stink head fermented fish (tepa) in the USA, fermented green cabbage (sauerkraut) in Germany, fermented walrus (igunaq) in Canada, and fermented sausage in Greece and Italy [34,35]. According to Brahmaprakash and Sahu, BFF is a low-cost technology with a high cost-benefit ratio. Given that BFF is sourced from local households, investments and supply costs may be even more feasible [18]. As such, interest in BFF, microbial cultures, and products to maintain and improve chemical-free growth environments, is predicted to become an increasingly common commercial practice in the future [36].

Numerous studies have been carried out on the utilization of raw food waste for plant growth development. Ellyzatul et al. [37], Rosewitawati et al. [38], Sairi et al. [24], and Wazir et al. [39] utilized fish waste, banana hump, fruit waste, rice after-wash water, banana peels and eggshell, to apply directly to plants. The microbial flora from raw food waste proved to enhance plant growth [37]. However, the amount of microbial flora from raw food waste could still be very low and might not be unsuitable [40]. Meanwhile, many studies involve composting and the utilization of effective microbe (EM) in composting [33,41]. However, composting requires a long time [41] and cannot be applied as a foliar treatment while the utilisation of EM as a starter culture might not be feasible for the community to practice in their home. EM, however, consist of LAB which also exist largely in fermented food [33,35]. The user-friendly, readily accessible fermented food and the presence of good microbial flora (especially LAB) in fermented food indicates its good potential as biofertilizer. To date, no studies have analysed the potential of fermented food as biofertiliser in substituting effective microbe (EM) or chemical fertiliser. Therefore, the current review aims to reveal the potential of different types of fermented food particularly from Southeast Asia as a biofertiliser. Moreover, the combined empirical evidence from agricultural application paired with a growing body of scientific evidence makes a convincing case for the utilisation of BFF in enhancing plant growth development. There is great potential to use fermented food as biofertiliser.

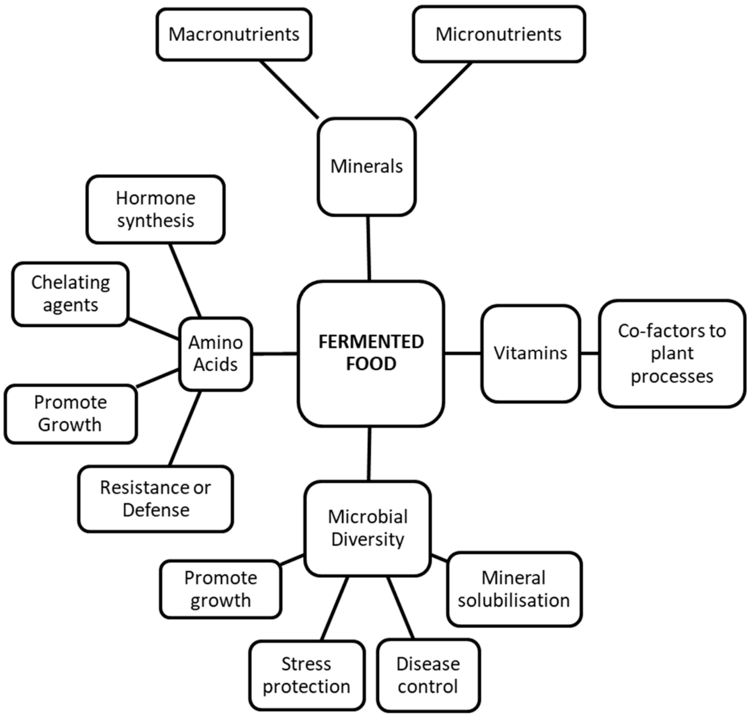

Figure 1. Possible mechanisms of plant-promoting features of fermented food. Fermented foods contain a rich amount of free amino acids [42], vitamins [43], minerals [44], and microorganisms [45] that are essential for plant growth.

2. Current Advances of Biofertilizer and Future Directions

Most of the current advances focus on the utilization of food waste, compost or microbe in promoting plant growth (Table 1). Although these approaches give good results, there are some drawbacks (such as the use of chemicals, polluting the environment, requiring pre-treatment, and taking a long time). Anaerobic digestion (AD) requires pre-digestion source separation methods to prevent organic contaminants from entering the AD system. Aerobic composting requires the adding of a bulking agent due to the high water content of food waste. Thereby, it requires quite a long time to complete the process. The chemical hydrolysis method utilizes chemicals to treat organic waste. The utilization of agriculture residue requires adding microorganisms to increase the degradation power. Lastly, direct burning crop residues cause soil erosion, air pollution, and soil organic matter loss [41].

Table 1. Current practices and advances of biofertilizer.

Current Biofertiliser Practice	Outcome	References
Fish waste	Increase vine length, number of leaves, chlorophyll content (SPAD), stomatal conductance, number of flowers, number of fruit, the weight of individual fruit, leaf chlorophyll content, carotenoids, TSS content and chlorophyll fluorescence	[37]
Eggshell powder, wood ash, banana peel, used tea waste, eggshell tea	Give the minimum average number of days to germinate, contribute to greater plant height and higher average leaf area, give a positive effect on the overall growth of pea plant, show a positive effect on yield and cause larger tubers	[39]
Efficient microorganism (EM) compost	Increase flower number and pigment content of plant and improve soil enzyme activities, reduction of the presence of pathogenic strains	[33]
Anaerobic digestion (AD)	Generation of biogas, biofertiliser, compost and soil conditioner, increase nutrient contents and promote nutritional value of biofertiliser	[41]
Aerobic composting	Generation of soil conditioner such as fertiliser, reduce pathogens and control germination of weeds	[41]
Agriculture residues (Direct returning to soil)	Release nutrients during decomposition of soil microorganisms and the nutrients are transported back to the soil directly or stored in soil microbes as efficient long-term nutrient sources	[41]
Direct burning crop residues	Directing some nutrient values of straw to the soil. Mineral elements, such as potassium exists in ash, which is then used as fertiliser	[41]
Food waste chemical hydrolysis	Contain nitrogen, phosphorus and potassium. Increased growth and productivity and reduced plant disease	[41]

The utilization of BFF takes advantage of food waste and microbe but in a more green approach and in its liquid form which can be used via foliar feed as well as a soil amendment. Beneficial microbe enriched in BFF includes lactic acid bacteria (LAB) which is one of the microbial flora composed in effective microbes (EM) [33]. LAB play a role as a biostimulant, biodecomposer and biocontrol agent for plant growth [32]. Therefore, fermented food is chosen due to the availability and enrichment of good microbial flora (especially LAB) [34,35,46]. Further discussion on the utilization of fermented food which consists of microbial flora, nutrients, and vitamins in enhancing plant growth has been carried out. This approach as well reduces the amount of food wastage and replace chemical utilization with green technology that support Sustainable Development Goals (SDGs) of the 2030 United Nations Agenda to achieve sustainability.

3. Seafood-Based Biofertiliser

Seafood-based items are an excellent candidate for BFF development. They are typically rich in protein or nitrogen and natural microbial flora which can be an excellent stimulator for plant growth [47]. Additionally, the degradation of carbohydrate or protein by microorganisms may lead to the production of beneficial bioactive compounds for the plant.

Table 2 summarizes the potential of selected seafood-based items that could be converted to BFF. Plants require nitrogen as their major nutrient especially for chlorophyll and leaf development [48], which is supplied primarily by ammonia in chemical fertiliser. In the case of a seafood-based biofertiliser, this component could be provided by degradation or putrefaction of seafood materials [49]. Furthermore, the degradation of protein-rich seafood could release beneficial amino acids into the soil, a trait that is often lacking in chemical fertilisers. In particular, seafood contains high levels of aspartate, arginine, leucine, lysine and glutamate [50], which can act as a biostimulant, metal ion chelators, cellular reactions, stress and others [23,51–53]. For example, *Budu* (Fisal et al., 2019) and *Balao balao* [54] is rich in amino acids including lysine and leucine which are essential for the cellular synthesis of enzymes, chlorophyll, DNA and RNA in plants [48]. In *Belacan*, the presence of proline, glutamate, tryptophan, methionine, alanine and many other amino acids can regulate growth, plant stress, pollen fertility, water balance protein synthesis, phytohormone and plant resistance [23,42,55]. These fermented products are usually higher in soluble amino acids and smaller peptide chains due to the protein-degrading action by the seafood and microbial protease, which will assist in plant nutrient availability. For example, after 10 days of *Balao balao* fermentation, soluble nitrogen, amino nitrogen and ammonia nitrogen increased from 6.19 to 11.07 mg/g, 1.67 to 5.03 mg/g and 0.25 to 1.29 mg/g respectively [56], while protein content in *patis* and *bagoong* can increase by up to 10% [54]. In a laboratory setting, *Arabidopsis thaliana* and *Hakea activities* were even shown to absorb dipeptide, tripeptide and oligosaccharides as nutrients [57,58].

Table 2. Physicochemical and microbial content of seafood-based product from (a) prawn and (b) fish from different countries in Southeast Asia. Depending on the region, certain products can either use fish or prawn as their substrate.

Types	Typical Amino Acid (>1 mg/100 g)	Chemical Elements (>10 mg/100 g)	Country of Origin	Fermented Food	Typical Microbial Content
Prawn/shrimp	Glu, Asp, Arg, Lys, Leu, Gly, Ala [59]	P, K, N, Ca, Mg [59,60]	Malaysia	*Cencalok*	*Lactobacillus* and *Pediococcus* sp. [61]
				Belacan	*Bacillus*, *Pediococcus*, *Lactobacillus*, *Micrococcus*, *Sarcina*, *Clostridium*, *Brevibacterium*, *Flavobacterium*, *Corynebacteria* [62]
			Philippines	*Balao balao*	*Leuconostoc*, *Pediococcus*, *Lactobacillus Enterococcus* [63]
				Bagoong	*Bacillus*, *Micrococcus*, *Lactobacillus* and *Staphylococcus* [54]
			Indonesia	*Bakasang*	*Pseudomonas*, *Enterobacter*, *Moraxella*, *Micrococcus*, *Streptococcus*, *Lactobacillus*, *Pseudomonas*, *Moraxella*, *Staphylococcus*, *Pediococcus* [64]
Fish	Pro, Arg, Lys, Ala, His, Glu, Tau [44,50]	K, Cl, S, P, Ca, N, Mg [44]	Philippines	*Burong isda*	*Pediococcus*, *Lactobacillus*, *Streptococcus*, *Micrococcus* [65]
				Patis	*Pediococcus*, *Micrococcus*, *Halobacterium*, *Halococcus*, *Bacillus* [66]
			Thailand	*Nam pla*	*Micrococcus.*, *Pediococcus*, *Staphylococcus.*, *Streptococcus.*, *Sarcina.*, *Bacillus.*, *Lactobacillus*, *Corynebacterium*, *Pseudomonas*, *Halococcus*, *Halobacterium* [67]
				Plaa-som	*Ped. cerevisiae*, *Lb. brevis*, *Staphylococcus* sp., *Bacillus* sp. [68]
			Myanmar	*Ngapi*	*Lactic acid bacteria, Clostridium, Halaanaerobium* [69]
			Indonesia	*Kecap Ikan*	*Bacillus*, *Flavobacterium*, *Cladosporium*, *Aspergillus*, *Caudida* [61]
				Peda	*Acinetobacter*, *Flavobacterium.*, *Cytophaga*, *Halobacterium.*, *Micrococcus*, *Staphylococcus*, *Corynebacterium* [61]
			Vietnam	*Nuoc Mam*	*Bacillus*, *Pseudomonas*, *Micrococcus*, *Staphylococcus*, *Halococcus*, *Halobacterium* [70]
			Malaysia	*Budu*	*Micrococcus*, *Staphylococcus*, *Lactobacillus*, *Pediococcus*, *Corynebacterium*, *Enterobacter*, *Saccharomyces*, *Candida* [71]

Values provided are approximate only. Seafood is typically rich in nutrients and can vary between different species, regions, seasonal changes, sexual maturity and food source.

Besides nitrogen, phosphorus and potassium are important macronutrients required by plants. Phosphorus is one of the most important elements involved in the process of biosynthesis, photosynthesis, respiration, signal transduction, and energy transfer, while potassium acts as a regulator of stomatal opening and closing to maintain water balance in the plant [72]. Both phosphorus and potassium can be found in high concentrations in fermented seafood-based BFF (Table 2). For example, fish can contain up to 190 mg/kg and 290 mg/kg of phosphorus and potassium, respectively [44], while prawn and shrimp consistently have phosphorus and potassium as their top two highest minerals [59,60]. This has also been reflected in their respective fermented products, such as *Bagoong* (which may contain up to 300 mg/100 g of phosphorus and potassium) [54]. As plants require around 2000 mg to 10,000 mg of these elements during their development stages (Itelima et al., 2018), periodical applications of BFF could supplement these nutrients that are lacking in the soil. Apart from those nutrients, seafood can also be rich in secondary nutrients for plants, such as calcium (hormonal activity), magnesium (chlorophyll and phosphorus regulator), and sulphur (enzymes, vitamins and seed formation) [44,73]. This can be observed in *Belacan*, which can contain up to 1400 mg/100 g of calcium and 190 mg/100 g of magnesium [55].

Perhaps the expensive cost of fresh seafood [74] makes it hard to justify its usage as a fertiliser. However, it should be noted that the product used for BFF production are leftover foods. Recently, due to the movement control order (MCO) in Malaysia, fishermen were forced to dump their excess fish stock at less than RM1/kg, which is equivalent to about 25c USD [75]. Although this cost is still expensive, the conversion to BFF would provide a solution for the unused or leftover seafood items and possibly compensate for some lost revenue for the fishermen during this tough period. According to the FAO (2018), around 28 million tonnes (35% per year) of fish and seafood are wasted annually, which represents a potentially significant source of BFF [76]. Additionally, the production of BFF is typically considered as a "stock solution", where further dilution can increase its volume and reduce the cost. Such an example is when fish can be fermented and commercially sold in three forms: fish meal, hydrolyzed meal, and fish emulsion.

The presence of suitable microorganisms such as *Bacillus* and lactic acid bacteria (LAB) in fermented seafood could improve soil quality by decreasing the incidence of disease, improving nutrients availability, providing biostimulants for plant growth and seed germination, and ensuring protection against abiotic stresses (this will be further discussed in the Plant-based biofertiliser section below) [32]. In particular, most seafood-based fermented foods are rich in *Micrococcus* sp., which is often reported to be a plant growth-promoting agent (Table 2) [12,77,78]. For example, Dastager S.G. (2010) et al. found that *Micrococcus* sp. could assist in phosphate solubilisation, auxin production, 1-aminocyclopropane-1-carboxylate deaminase activity, and siderophore production [77]. Other types of microorganisms present in fermented seafood products, such as *Pseudomonas*, *Enterobacter*, *Flavobacterium*, *Achromobacter*/*Moraxella*, and *Clostridium*, are an important source for bioprotectants against biotic and abiotic stress, mineral solubilisation, and siderophore production [12,79]. *Corynebacterium* and *Flavobacterium* have also been reported to possess nitrogen-fixing abilities and induce plant growth when tested against maize and wheat [80,81]. Additionally, *Acinetobacter* and *Staphylococcus* have been shown to act as phosphate solubilisers and nitrogen fixers in certain plants, and also act as an important soil microbiome [82,83].

Although fresh seafood materials contain various natural microorganisms, their amount of beneficial microorganisms could still be very low [84] and some of the presence of the microorganism might be unsuitable for plant growth. On the other hand, fermentation allows the enrichment of beneficial microbial flora, accompanied by a change in nutritional profile. A typical BFF from fish only requires effective microorganisms and two weeks for natural fermentation, which is simpler and achievable on large scale [85]. To further ensure the appropriate microorganisms are present, seed culture and appropriate carbon sources can be introduced during the fermentation process. Such an example can be seen following the traditional practice, whereby the leftover food is added with brown sugar and LAB from cultured drinks to allow for better BFF production [86].

Seafood-based fermented food can contain a large amount of fat or fatty acids, especially from fish. For example, different fish could contain as low as 1% to up to 30% of fat content [44]. Unfortunately, there is very limited literature regarding the role of fat as a BFF. Due to the wide presence of fat in both the animal and plant kingdom, it is possible that certain fatty acids, either saturated, monounsaturated, or polyunsaturated could benefit plant growth and offers some protection. So far, it has been shown that fatty acids in food can be further converted via fermentation to beneficial plant compounds such as acetic acids, pyruvic acids, carbon dioxide, and others which will eventually be consumed by the plant [87]. However, no findings have ever shown the direct role of fatty acids to plant growth. Therefore, further research is needed to validate their role (if any).

4. Plant-Based Biofertiliser

Plant-based substrates are a very popular choice for BFF. Apart from being cheap and widely available, its preparation and application are simpler and akin to composting. Furthermore, similarly to seafood, the enforcement of quarantine measures due to COVID-19 has caused the price to plunge and large volumes to be dumped in landfills [88,89]. The most popular items used for fermentation include vegetables such as cabbage (kimchi, sauerkraut), tea (kombucha), local fruits such as durian (*tempoyak*) [90] and legumes such as soybean (*tempeh*, soy sauce, and *natto*) [91]. Typically, fermentation of vegetables will produce a diverse population of LAB, which are beneficial as biocontrol agents, nutrient solubilisation, and biostimulants. Previous studies have shown that fermented tea contains antipathogenic LAB, which are effective in preventing fungal diseases such as powdery mildew on a variety of crops including pumpkin, cucumber, watermelon, and gourd [32]. A study by Jangiam et al. [49], found that the height of Chinese cabbage can increase significantly when fermented food waste and fermented vegetables are applied as fertiliser.

Soybeans are one of the most used fermented legumes in Asia and possesses tremendous potential as a BFF (Table 3). Soybean production reached 340.1 million metric tons per year in 2018 [92]. *Sieng* (Cambodia/Laos) and *Thua Nao* (Thailand) contain a rich amount of *Bacillus* spp., similar to those of *natto* in Japan, which is vital in many plant processes (Table 3). Previous research has shown that *Bacillus* spp. can act as mineral solubilisation and mineralisation, a fungicide, induce systemic resistance and plant growth regulator, enhance growth, control soil pathogens, and inhibit mildew growth [12,93,94]. As with other fermented foods, the presence of fermenting microorganism helps to break the protein in soybean into simpler forms and in many circumstances, increase the amount of amino acids that could be beneficial for plant growth [95]. Furthermore, Lee, B. H. [96] and Nyoki and Ndakidemi [48] reported that fermentation of *Bacillus* sp. with soybean leads to significant increases in ammoniacal nitrogen, minerals (Fe, Mg, Ca, and K), and vitamins. This genus of bacteria is also known to be beneficial in breaking the calcium in soil by releasing urease [97].

One of the major differences with seafood-based fermentation is the bigger presence or use of yeast and fungi. In Malaysia and Indonesia, yeast (such as *Candida* spp. and *Saccharomyces* spp.) and fungi (such as *Rhizopus* spp. and *Aspergillus* spp.) are widely used in traditional plant fermented products such as *Tapai* (Malaysia), *Tauco* (Indonesia), *Peujeum* (Indonesia), *Tempeh* (Indonesia), and *Khao-mak* (Thailand) (Table 3). Certain fungi, including *Aspergillus*, *Rhizopus*, and *Mucor* spp., are capable of solubilising minerals, especially phosphate [98–101], while some of them act as a biocontrol agent towards other soil-borne fungi [102,103]. Similarly, yeast also plays a major role in influencing plant growth. For example, Baker's yeast (*S. cerevisiae*) found in *Khao-mak, Khanom-jeen* and *Idli*, has been linked to an increase in nitrogen and phosphorus in roots and shoots, increased root-to-shoot formation ratio, and stimulation of species-specific morphological changes in tomato and sugarcane plants [104]. The improvement could also be seen in other plant species, such as mustard [105], wheat, barley [106], and soybeans [107]. *Tapai Pulut*, *Tapai Ubi* and *Khao-mak* contain *Saccharomycopsis* sp., which is famously known for their ability as biocontrol agents via secretion of lytic enzymes and mycoparasitism [108]. *Candida* spp. found in *Tapai Ubi* and *Idli* may inhibit plant pathogen via secretion of antifungal enzymes, biofilm formation, high osmotolerance, induction of resistance in the plant/fruit, and direct parasitism of hyphae [108].

Another defining characteristic of plant-based fermentation is the presence of highly varied microflora of LAB, especially those involved in spontaneous fermentation. LAB mainly works as a biofertiliser by decomposing a variety of organic substances in *Tempoyak, Tauco, Sayur Asin, Puto Burong, Mustasa, Pak-gard-dong*, and *Idli* (Table 3). *Fructobacillus* spp. found in *tempoyak*, relatively new taxa, may work by detoxifying phenolic compounds and protect plants against environmental stressors, while more common ones such as *Lactobacillus plantarum* and *Lactobacillus brevis* are well known to stimulate germination, shoot, root, yield and height in radish [109], tomato [110], cucumber [110,111], wheat [112–114], and many others [115]. Furthermore, the presence of LAB as a plant microbiome, such as *Lactobacillus* spp. and *Leuconostoc* spp., on certain plants such as fruit, grain, vegetable, flowers, grasses, trees and vines suggest their important role in plant growth [115].

One of the major advantages of using fermented food as a biofertiliser instead of a chemical fertiliser is the presence of many vitamins from the substrate and its subsequent breakdown. For example, *tempoyak* contains appreciable quantities of vitamin C (co-factor to many plant processes), niacin (B3, important for metabolic processes), pantothenic acid (B5, lipid and secondary metabolite biosynthesis), and folic acid (B9, plant biosynthetic enzymes) [29,43,116]. Fermentation of soybean typically produces rich B-type vitamins including cobalamine (B12, important for certain aquatic plant) [43,117–119]. The use of vegetables as substrates, such as cabbage and leafy vegetables used in *Sayur asin*, *Dhamuoi* and *Pak-gard-dong*, has been shown to produce high amounts of vitamin C, folic acid (B9), and minerals such as Fe and Ca. This is also true for many seafood-based fermented foods, especially fish and shrimp [44]. Additionally, the bioconversion of sugars from the plant substrate by microorganisms has also been shown to produce beneficial substances for plant growth. In *Tapai* fermentation, the protein content of the substrate doubled to approximately 16% by the action of microorganisms [120], which is as great as BFF due to the possible increase in growth-inducing amino acids.

Table 3. Examples of plant-based fermented food in Southeast Asia with microbial flora and nutritional content.

Fermented Food	Country of Origin	Microbial Flora	Nutritional Content	Potential Nutrients for Plant Growth
Tempoyak (Durian paste)	Malaysia	*Bacillus, Acetobacter. Lb. plantarum, Lb. brevis, Fructobacillus durionis* [63,121]	Carbohydrate (27%), protein (2%), fat (5%) [116]	Rich in vitamins and minerals, particularly potassium (up to 15,000 mg/kg) [116]
Tapai pulut (Rice)	Malaysia	*Hansenula, Saccharomycopsis, Chlamydomucor, Rhizopus* [122]	Carbohydrate (21.5–31.1%), protein (16%) [122]	Increase in protein and amino acids, and vitamin B_1 [122]
Tapai ubi (Cassava)	Malaysia	*Saccharomycopsis, Chlamydomucor, Candida, Mucor* [122]	Protein (4%) [122]	Increase in protein and amino acids, and vitamin B_1 [122]
Tauco (Soybean)	Indonesia	*Aspergillus oryzae, Rhizopus oligosporus, R. oryzae, Lactobacillus, Hansenula, Zygosaccharomyces* [63,123]	Carbohydrate (22.2%), protein (11.4%), fat (5.5%) [124]	Hydrolysis of protein by fungi, increase in amino acids, particularly sodium glutamate [124]
Tempeh (Soybean)	Indonesia	*Rhizopus, Mucor, Aurebasidium, Geotrichum, Alternaria,* LAB [124]	Protein 18%, fat 10%, carbohydrate 3% [125]	Proteins are hydrolysed into peptides, amino acids and peptides. Presence of many vitamins and minerals [124]
Oncom(peanut)	Indonesia	*Rhizopus, Neurospora*	Carbohydrate 22%, protein 13%, fat 6% [124]	Hydrolysis of protein, increase in riboflavin, niacin and thiamine [124].
Sayur asin (mustard leaves, cabbage, coconut)	Indonesia	*Leuconostoc mesenteroides, Lb. plantarum, Lb. brevis, Lb. confuses, Ped. pentosaceus* [45]	Carbohydrate 4.5%, Protein 0.5%, Fat 2.5% (based on the vegetable used) [125]	Rich in vitamins and minerals [125]
Sieng (Soybean)	Cambodia/Laos	*Bacillus* [63]	14% carbohydrate, 18% protein, fat 11% [125]	Rich in Mg, Ca, Fe and Vitamin C [125]
Burong Mustasa (Mustard)	Philippines	*Lb. brevis, Ped. cerevisae* [45]	Carbohydrates 4% Protein 5% Total fat 1% [90]	Rich in vitamins and minerals [125]
Pak-gard-dong (Vegetable)	Thailand	*Lb. plantarum, Lb. brevis, Lb. cerevisae* [126]	Carbohydrate 4.5%, Protein 0.5%, Fat 2.5% (based on the vegetable used) (USDA, 2020)	Rich in vitamin B, C and minerals [90]

Table 3. *Cont.*

Fermented Food	Country of Origin	Microbial Flora	Nutritional Content	Potential Nutrients for Plant Growth
Thua nao (soybean)	Thailand	*Bacillus subtilis, B. pumilus, Lactobacillus* spp. [63]	14% carbohydrate, 18% protein, fat 11% [125]	Rich in Mg, Ca, Fe and Vitamin C [125]
Khao-mak, Khanom-jeen (Rice)	Thailand	*A. oryzae, S. cerevisae, Candida, Saccharomyces, Saccharomycopsis fibuligera, Amylomyces rouxii, Rhizopus, Mucor* [63,127]	38% carbohydrate, 3.11% protein, 0.35% fat [128]	Rich in vitamin B, Mg, P and Zn [128]
Idli (Rice)	Sri Lanka	*Leuconostoc mesenteroides, Pediococcus, Candida, Lactobacillus, Ent. faecalis, S. cerevisae, Debaryomyces* spp., *Tor. Holmii, Tor. candida* [63]	~7% carbohydrate, ~3% protein, 0.1% fat [129]	Increased in vitamin B, C and minerals and hydrolysis of proteins into amino acids [130]
Dhamuoi (Cabbage)	Vietnam	*Lb. fermentum, Lb. pentosus, Lb. plantarum, Ped. Pentosaceus, Lb. brevis, Lb. paracasei, Lb. pantheris, Ped. Acidilactici* [63]	Carbohydrates 5.8%, Protein 1.28% Fat 0.1% [90]	Rich in vitamin B, C and minerals [90]

5. Animal-Based Biofertilisers

The bulk of animal fermented products are from dairy sources, but there are also a few other meat-based fermented products such as sausages (dried, smoked, or simply fermented) [131]. A study by Medeiros et al. found that the application of fermented milk or uninoculated milk to leaves contributed to antifungal activity via proliferation of LAB [132]. Unfortunately, only very few fermented dairy and meat products originate from Southeast Asia, such as *Dahi* (Sri Lanka), *Dadih* (Indonesia/Malaysia), and *Sua Chua* (Vietnam) [45]. They are typically rich in LAB and macro- and micronutrients for plant growth, such as protein (nitrogen), amino acids, and minerals [45]. For fermented meat, the typical base being used is pork, such as *Nem Chua* (Vietnam), *Tocino* (Philippines), and *Nham* (Thailand) [63,133,134]. Their major microflora also consists of LABs [133] with a wide range of nutrients such as amino acids (>2 g/100 g—Glu, Asp, Leu, Lys), minerals (>200 mg/100 g—K, P), and vitamins (B and C) [125] that could be beneficial to plant growth.

6. Current Biofertiliser Fermented Food (BFF) Practice and Concluding Remark

Although the use of BFF has been widely practised in Southeast Asia, its mechanisms are still not fully understood until now. Such practices are known as MOL (*Mikroorganisma Lokal*) in Malaysia and Indonesia [135] usually involve the inoculation of microorganisms, presence of substrate, the addition of additional carbon sources and further incubation time to sustain to produce any beneficial compounds during the growth of the microorganism (Table 4). Particularly, the food waste or household waste and water will be added by any leftover fermented food that acts as a starter culture for the fermentation process. Molasses or brown sugar will be added to the formulation as a source of carbohydrate for the microbial flora to undergo the fermentation process [37].

Table 4. The basic practice of food-based fertiliser involving fermentation by local households in Southeast Asia.

Local Practice	Method of Preparation (Simplified)	Method of Application (s)	Intended Outcome (s)
Fish MOL or FAA (Fish Amino Acid)	Ferment fish pieces with an equal amount of brown sugar for a month. Open the container to release the gas every day. The compound should smell sweet and sour.	Dilute the stock solution 1 in 100. Apply to soil or leaves twice a week	To provide nitrogen and essential plant nutrients [136]
Vegetable MOL or FPJ (Fermented Plant Juice)	Ferment vegetable with an equal amount of brown sugar for a week.	Dilute the stock solution 1 in 100. Apply to soil or leaves twice a week	To increase yield, possibly by the action of LAB [32] and nutrients [43]
Fruit MOL or FFJ (Fermented Fruit Juice)	Ferment fruits (in this case, ripe banana) with an equal amount of brown sugar for a week.	Dilute the stock solution 1 in 100. Apply to soil or leaves twice a week	To increase flowering and fruiting, possibly by the presence of P and K [30,72]

As there is no proper previous literature, this list is obtained from the largest Malaysian local agricultural community on Facebook, which contains up to 500,000 members at the time of writing [136]. Many other variations are being practised, such as [137–139], depending on the creativity of the person.

Based on Table 4, the current practices of the local household correlate well with previous evidence demonstrating that fermented foods have strong potential as a BFF. As meat and dairy fermentation is uncommon and expensive, local communities rarely option for this substrate. Based on their practice, the use of fermented fish is beneficial in terms of its protein and amino acid content. Moreover, fermented vegetables provide vitamins while fermented fruits provide minerals. Additionally, the application of organic matters such as rice, eggshell, or household waste [24,140] were practiced in which all of these items underwent a fermentation process, resulting in the enrichment of microbial consortia and nutritional content for plant growth. Fermented food as discussed in this review consists of varieties of beneficial microbial flora, and in particular LAB depends on the sources.

The ability of LAB to degrade food waste and organic materials has improved the nutrient availability needed by the plant. LAB also play a role as a biostimulant, biodecomposer, and biocontrol agent in enhancing plant growth. Overall, fermented foods in Southeast Asia possess tremendous potential for the biofertiliser industry and further research is warranted based on the strong evidence provided.

Although the concept may seem unconventional for now, BFF is gaining traction as consumer and farmer preference for the use of natural-based products grows. The world population is on the rise, requiring increases in current food production volumes. A recent documentary by the renowned naturalist Sir David Attenborough painted a grim picture of the future [141]. Humans are overfishing global fish stocks by 30%, and up to 56% of mammal's biomass on earth is livestock. Food wastage is a global phenomenon, with landfills around the world reaching maximum capacity every day. BFF offers tremendous potential in alleviating this problem, enabling wastage to be utilised in a circular flow economy and contributing to more defined nutritional and microbial characteristics in comparison to traditional composting methods.

The major limitation in implementing BFF is developing effective and efficient formulations for applying BFF as biofertiliser. Since this is a brand-new approach, limited information is available regarding the optimum formulation such as the quantity of fermented food, the temperature and time for the fermentation process, and the frequency and amount of biofertiliser for the plant application. Another major constraint on the application of BFF is the effect of BFF on the environment. Saer et al. (2013) found there are four main gases possible emitted from feedstock decomposition which are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3). However, CO_2 emission from the degradation of organic material is considered biogenic and not included in the global warming potential [142]. Besides, studies show that fertilisation with the waste has a low amount of metals and the presence of heavy metals are from the fields and is not related to the biofertiliser process. Meanwhile, the issues of pollutants leaching into the groundwater such as nitrate can be overcome by balancing the C/N ratio with the crop requirement [143,144]. However, the information gathered is from composting studies since there are no studies for the effect of BFF application on the environment. In addition, further research is necessary to identify the optimum formulation for the application of BFF and the effect or long-term effect of repeated BFF application on the soil and environment.

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