

Biodegradation of poultry feather using *Streptomyces* sp. for nitrogen and its effect on growth and yield of okra

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Abstract

Purpose Improper management of poultry feather (PF) leads to various environmental problems. Biodegradation of PF using *Streptomyces* sp. was initiated to recover N because PF is rich in keratin protein which is difficult to break down.

Method PF was collected, washed, chopped, and was transferred to plastic pots (200 ml each containing 30g PF). *Streptomyces* sp. was cultured using selective media and transferred to plastic pot at different concentrations (0, 1, 2, 3, 4, and 5 ml broth) with three replications. PF was composted under this condition for 75 days. The poultry feather compost (PFC) was used as fertilizer to grow okra in a separate experiment in pots. Different rates (0, 153, 306, 460, 613, and 766 kg ha⁻¹) of PFC equivalent to 0, 50, 100, 150, 200, and 250 kg urea ha⁻¹ based on N content was applied. Inorganic N was applied at the recommended dose (150 kg urea ha⁻¹).

Results Both total and available N content increased significantly in PFC with increasing concentration of *Streptomyces* sp. broth in composting media. Maximum N (15.31% total; 1.51% available) was found when PF was treated with 4 and 5 ml of *Streptomyces* sp. broth. Considering the plant's agronomic attributes and fruit yield, the application of 460 kg ha⁻¹ PFC was found most suitable for growing okra.

Conclusion Composting of PF with *Streptomyces* sp. is a viable technique to recover N from PF. PFC can make N rich organic amendment and reduce the use of chemical fertilizer (urea) in the agricultural field.

Keywords Poultry feather, *Streptomyces* sp., Biodegradation, Nitrogen, Soil amendment

Introduction

Commercial poultry production is one of the evolving and important sectors that have been playing a very significant role in the reduction of poverty, malnutrition, and unemployment problems. The poultry industry has grown at more than 5% annually worldwide (FAO 2006). Within the last two decades, the rate is nearly 20% in Bangladesh (Islam et al. 2014). This industry generates a huge amount of wastes in the form of feathers, bones, blood, faecal excreta, bedding materials, remaining feed, departed chickens, damaged eggs, packing materials, poultry carrying materials, conveyer

belt, and cleaning systems (Kelleher et al. 2002). Feather is the major component (by-product) of these wastes (Zhao et al. 2012) that creates a severe solid waste disposal problem (Parkinson 1998; McGovern 2000; Acda 2010a). Each chicken contains up to 125 g of the feather (Han et al. 2012) and the ordinary amassing of this waste degree five million tons comprehensively (Han et al. 2012). Traditional disposal systems (burning and land burying) of PF are difficult and expensive (Nahm and Nahm 2004) which causes soil, water, and air pollution too (Acda 2010a). Occasionally, PF is used as the supplement of feed for livestock, but they are poor in quality and economically nonviable (Ekta and Rani 2012). PF is naturally resilient to deterioration and persists for decades (Acda 2010b) due to the presence of pure keratin protein which is an insoluble and highly durable protein (Karshan 1930; Schmidt 2001) but rich in N and S. PF contains 90% of keratin protein, 15–18% of N and 2–5% of S (Kornilowicz-Kowalska 1997; Onifade et al. 1998; Kunert 2000). Despite

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its resistance, keratinase enzymes can degrade keratin proficiently (Tamreihao et al. 2018). These keratinase enzymes are produced by some species of bacteria-especially *Microbacterium* sp. (Thys and Brandelli 2006), actinomycetes (Vasileva-Tonkova et al. 2009), *Bacillus* and *Streptomyces* (Williams et al. 1990), and by some keratinolytic Fungi (Yamamura et al. 2002). Keratinolytic actinomycetes (*Streptomyces* sp.) that grow in the soil can degrade PF (Bressollier et al. 1999; Tatineni et al. 2007; Yadav et al. 2011). So, composting with the inoculation of *Streptomyces* sp. might be a management approach of PF. This method may help to drop GHGs emission, to reduce soil and water pollution, and to produce nutrient-rich (high N) organic fertilizer. Bangladesh is a densely populated country and the country soils have been exposed to extensive use for cultivation to feed the high population. The physical, chemical and biological health of soils is deteriorating day by day due to intensive cultivation and excessive use of inorganic fertilizers leading to nutrient imbalance, soil and surface water contamination, and reduced crop yields (Widowati et al. 2012; Usman et al. 2015; Oshunsanya and Aliku 2016). The soil organic matter (SOM) status in Bangladesh is poor and getting worse day by day. Recent information showed that Bangladesh soils contain a very low amount of SOM and most of them contain less than 1.5% (SOM) and few soils contain even less than 1% SOM (FRG 2012). The N status of Bangladesh soils is quite low (0.091–0.18% based on the total N) due to the low level of SOM. The status of available P in Bangladesh soils is considered between low to medium. The K content in Bangladesh soil is not deficient except that of nonalluvial soils and the coastal saline soils. The deficiency of S is common in most soils of Bangladesh except in coastal saline soils, acid sulphate soils, and some acidic soils (Imamul Huq and Shoab 2013).

Compost has been used to improve the health of agricultural soils for hundreds of years. Composts generally represent a high organic matter (OM) medium containing all of the nutrients needed by plants. Composts have several advantages compared to plant and animal residues when applied to soils, such as reduced volume, slower mineralization rates and recycling of biosolid wastes (de Bertoldi et al. 1983; Bernal et al. 2009). Compost application improves the soil physical, chemical and biological characteristics, replenish SOM, and supply plant nutrients to the soils (Sanchez-Monedero et al. 2004; Tejada et al. 2009). Other beneficial effects

of composts include increasing water holding capacity and plant water availability (Farrell and Jones 2009), decreasing nutrients leaching (Gale et al. 2006; Hopperly et al. 2009), reducing erosion and evaporation and prevention of plant diseases (Arthur et al. 2011). Further, compost can act as a long-term slow-release fertilizer.

However, the attributes of compost vary widely depending on the diversity of compost feedstocks and composting procedure (de Bertoldi et al. 1983; Bernal et al. 2009). Most of the composts are quite nutrient lacking and must be amended with plant nutrients, particularly with available N. The beneficial effects of compost are only achieved when the nutrient composition of the compost is considerably higher than that of soil. Utilizing good quality compost in agriculture has the likely advantages of improving nutrient cycling, increasing soil quality and productivity, enhancing crop production and reducing the use of chemical or synthetic fertilizer as well as increasing the sustainability of agricultural production. So, PF as compost can act as a source of SOM and alternatives of inorganic N fertilizer.

Though there are various processes (traditional disposal systems such as burning and land burying; converting to protein hydrolysates by using of chemicals; making feed supplement for livestock by alkali hydrolysis and cooking under steam pressure) to manage PF, the consequences of these processes have some restrictions regarding product quality, cost proficiency, pollution, and environmental quality control (Kim and Patterson 2000). The present research work was aimed to study the biodegradation of PF using *Streptomyces* sp. to recover N and to use poultry feather compost (PFC) as organic fertilizer to grow okra.

Materials and methods

Poultry feather collection and processing

PF was collected from Gollamari slaughterhouses beside Khulna University, Bangladesh, and washed thoroughly to remove blood, flesh, or other wastes. It was then air-dried and chopped into small pieces.

Isolation of *Streptomyces* sp.

Peat soil was collected from the nearby area (N22°47.892'/E89°32.065') of Khulna University, Ban-

gladesh as a source of *Streptomyces* sp. Casein agar was used as the selective medium to grow the bacteria (Kuster and Williams 1964). 1.0g of peat soil was diluted into 100 ml of saline solution (physiological water-85% NaCl solution). Ten different dilutions (1:10, 1:100 to 1:10000000) were made using sterile saline solutions in a total volume of 10 ml. An aliquot of 0.1 ml of each diluted solution was plated on Casein agar as the selective medium for keratinolytic *Streptomyces* sp. Plates were incubated at 30°C for 72 hours. Visual observations of both morphological and microscopic characteristics were performed using light microscopy, acid-fastness, and Gram-stain properties. These colonies were grown again in a broth culture medium at five different concentrations. Broth culture medium was arranged uniquely except the hardening specialist agar (Table 1) and developed again on Petri plate for the counting of viable cells. The plate number 10^{-5} was taken because the number of colonies was 38 (in 1ml broth). Viable cells in 1 ml broth were counted by the following equation:

Count \times dilution factor = Microbes in sample plated;

$$38 \times 10^5 = 3.8 \times 10^6 \text{ cfu}$$

Taking the volume plated into consideration

$$38 \times 10^5 \times 10 = 3.8 \times 10^7 \text{ cfu ml}^{-1}$$

Table 1 Composition of broth culture

Ingredients	gL ⁻¹
Sodium caseinate	2.000
L-asparagine	0.100
Sodium propionate	4.000
Di-potassium phosphate	0.500
Magnesium sulfate	0.100
Ferrous sulfate	0.001

Compost preparation

30g PF was taken into plastic containers of 200-ml in size. Five different broth concentrations (1, 2, 3, 4, and 5 ml) along with control were applied as treatment with three replications for each concentration. Each container was opened at every 2 days interval to release the heat produced inside the container. After 75 days, compost samples from all the containers were collected and mixed thoroughly to get a composite sample and were analyzed for nutrients and minerals (Table 2). Analogous procedures were used for chemical analy-

ses of soil and PFC. pH and EC were determined by using a glass electrode pH meter and EC meter (D-54, Horiba, Japan), respectively (Jackson 1973). Total N was measured by the Micro-Kjeldahl method following H₂SO₄ acid digestion, as suggested by Jackson (Jackson 1973). Organic carbon was determined by the wet oxidation method using potassium dichromate and sulfuric acid system (Walkley and Black 1934). The other total nutrients, P and S by using a spectrophotometer (T60U, UV-visible spectrophotometer, PG Instruments Ltd), K by using flame photometer (PFP7 Flame Photometer, JENWAY), Ca, and Mg by titrimetric method, were measured by following the methods described in Imamul Huq and Alam (Imamul Huq and Alam 2005).

Table 2 Properties of prepared PFC and experimental soil

Parameters	PFC	Soil
pH	6.75	8.06
EC (dS m ⁻¹)	2.0	0.3
N (%)	15.61	1.29
P (%)	0.017	0.013
K (%)	2.16	0.43
S (%)	0.029	0.018
Ca (%)	0.40	0.09
Mg (%)	0.76	0.17
OC (%)	20.40	1.16

Soil sample collection and preparation

Soil samples were collected from the agricultural field behind Khulna University, Bangladesh (N22°48.104'/E89°31.907'). Then the samples were air-dried, hammered, and were screened through a 2-mm sieve (USDA 1951). This processed soil was used for plant growth. Nutrient and mineral contents of the soil have been presented in Table 2.

Test plant

Okra [*Abelmoschus esculentus* (L.) Moench] is a high yielding and nutritious vegetable that grows all the year round in Bangladesh. Okra was grown as a test plant to observe the effect of PFC as a source of N because N plays an important role in plant growth, fruit, seed, and quality development of okra (NIHORT 1985).

Experimental set-up

A pot experiment was carried out to evaluate the effect of PFC on growth and yield of okra. Based on total N content in PFC, five different rates viz. 153 kg ha⁻¹, 306 kg ha⁻¹, 460 kg ha⁻¹, 613 kg ha⁻¹ and 766 kg ha⁻¹, which were equivalent to 50, 100, 150, 200, and 250 kg urea ha⁻¹, respectively, were applied. Additionally, an inorganic source of N (urea) was applied at its recommended dose for the test plant (150 kg urea ha⁻¹) along with a control. There were twenty-one pots (324 cm² surface area and 21.5 cm depth each) of equal size containing 2.0 kg of soil in each pot. The required amount of PFC for respective treatments were mixed into the soil, regularly watered, and left for one week. Seeds of okra were soaked into water for 24 hours and 3 seeds were sown in each pot. Two weeks after seed germination, the plants were thinned keeping one healthy and strong plant in each pot. Visual symptoms were monitored carefully and noted throughout the growing period. During the growth period, the fungal attack was observed and controlled with GOLDAZIM 500SC using a trigger garden sprayer. Fruits were harvested at its maturity stage.

Data collection

Plant height (cm) at every 15 days interval after germination, date of first flowering, number of fruits per plant, fruit length (cm), fruit girth (cm), and fruit fresh weight (g) were measured and recorded.

Statistical analysis

The mean (n=3) data were subjected to proper statistical analysis. Statistical software program Minitab-18 was used for data analysis by employing the ANOVA technique. Differences between means were statistically analyzed using the Fisher method ($p < 0.05$).

Results and discussion

Identification of keratinolytic *Streptomyces* sp.

Colonies that grew on Casein agar were slow-growing, chalky, heaped, and folded. Besides, colonies possessed an earthy odour. A confirmatory identification to genus was based on acid-fastness, Gram-stain, and degradation of casein. Strains were acid-fast negative and Gram-stain positive. This result was in good agreement

with Taddei et al. (2006). However, reliable supra-generic classification was not possible using traditional approaches based upon a few morphological and physiological features of actinomycetes (Stackebrandt et al. 1983; Ludwig et al. 1992).

Nitrogen content of PFC

Both the total and available N content of PFC are presented in Table 3. The maximum N (total N, 15.41 ± 0.03% and available N, 1.51%) content was measured in the treatment of 4 ml *Streptomyces* sp. broth. The total N was significantly ($p < 0.05$) increased with an increasing rate of *Streptomyces* sp. broth application as compared to control. This might be due to the role of *Streptomyces* sp. in PF decomposition (Kansoh et al. 2009). This result is in good agreement with the results of other researchers (Williams et al. 1990; Bressollier et al. 1999; Tatineni et al. 2007; Vasileva-Tonkova et al. 2009). Only 4.0% of total N in PFC was reported when it was made through the traditional decomposition process (Joardar and Rahman 2018). The reason for high N content in this research is due to the degradation of keratin by keratinolytic microorganisms' nature (Bohacz 2017).

Table 3 Nitrogen content in PFC

Volume of <i>Streptomyces</i> sp. broth	Total N (%)	Available N (%)
0 ml	12.77±0.01 ^c	0.09
1 ml	14.59±0.24 ^b	0.14
2 ml	14.98±0.41 ^{ab}	0.36
3 ml	14.66±0.13 ^b	0.65
4 ml	15.41±0.03 ^a	1.51
5 ml	15.30±0.35 ^a	1.45

Results are the average value of three replications with standard deviation. Different letters indicate significant differences ($p < 0.05$)

Effects of PFC on okra

Visual observations

The visual growth of okra under PFC and urea application showed that the growth of plants was gradually increased with the increasing rate of PFC up to 460 kg ha⁻¹ then gradually decreased to 766 kg PFC ha⁻¹. The

maximum vegetative growth was observed at 460 kg ha⁻¹ PFC application than that of the recommended dose of (150 kg ha⁻¹) urea.

Plant height

The average plant height (cm) at different treatments is shown in Table 4. Statistical analysis of the results revealed that in the case of both PFC and urea application, plant height was significantly ($p < 0.05$) increased in all the treatments except 613 and 766 kg PFC ha⁻¹ as compared to control (Table 4). Application of PFC and urea influenced plant height variably from 15 days after sowing (DAS) to 75 DAS. Plant height at 15-75 DAS was highest in the treatment of 460 kg ha⁻¹ PFC application than other treatments. In the case of urea application (150 kg ha⁻¹), the plant height was also significantly ($p < 0.05$) higher than control but lower than 460 kg ha⁻¹ PFC application. Degradation of a feather by keratinase produced plant growth-promoting (PGP) compound (Rai and Mukherjee 2015). The improvement of plant height with increasing N rate could be due to increased uptake of N. These results are in accordance with Jasso-chaverria et al. (2005) that available N played a significant role in chlorophyll synthesis and photosynthesis process and carbon dioxide assimila-

tion that enhanced plant growth. It is known that N is the most limiting factor in crop production. Cole et al. (2008) also observed that crop productivity depended on the availability of N. Organic composts increase the N availability to plants because they have higher levels of nutrients, e.g. N, P, and higher amounts of OM that are easily available to plants (Taylor et al. 2003; Peyvast et al. 2007, 2008; Suthar 2008; Olfati et al. 2009; Shabani et al. 2011). Kasthuri et al. (2011) also reported that the application of compost to soil improved soil fertility which enhanced plant growth. El-Desuki et al. (2001) also stated that plant height was significantly increased by increasing the levels of PFC which support the present results found in the case of PFC application in okra. The positive effect of compost on plant height, plant growth, and yield are also reported (Abdel-Mawgoud 2006; Olaleye et al. 2008). On the other hand, excessive N in the 613 and 766 kg, PFC ha⁻¹ stunted the growth of plants from all 15-75 DAS than control. It has been found that when N application exceeds the nutritional demands of the plants, excessive N addition causes soil acidification, nutrient imbalance, and inorganic N toxicity, as well as a decline in plant growth (Li et al. 2018). Wolf (1999) also stated that excessive N resulted in lush plants with soft tissue and lateness in maturity.

Table 4 Effects of PFC, urea and time on plant height

Treatments (kg ha ⁻¹)	Plant height (cm)				
	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS
0	7.17(±1.04) ^{bc}	12.67(±1.16) ^{ab}	19.33(±3.21) ^{bc}	23.67(±5.03) ^{cd}	23.67(±5.03) ^{cd}
153	8.17(±1.26) ^{ab}	13.0(±2.65) ^{ab}	21.33(±6.66) ^{bc}	24.0(±5.20) ^{bcd}	24.0(±5.77) ^{bcd}
306	8.17(±0.29) ^{ab}	12.83(±1.89) ^{ab}	24.0(±2.0) ^{ab}	27.0(±2.65) ^{bc}	28.0(±2.65) ^{abc}
460	9.17(±0.76) ^a	17.67(±6.03) ^a	29.33(±4.04) ^a	35.33(±7.57) ^a	35.33(±7.50) ^a
613	6.83(±0.29) ^{bc}	10.83(±1.26) ^b	16.83(±3.75) ^c	18.77(±3.21) ^d	19.33(±2.08) ^d
766	6.17(±0.29) ^c	10.33(±1.16) ^b	17.5(±0.87) ^{bc}	17.0(±2.65) ^d	17.0(±2.65) ^d
Urea 150	9.0(±0.87) ^a	13.5(±3.50) ^{ab}	29.0(±3.61) ^a	31.67(±1.53) ^{ab}	31.67(±1.53) ^{ab}

Results are the average value of three replications with standard deviation. Different letters indicate significant differences ($p < 0.05$)

Days to the emergence of the first flower

First flowering was observed at 36 DAS in 460 kg ha⁻¹ PFC treated plants. Required days to flowering were found to decrease up to 460 kg PFC ha⁻¹, then it was increased. The statistical data (Table 5) indicated that

the interaction effect of N was significant. Early flowering in okra was initiated by N which encouraged the differentiation of bud. A similar finding was reported by Prabhu et al. (2002). This result is also in a good agreement with Blake and Harris (1960). However, Anwar et al. (2016) found that application of the N delayed

flowering. It was reported that barley and wheat flowering was accelerated by low N supply (von Denffer 1940). The delay in flowering that occurred in 613 and 766 kg PFC ha⁻¹ treated plants was probably due to the excessive nutrients that caused stress resulting in late flowering (Bk Birbal and Malik 1995).

Number of fruits per plant

Maximum numbers of fruit were recorded in plants treated with urea at 150 kg ha⁻¹ (Table 5). Though the

fruit number was increased with the increasing level of PFC application from the control, it was decreased beyond its recommended dose (460 kg PFC ha⁻¹). Similar findings of a higher number of fruits per plant by the integrated application of fertilizers have also been reported by Prabhu et al. (2003) in okra. Proper available N had a significant effect on the promising number of fruits reported by Phu (1996). Minimum numbers of fruits at its higher doses might be due to excessive nutrients (Li et al. 2018).

Table 5 Effects of PFC and urea on agronomic parameters of okra

Treatments (kg ha ⁻¹)	Days to 1 st Flowering	Fruit number	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)
0	44	2	9.57±0.51 ^a	4.82±0.38 ^{bc}	6.11±1.23 ^b
153	41	2	8.55±1.43 ^{ab}	5.02±0.89 ^{bc}	7.24±1.77 ^b
306	40	3	8.81±1.38 ^{ab}	5.07±0.08 ^{bc}	7.0±1.25 ^b
460	36	4	8.17±0.59 ^{ab}	6.12±0.22 ^a	10.52±1.58 ^a
613	52	2	7.47±0.92 ^b	5.45±0.57 ^{ab}	6.46±1.51 ^b
766	51	2	8.0±0.86 ^{ab}	4.46±0.14 ^c	5.74±0.79 ^b
Urea	150	5	8.43±0.56 ^{ab}	4.89±0.45 ^{bc}	7.58±0.53 ^b

Results are the average value of three replications with standard deviation. Different letters indicate significant differences ($p < 0.05$)

Fruit length and girth (cm)

The longest fruit was recorded at the control plants than any other treatment but it was statistically insignificant except in the case of 613 kg PFC ha⁻¹ application. The maximum fruit girth was found at 460 kg PFC ha⁻¹ which was significantly higher than others and the lowest girth of okra fruits was found in the application of 766 kg PFC ha⁻¹. A higher value in fruit girth of okra observed might be due to the integrated application of PFC. Similar findings were reported by Naidu et al. (2000). Excess N affects fruit quality such as length, girth (Gerendás et al. 1997).

Fresh fruit weight (gm)

The maximum average fruit weight was measured at 460 kg ha⁻¹ PFC treated plant which was significantly higher than other treatments as well as inorganic fertilizer (urea) (Table 5). The fruit yield noted under 460 kg PFC ha⁻¹ (equal to 150 kg urea ha⁻¹) was 1.72 times higher

than control and 1.40 times higher than urea. However, increased PFC application (higher N) up to 766 kg PFC ha⁻¹ did not result further increase in fruit yield over the application of 460 kg PFC ha⁻¹. This result is in agreement with Talukder et al. (1999) and Verma and Batra (2001) who reported that the application of 100 kg and 150 kg N ha⁻¹, respectively, resulted in the highest fruit yield. But the result is opposite to the findings of Paliwal et al. (1999) and Rahman et al. (1992). However, Natarajan (2007) and Sreenivasa et al. (2009) also stated that organic fertilizers comprise various macro- and micro-nutrients, vitamins, growth-promoting factors indole 3-acetic acid (IAA), gibberellic acid (GA), and beneficial microorganisms, which rise production in such ways that are similar to inorganic fertilizers (Bulluck and Ristaino 2002; Arancon et al. 2004; Heeb et al. 2006; Liu et al. 2007; Tonfack et al. 2009; Maske et al. 2015). The maximum weight occurred may be due to enlarged photosynthetic area and translocation of photosynthates in plants which later enhanced the formation of numbers of large-sized fruits increasing fruit

weight (Mal et al. 2013). Jayapandi and Balakrishnan (1990) reported that characters like days to flowering, plant height, fruit length, fruit weight, and fruits per plant were significantly and positively correlated with the yield. These findings supported the yield results found in the case of PFC application in okra. Shaikh (2005) found that organic or biofertilizers reduced the application of 75% of the recommended dose of N and P fertilizers. Similar results were reported earlier by Jha and Mathur (1993). However, as expected the lowest weight (5.74 ± 0.79 g) was recorded in 766 kg PFC ha⁻¹ that is beyond the recommended dose. This might be due to the excess N that caused stress to other nutrients availability. Excess N reduced fruit production, delayed in production, and resulted in toxicity (Omotoso and Akinrinde 2013). Sharifi et al. (2011) also found that excess N that gathers in the soil may result in a reduction in yield.

Conclusion

Intensive agriculture, mismanagement and unnecessary use of chemical fertilizers in agricultural soil lead to depletion of nutrients and loss of SOM. It has adversarial effects on the environment and can threaten food value and safety. Organic amendments like compost and manure are considered a lucrative and environmentally-friendly alternative as a source of nutrients and SOM. Due to poor management, poultry waste especially feathers have become one of the major pollutants. This PF can be converted into valuable N-rich organic fertilizer for being a rich source of keratin proteins and amino acids. Traditional degradation methods of PF waste reduce the overall quality of proteins and destroy essential amino acids. An alternative method of PF waste degradation was initiated by *Streptomyces* sp. to recover N from keratin proteins and amino acids. 75 days long biological treatment by *Streptomyces* sp. resulted in N recovery of 15.41% (total), and 1.51% (available) which was 15 times higher than untreated feathers. Both total and available N was found to be significantly higher after treating with *Streptomyces* sp. than control. In this method, the maximum total and available N was found when PFC was treated with a higher level of (4 and 5 ml) *Streptomyces* broth. Visual observations and experimental results revealed that growth and yield of okra were increased significantly when treated with PFC (460 kg ha⁻¹) than control. The N content in 460 kg ha⁻¹ PFC is equal to the N content in

150 kg ha⁻¹ urea fertilizer which is recommended as the best dose for the growth and yield of okra. PFC could be an alternative source of N if properly managed through decomposition by *Streptomyces* sp. This approach will be helpful for sustainable agriculture which would ultimately reduce the use of inorganic fertilizer (urea) and will also help to attain food security. The present composting system for keratin-rich PF through biological degradation for N recovery might be an efficient, cost-effective, and environmental-friendly method for bioconversion of PF waste into useful organic products.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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