Disposable Diapers Home-scale Composting Enhanced by *Spirulina Platensis* and Its Utilization As a Growing Medium for Maize and Cayenne Pepper

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Research

Keywords: composting, disposable diapers, phytotoxicity tests, *Spirulina platensis*

Posted Date: May 5th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-466350/v1>

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1 Disposable diapers home-scale composting enhanced by
2 *Spirulina platensis* and its utilization as a growing medium for
3 maize and cayenne pepper

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9

10 **Abstract**

11 Disposable diaper waste harms the environment and human health. Composting has
12 gained attention for diaper waste recovery because of cost-effectiveness and wastes
13 conversion into value-added products. Cyanobacteria advantages over other
14 microorganisms to enhance the disposable diapers composting has studied. This
15 research aimed to determine the affection of *Spirulina platensis*, which is one of the
16 Cyanobacteria species, in the diapers composting. Given the complexity of separating
17 materials, the process involves all parts of disposable diapers. The reactor volume is
18 30 litres, made of clear plastic to allow *Spirulina* absorbs light to carry out
19 photosynthesis. A total of 3 kg of disposable diapers composted together with 7 kg of
20 food waste, 250 grams of rice husks as a bulking agent, and pure culture of *S.*
21 *platensis* with various density: 1.5, 3.0, 6.0 million of sinusoids. All composting
22 reactors operated in triplicates. The parameters analyzed were organic Carbon, Total
23 Nitrogen, C / N ratio, moisture content, pH, and temperature. After a 6-week
24 composting process, compost with the 6.0 million sinusoids attained the highest
25 degradation rate and the total nitrogen 47% higher than the control. The final compost
26 had good quality and accomplished the limits set in the national regulation. It can be

used as a growing medium, as shown in the phytotoxicity tests performed using maize and cayenne pepper. It is a feasible and affordable option for the valorization of disposable diapers, which can apply on a small or home-scale by the community.

Keywords: composting; disposable diapers; phytotoxicity tests; *Spirulina platensis*

1. Introduction

A kind of waste that cause the problem almost all over the world is disposable diapers, which can be in baby diapers, sanitary napkins, personal care wipes, and adult incontinence products. The use of disposable diapers is inevitable in human life today. This product contributes to economic development and community welfare. Also, better hygiene, skin protection, comfort and convenience in human life in general. While this also poses significant problems for the environment compared to cloth diapers in terms of resource consumption, increased waste generation, environmental pollution, greater energy use, and harmful risk to human health from its waste, many people still use disposable diapers ([1](#)). Disposable diaper waste composition consists of 88% human excreta in the form of urine (74%), followed by faeces (14%), then the diaper material itself (12%) that is Cellulose, Super Absorbent

44 Polymer (SAP), Polypropylene (PP), Low-Density Polyethylene (LDPE), and others
45 (2). The improper handling of diaper waste endangers the environment and human
46 health.

47 In almost all developing countries where the waste management system is
48 inadequate compared to waste generates, processing diaper waste easily at affordable
49 costs and providing direct benefits to people lives is meaningful. Composting is a
50 promising method to treat diaper waste for the following reasons. Composting
51 reduces organic waste with cost-effectiveness and wastes conversion into value-added
52 products, namely compost. Composting restoring valuable nutrients such as nitrogen
53 and phosphorus from human waste as the main components of organic fertilizers (3).
54 The application of fertilizers resulting from SAP recovery can increase water
55 retention in soil (4). In terms of LDPE and PP contain in diapers, degradation of
56 plastic by microbes is one of the eco-friendly and innovative methods even though no
57 protocol has developed yet to biodegrade polyethylene on a commercial scale (5).

58 Some research has studied disposable diapers composting. However, some issues
59 remain to address, such as a long time duration of 60-106 days. While the waste
60 generated every day, a long composting will require a large area of land. The

61 pathogens, undecomposed plastic polymers, the lack of data about compost
62 application was also challenges in composting diapers. According to the prior study,
63 the advantages of diaper composting at home-scale and the possibility of
64 cyanobacteria utilization to enhance it has discovered (6). Enhanced composting
65 performance could mean better organic matter degradation, faster stability time (7),
66 and reduce nitrogen loss (8).

67 In this study, *Spirulina platensis*, as one of the cyanobacteria species, was chosen
68 as a microbial agent because of several advantages studied previously, in addition to
69 nitrogen fixation, such as: can live in a wide-range natural habitat, including in
70 aerobic composting conditions (9), proven utilization as a biocontrol agent because of
71 the higher phenol and polysaccharide concentrations compared to other cyanobacteria
72 strains (10), as inoculants (11), absorb DDT and possibly other organochlorine
73 pesticides (12), can grow and colonize on plastics which allows decomposing plastic
74 polymers, can remediate heavy metals and various other pollutants (13), increase
75 nutrients in the soil (14) because it has a very high content of macro and
76 micronutrients (such as essential amino acids, proteins, lipids, vitamins, minerals and
77 antioxidants), and easy to cultivate (15), those *S. platensis* abilities make them a

78 significant microorganism for environmental and agricultural sustainability.

79 Co-composting considered a suitable method to face the problem in diapers
80 composting. Co-composting is composting more than one organic waste to give
81 advantages in the composting system ([16](#)). Food waste comprises the main fraction
82 (55%) of total municipal solid waste in developing countries. The environmental
83 impacts connect to food waste composting are emissions of greenhouse gases and
84 odours ([17](#)). Likewise, the disposal of agricultural wastes such as rice husk will
85 occupy huge lands and seriously threaten the environment because of the risk of
86 releasing nutrient, odorous and hazardous substances. However, from another view,
87 these wastes are valuable for soil erosion control and nutrient replenishment if
88 suitably treated before disposal ([18](#)). Disposable diapers co-composting with food
89 waste and agriculture waste is a potential way of dealing with waste generation. It
90 enables the production of compost with better quality while contributing to
91 sustainable waste management. Apart from the reasons for the diversity of
92 microorganisms, co-composting human excreta with food waste is rich in nutrients
93 ([19](#)).

94 So far, not many studies have reported on the diaper compost application. A few

of them is for mushroom cultivation of *Pleurotus ostreatus* (20,21) and tomato plants (22). What distinguishes this study from the previous ones is, all those three studies used the diapers containing urine only. While this study involves all parts of the diaper, include urine and faeces and an improving method through the *S. platensis* addition to maximize the composting process. It cuts composting time and enriches total nitrogen in the compost. There are no pathogenic bacteria detected in the compost, even though faeces is one of the compost feedstock. As the main challenges of using diapers containing human excreta in co-composting are the availability of pathogenic microorganisms in the slurry. So, this research proved that no need to worry about composting the diapers filled with faeces at home-scale, with simple equipment, then using the compost in the food resources provision.

This research focus is to determine *S. Platensis*' effect in enhancing the co-composting process. Also, to test the feasibility of compost resulted as a growing medium. Following the different formulation of the medium from the compost, it evaluated its performance in growing maize and cayenne pepper in the polybag. The germination index observed as an evaluation of the utilization of the compost for plant's growth. The findings of this study advocate the concept of recycling waste as a

valuable resource. While simultaneously serves as a promising alternative to the community concerning a healthy environment and income generation.

2. Materials and methods

The selection of composting additives, the equipment, and the operating procedures must consider the aspects of cost and ease of implementation. Although some additives, equipment and methods have proven to be successful in the composting process, if they are expensive and complicated to operate, it will be hard to apply by the community.

2.1. Materials

2.1.1.Composting process

The equipment used is knives to chop food waste; scissors to cut diaper waste; wooden stirrers to stir trash; scales to measure the mass of equipment and materials; Soil Tester to measure the temperature and pH of compost. Personal protective equipment, such as masks, gloves are used as protection from pathogens exposure when experimenting; 4 units of composting reactor as illustrated in [Figure 1](#).

Fig. 1. Composting reactor with lid and aeration pipe

Each reactor is assigned a number and description. The reactor capacity is 30 litres, made of thick and clear plastic to allow sunlight to enter because *Spirulina* requires sunlight to carry out photosynthesis. The moisture content removed through evaporation and leachate separation. For this reason, gauze is used for daily covering to facilitate the water evaporation from the compost pile but still avoid disturbing animals such as flies. The reactor also has a plastic lid so that composting applied in open or closed systems. The reactor cover used when a rainy day. Four PVC pipes with a diameter of $\frac{1}{2}$ " given holes along the pipe length, installed vertically in each reactor. The purpose is to circulate air in the composting system.

The raw material used is disposable baby diapers pants in various brands that contain both urine and faeces. Disposable baby diapers obtained from several households around the study site. And also from the Martopuro Waste Processing Site in Pasuruan Regency. Diaper waste chopped using scissors with a size of <5 cm. All parts of disposable diaper waste tested for composting.

The food waste consists of staple food, vegetables, fruit, side dishes and dairy product, such as rice, carrot, papaya, tofu, and milk. Rice husks as bulking agent obtained from rice fields in the Pasuruan Regency. Pure culture of *S. platensis* from the Center for Brackish Water Cultivation Fisheries (Balai Besar Perikanan Budidaya Air Payau or BBPBAP) in Jepara, Indonesia. The *S. platensis* cultivation in BBPBAP carried out with the initial culture density > 10,000 sinusoids/ml. The fertilizers used are Urea (80 ppm), SP-36 (40 ppm), ZA (20 ppm), EDTA (5 ppm), FeCl₃ (1 ppm) and vitamin B₁₂ (0.001 ppm). The culture process includes preparation of tools and materials, fertilization and inoculation of seeds to culture treatment. The culture medium prepared at a salinity of 15 ppt, and the incoming sunlight intensity was around 3000 lux (12 hours light: 12 hours dark). The density of *S. platensis* used was 60,000 sinusoids/ml in the exponential phase.

The materials used in each composter are 3 kg disposable baby diapers, food waste consisting of rice (1,4 kg), carrots (1,4 kg), tofu (1,4 kg), papaya (1,4 kg), milk (1,4 kg), and 250 g of rice husks. All the materials put into the reactors then stirred to make them homogeneous. The concentrations of *S. platensis* added at the initial stage as follows: R1 (0 ml, as control), R2 (25 ml or 1.5 million of sinusoids), R3 (50 ml or 3 million of sinusoids), and R4 (100 ml or 6 million of sinusoids).

2.1.2. Phytotoxicity test

Relate to the compost application, phytotoxicity-test carried out on the maize and cayenne pepper, kind of plants that people consume, and resistant to widespread environmental conditions. Those plants had been used in several previous studies to determine the effect of a pollutant on its growth. Some phytotoxicity testing procedures require the representatives of two classes of flowering plants, which is monocots and dicots ([23](#)). Cayenne pepper (*Capsicum Frutescent* L.) belongs to the Solanaceae family and represents dicot plants. Meanwhile, maize (*Zea mays* L.) is monocot plants and belongs to the Poaceae (Gramineae) family.

The preparation conducted independently by drying 20 maize kernels and 40

cayenne pepper, then soaked in water for 12 hours. It is to provide sufficient moisture and to determine the quality of the seed. This study only used the sunk ones. Other materials and equipment are as follows: Ten pieces of polybag measuring 10 x 20 cm, diaper compost from research results as much as 500 gr, and natural soil 500 gr.

2.2. *Methods*

2.2.1. *Composting process*

Research conducted in triplicates for 42 days in Pasuruan City, Indonesia. The process held not in laboratory condition but the house situation (home composting) with an in-vessel method by placing the composting reactor in the backyard. It is in a place that allows sunlight to enter into the reactor with no additional lighting at night. Light is a necessary growth factor for *S. platensis*, but lighting 24 hours a day not recommended. During the dark period, chemical reactions such as protein synthesis and respiration occur ([15](#)). Composting conducted under aerobic conditions, in which aeration required to control the environment needed for the growth of the aerobic microbial community ([24](#)). Aeration was carried out manually by agitating the compost every day beside the perforated pipes. This treatment aims to provide

sufficient oxygen and evaporate excess moisture, resulting in a higher rate of evaporation, faster drying of compost, as well as cooling of compost, preventing excessive methane emissions. At the end of the composting period, the final density of *Spirulina* was unmeasured.

Analysis of compost characteristics for moisture content using the Gravimetry method, C-Organic using the Kormier method, and Total N using the Kjeldahl method carried out at the Laboratory of the Faculty of Public Health, Airlangga University, Surabaya. While the analysis of *Escherichia coli* pathogens using the MPN method at the Regional Health Laboratory of the Health Service Pasuruan Regency. The pH and temperature observations used a soil tester by measuring at 3 points in 50% of the compost pile depth, which carried out every day (25). The characteristics test analyzed at the initial stage, then periodically every 5-6 days. All part of the highest degradation rate compost, not chopped, then tested for phytotoxicity.

2.2.2. Phytotoxicity test

The phytotoxicity test carried out using the 'Direct growth test' method for 21

214 days (26). Polybags filled with a growing medium made of compost and natural soil
 215 with a total weight of 100 grams per polybag (P). The composition of natural soil and
 216 compost are 100:0 (P1), 70:30 (P2), 50:50 (P3), 30:70 (P4), and 0:100 (P5). The sown
 217 seeds densities on the growing medium in polybag are four maize kernels and eight
 218 cayenne pepper seeds. Testing held by placing polybags unexposed to direct sunlight,
 219 protected from rain and adding water if needed. The best composition of growing
 220 medium for maize and cayenne pepper germination determine by observations and
 221 calculations carried out on the parameter: Relative Seed Germination (RSG), while on
 222 plant growth, root length is calculating to measure the Germination Index (GI) using
 223 the formula:

224

- 225 • Seed Germinated (SG):

$$226 \quad SG = \frac{\text{Number of normal sprouts}}{\text{Number of seeds planted}} \times 100 \% \quad (1)$$

- 227 • Relative Seed Germination (RSG):

$$228 \quad RSG = \frac{SG_{\text{sample}}}{SG_{\text{control}}} \times 100 \% \quad (2)$$

- 229 • Relative Root Length (L)

$$230 \quad L = \frac{\text{Average length of plant roots}_{\text{sample}}}{\text{Average length of plant roots}_{\text{control}}} \times 100 \% \quad (3)$$

- Germination index (GI)

$$GI = RSG \times L \quad (4)$$

2.2.3. Statistical analysis of the result

An ANOVA (Analysis of Variance) test performed to assess if the *S. platensis* inoculation affected the composting. Also, the effect of the diapers compost in the growing medium on germination and plant growth in the phytotoxicity test. Microsoft Excel version 14.0.4734.1000 by the data analysis feature used for that purpose.

3. Results and discussion

3.1. The characteristics of the compost material

The properties of the initial feedstock material and the compost illustrated in [Table 1](#). From the first day to the third day, a mesophilic phase occurred with a temperature range between 29.3–38.7 ° C. According to [\(16\)](#), the mesophilic phase lasts between 25–40 ° C for several hours to several days. In this phase, microorganisms adapt to the environment and degrade simple compounds, such as sugars, amino acids, and proteins.

The temperature increased on the fourth day to above 40 ° C, known as the thermophilic phase ([27](#)), in R1, R3, R4. It happened just one day, and then the temperature fluctuated and varied below 40 ° C, except at R1 that reached 42 ° C on the 8th day. In the thermophilic phase, there is the degradation of organic matter (polysaccharides, protein and fat) ([28](#)) and macromolecular compounds (hemicellulose, cellulose, and lignin) ([16,29](#)). Pathogens and weed seed destruction can effectively occur in this phase ([30](#)). The relatively short duration of the thermophilic phase, caused by the inactivation of the microorganism and the higher oxygen demand by aerobic microorganisms than supply oxygen ([31](#)). It can also attribute to the amount of raw material used in the composting experiment that only 10 kg per reactor. The size of the small-scale composting reactors cannot generate enough heat. In this condition, the compost pile temperature is almost the same or adjusts to the ambient temperature.

Starts from the fifth day, the temperature fluctuated below 40 ° C. It is called the cooling phase. For the last two days of composting, the heat in all reactors recorded at 28-29 ° C, which indicates that the compost has entered the maturation phase. The cooling phase characterized by low microbial activity and slow biological

processes associated with degradable organic substrates depletion. During this phase, the mesophilic microorganisms adapt and reappear after being inactive in the thermophilic phase and hydrolyzing the remaining cellulose and lignin material. Humification of the organic matter and maturation occurs. The longer this phase lasts, the greater the degree of humification (30). In this study, the average pH range of R2, R3, and R4 were 5.58, 5.39 and 5.63. Relate to the low pH, even though pH 9-11 is the optimum pH for Spirulina growth (15), these microorganisms can found in acidic environments with pH values lower than 5-6 because cyanobacteria can adapt to extreme stresses and environmental conditions quite well. However, it rarely happened (10). The temperature and pH changes during composting shown in Figure 2.

Humidity is a critical factor in decomposing because microorganisms need water to grow and carry out their activities (24). Composting material should not be too wet because it reduces the degree of porosity as air space, forms water logs, limits oxygen supply, and results in anaerobic fermentation. It stops the biological activity of composting in the form of metabolism, movement and transportation of nutrients.

Fig. 2. Temperature and pH during composting

The composting system should also not be too dry since it slows down microbial degradation. The optimum water content for biological activity during composting is between 50 and 60% by weight of compost (29), but as an exception, because there is cellulose in diaper waste, composting requires a higher water content to soften fibrous materials such as lignocellulose (32). The moisture content at the beginning of composting was 73.3 - 75%. The high water content in all reactors causes the movement of oxygen hampered because the compost pores are closed with water so that the process becomes anaerobic and produces odours, which smells like yeast at the beginning of the composting process. The water content at the final compost decreased to 49.7-52.1%, which indicates that the compost is mature and

300 stable ([33](#)).

301 Pathogens originating from human waste can be a problem in composting ([16](#)).

302 Since pathogens from organic waste used as compost raw materials can pose health

303 risks to humans and animals by causing outbreaks transmitted through contaminated

304 compost ([28](#)). Therefore, it is necessary to minimize this pathogenic problem because

305 the compost produced is expected to be rich in nutrients, biologically stable, free from

306 pathogens and weed seeds, thus can be used as a soil improvement material without

307 any restrictions. At the beginning of the study, *E. coli* detected in all reactors with

308 values >1600 MPN / g. This amount decreased on the 10th day for all reactors in the

309 value range <1.8 to 7.8, although the compost pile temperature in R2 did not reach

310 40 ° C. According to ([31](#)), the removal of pathogens requires temperatures above 55 °

311 C but can be damaged even at low temperatures in compost. On the 34th day, *E.*

312 *coli* increased to 350 MPN / g and 170 MPN / g at R1 and R4 while R2 and R3

313 remained at <1.8 MPN / g. This increase indicates that the previous decrease in the

314 number of *E. coli* does not mean that the bacteria have degraded but can also be due

315 to the bacteria becoming inactive during thermophilic conditions, then reactivating

316 when they enter a mesophilic state.

317 Removing or inactivating pathogens during composting is a complex combination
318 of accompanying factors that cause by heat production, microorganisms competition,
319 nutrient deficiencies, or high ammonia (NH₃) concentration (31). The composting
320 duration is an essential factor in pathogens removal, where the thermophilic phase
321 should last at least one week for complete elimination of pathogens and ensuring
322 maximum sanitary conditions for composting human waste (28). The increase in the *E.*
323 *coli* population in compost is closely related to the availability of digestible carbon
324 and low microbiological competitiveness at the mesophilic maturation stage (34). The
325 compost storage conditions also influence the pathogen regrowth phenomenon (35)
326 because composting facilities can be a significant source of aerosol pathogens (28). At
327 the end of the composting period, the *E. coli* concentration dropped for R1 and R4
328 into 79 and <1.8 MPN / g. It showed that the pathogen growth decline along with
329 the compost complete matured.

330 Composting microorganisms need C as an energy source and N to maintain and
331 develop cells, proteins, enzymes, and hormones (24). C / N ratio that is too high
332 indicates insufficient N for optimal microorganism growth so that decomposition
333 takes place slowly (32). A low C / N ratio will tend to produce excessive amounts of

334 NH₃ and volatile fatty acids, which lead to the release of unpleasant odours ([16](#)), and
335 a large number of dissolved base salt, thus making the soil unsuitable for growing
336 plants ([28](#)).

337 The initial C-Organic was around 63.2 - 63.3 and finished at 62.3 - 51.5. Total N
338 levels at the beginning of the study ranged from 2.11 to 2.12. R2, R3, and R4
339 experienced an increase in Total N by 16%, 19%, and 22%. While R1 decreased by
340 17%, indicating a loss of nitrogen in the compost pile. The C / N ratio was obtained
341 from the organic C content with the total N comparison, referring to several studies
342 that determined the C / N ratio in this way. Organic C are measured based on carbon
343 dioxide emissions released, or the rate of microbial respiration, while total N is
344 nitrogen in organic and inorganic forms ([30,33](#)).

345 At the first stage of the composting, the C / N ratio for all reactors was 29.86 and
346 29.95. It expected that composting run effectively since the optimal C / N ratio for
347 composting is around 25 to 30 ([24](#)). According to ([32](#)), the decomposition of organic
348 C will occur gradually along with the C / N ratio of the material decrease, as long as
349 N does not lose through gas emissions. R1 recorded an increasing C / N ratio because
350 total N continued depleting. While in R2, R3, and R4, a decrease in the C / N ratio

along with the increase in total N. At the end of the composting period, the lowest C / N ratio is in R4, which is 19.96, which indicates the compost is mature because the C / N ratio below 20 is accepted indicator for maturity. Figure 3 shows changes in Organic-C, Total N, and C / N Ratio during composting.

Fig. 3. Organic-C, Total N, and C / N Ratio during composting

3.2. Interparameter Relations

In the composting process, there is a relationship between parameters. The correlation coefficient calculated for that purposes. The correlation coefficient is a value that indicates whether or not a linear relationship is strong between two variables. The usual correlation coefficient denoted by the r-value that varies from -1

368 to +1. The r -values close to -1 or +1 indicate a strong relationship between the two
369 variables. While the r-value close to 0 determine a weak relationship between the two
370 variables. The + (positive) and - (negative) signs provide information about the
371 relationship between the two variables. If it is positive, the two variables have a
372 unidirectional relationship. In another sense, an increase in X will coincide with an
373 increase in Y and vice versa. If it is negative, it means that the correlation between the
374 two variables is opposite. An increase in X value, accompanied by a decrease in Y.

375 In R1, the moisture content appears to be related to Total N and the C / N ratio.
376 The Total N falls with water content decreasing. It appears that N released into the air
377 through emissions along with water evaporation. The decrease in Total N value is
378 closely related to the increase in the C / N ratio in R1, by a correlation value of -0.99.
379 R2, R3, R4 show a close relationship between temperature and E. coli, as previously
380 described from some literature on this subject. The decrease in C-Organic related to
381 the increase in Total N, by a correlation value of -0.98 in R2 and R3, and -0.99 in R4,
382 while Total N increasing accompanied by a decrease in the C / N ratio where the
383 relative coefficient values are -0.99. While the water content in R2, R3, and R4, when
384 connected to Total N, always shows the value - (negative). It means that the lower the

water content, the higher Total N. It is related to the ammonification process, where ammonia will react with water to form ammonium so that when the water content decreases, the Total N increases. The pH and temperature values together can influence the waste degradation process, but this study concludes that pH does not depend on temperature where the correlation coefficient value in all reactors for pH and temperature is closer to zero. The correlation coefficient for each reactor showed in [Table 2](#).

3.3. *Effect of S. platensis in composting*

ANOVA test with a P-value of 0,9999 showed that the water content in the composting of diaper waste was not affected by the addition of *S. platensis*. The perforated piping system and daily agitation reduced the moisture content in all reactors faster than in the previous study, where water content is at 53.1 - 58.76% on the 60th day of diapers composting ([36](#)).

In this study, the content of *E. coli* > 1600 MPN / g assumed to be 1650 MPN / g and <1.8 MPN / g to be 1.5 MPN / g so that calculations made for statistical analysis using the ANOVA method. The C-Organic and *E. coli* depletions in the composting

process with P-value 0,1358 and 0,9986 in the ANOVA test was unaffected by the addition of *S. platensis*. Co-composting between disposable diaper waste and food waste provides a diversity of microorganisms in the composting system, which is sufficient for the degradation of C-Organic and *E. coli*.

P-value of 0,0025 showed that the temperature influenced by *S. platensis*. Same as the temperature, P-value of 2,03E-13 showed that *S. platensis* affected pH in diaper composting. The low temperature and pH in this co-composting, if associated with cyanobacteria, is due to its ability to carry out nitrogen fixation.

In high water content composting containing *S. platensis*, even though the potential of formed NH_3 increases as a nitrogen fixation result, it will react with water to form NH_4 (ammonium). This ammonification process prevents NH_3 emissions from being released into the air. It is the reason the temperatures in the R2, R3, and R4 tend to be lower than R1 since NH_3 emissions did not occur.

The thermophilic phase followed by a maturation phase where nitrification occurs and converts NH_4 to nitrate (37). This process causes a decrease in the pH value (32). R2, R3, and R4 have higher nitrification potential than the control, which seen from the increases of total N during the composting process. That is why the pH value is

almost always lower than the pH of R1 that does not contain *Spirulina*. With plenty of Total N due to nitrogen fixation, the ANOVA test with a P-value of 0,0003 showed the effect of *S. platensis* inoculation on the C / N ratio in composting this diaper waste.

3.4. *Compost degradation rate*

The rate of degradation determined by the level of inactivation of microorganisms using the D value. It known as the Decimal reduction time. Determining the D value can be done by plotting the time (days) and the log N value of C-Organic (36). Likewise, not all inactivation described by a constant D-value. Some processes return inactivation curves with a profile similar to the inverse of a growth curve. In these curves, it is possible to define a shoulder (that is, the period before the number of living cells begins to decrease) where the cells had not received enough damage to start dying. When a critical amount of damage occurred, the inactivation phase began. Then a tail phase (that is, the period where no further reduction achieved). Not all curves exhibit all three stages. Sometimes only two are noticeable (38).

Overall, in cyanobacteria composting, all the parameters reached stable condition

after 18 days (39), and the organic matter reduced by 7.46% to 10.33% on the 24th day (8). Meanwhile, in this composting, until days 34, the curve showed the shoulders because, during this initial period, Spirulina need a couple of time to adapt to the composting environment before they do the waste degradation rapidly. The highest D value is R1, followed by R2, R3, and R4. It means a composting system in R4 has the fastest degradation rate compare to others. This profile described with the Exponential graph of Log N vs Composting Time seen in Figure 4.

Fig. 4. Log N vs Composting Time

The degradation was slow compared to other organic waste composting because cellulose, LDPE and PP polymers from disposable diaper waste were unseparated.

Composting cellulose is known to require a long time, in which the bioconversion process of lignocellulose under natural conditions is six months (24). Meanwhile, plastic polymers are unexpected material present in the composting system, apart from glass, metal, stone, and any other non-stone fragments > 2 mm, and weed seeds, which can negatively affect plant growth (27). However, in household-scale diaper composting, separating LDPE and PP polymers from disposable diaper waste is difficult because of the human waste that adheres to the diaper material. And disposing of plastic polymer material contaminated with human waste to the landfill will leave problems in terms of waste collection, transporting waste and handling plastics in the landfill, which requires costs and energy, also possibility of pathogen transmission.

3.5.Compost quality

The quality of compost largely determines the overall productivity in the waste degradation process. Maturity and stability are two critical parameters that assess compost quality. The term maturity validates the compost suitability for agricultural purposes, subject to biological and chemical effects. While the stability is indirectly

linked to microbial activity, judging the proper humidification of the organic fraction (32). Unstable or immature compost deliver negative impacts for seed germination, plant growth and the soil due to oxygen supply reduction, insufficient available nitrogen, or the phytotoxic compounds present (40). Integrated evaluation obtained through principal component analysis, linking physicochemical indicators with biological and ecotoxicological indicators. This study uses parameters including pH, temperature, moisture content, C / N ratio for physical and chemical indicators and levels of pathogens for biological indicators. The GI (Germination Index) value as an ecotoxicological indicator.

Table 3 shows the quality of compost produced in R4 compared to the Indonesian Regulatory Standard. These results show that the water content is still above the quality standard viewed from the Decree of the Minister of Agriculture of the Republic Indonesia (41). This problem solving is drying the compost. Meanwhile, the C-Organic value exceeds the Indonesian National Standard (42). The suggested resolution is by increasing the dose or density of inoculants considering the potential of *S. platensis* in accelerating the rate of C-Organic degradation and biodegradation of plastics. The low pH overcome by adding natural alkaline ingredients to neutralize the

pH of the compost.

The final compost material in this study appears to leave rice husks, cellulose and plastic scraps. Although the water content in all reactors is not too big a difference, R2, R3, and R4 appear more moist and oily because the oil content of *S. platensis* is 4-17 (% dry weight) (43). The compost was not milled or sieved, but all parts used in the phytotoxicity test. It causes the compost is not homogeneous and possible the presence of phytotoxins from the remaining plastic polymer.

3.6. Phytotoxicity test

Observation shows that maize plants are better able to withstand the effects of phytotoxins to sprout up to the 4th polybag, while cayenne pepper plants only to the 2nd polybag. However, normal seed germination emerged in Polybag 1 (P1) as control and Polybag 2 (P2). Figure 5 shows the seeds germination in all samples compared to controls, which resulted in 133% for maize and 100% cayenne pepper.

Fig. 5. RSG for maize and cayenne pepper

P2 showed that maize roots were thicker, interconnected among sprouts, and even penetrated the diapers cellulose so that it was difficult to separate and measure, while maize roots in P1 had almost the same length but not as thick as in P2. Since maize is filamentous and impossible to count individually, the average of three roots used representing the long, medium, and shortest ones. The cayenne pepper grew in the control soil presented slightly higher shoot and root longer than those cultivated on P2. While in P2, the stem diameter appears larger. The ANOVA analysis confirmed the observation; the compost composition affected SG and RSG presented a P-value of 0,0004 and 0,0007, respectively, while the plant type does not affect. The Germination Index (GI) for maize is 124%, and cayenne pepper, 83%. Considering the GI maize exceeding 100%, based on a compost phytotoxicity study, the compost

composition can be used as a phytonutrient, while cayenne pepper, the GI value is lower, but above 80%, indicating that compost does not have a phytotoxin effect on plants ([26](#)).

The composting effect on other plants requires further research on the compost application to various types of plants, representing agricultural, horticultural, and forestry plants, to link the resulting compost to resource sustainability. The authors recommend not only the germination test but until the plants bear fruit to know the long-term toxicity effects of compost on these plants. It is essential to identify different plant behaviour in the growing media that the compost is applied because the compost still contains high levels of carbon while at a certain level, carbon can increase growth, but at high levels, it can reduce growth. Therefore, a phytotoxicity test required to ensure the range of compost concentrations in planting media that does not lethal plants ([44](#)).

The compost utilization can also associate with phytoremediation because of cyanobacteria content in the compost, as the use of cyanobacteria is prospective for environmental quality improvement by restoration of polluted environments ([45](#)). However, it needs to test several plants since there are kinds of plants to eliminate

different contaminants. One of them is indoor phytoremediation using decorative plants, related to the new habits of the people nowadays who use limited land or indoors for greening. It brings advantages to maintaining environmental health ([46](#)).

4. Conclusion

S. platensis accelerated the composting time from 60-106 days in the previous study to 42 days. The best degradation rate obtained in the composting system by 6.0 millions sinusoids of *S. platensis* addition. Since no analysis of Spirulina final density, its growth is unknown. There is the potential for a faster degradation rate than the denser *S. platensis* or from more doses. More investigation needed at several variations, or with a Spirulina density above 60,000 sinusoids/ml, with a density test at the initial and end of the study. Also, the possibility of Spirulina degrading the plastic and microplastics that might present in the compost trigger to do detailed research. *S. platensis* enriches the compost nutrients in the form of Total N due to its nitrogen-fixing ability. It recorded from the Total N at the final stage in R4 was 47% greater than R1, while as at the beginning of composting, the difference was only 0.5%. This gap caused by increasing 22% Total N at R4 while decreasing occurs in R1. Given the high GI value on the phytotoxicity test from the composition of soil:

compost is 7: 3, it concluded that the presence of degraded polymers did not affect the potential utilization of compost as a growing medium for maize and cayenne pepper.

Home scale composting diaper waste can be a solution for the community with a lack of budget for waste management. Nevertheless, this is not widely practised in waste management by the community yet. Diaper waste is often categorized as residue and ends up in the landfill or even in water bodies. According to this study result, that *S. platensis* enhancing disposable diapers composting, both in the process, as well as the utilization of compost, it is recommended to apply this method so that the community can save on waste collection costs to the dumpsite, transportation costs and waste management at the landfill, labour costs, and stop the risk of exposure to pathogens to the labour and residents around the landfill. Besides, waste management in which the community plays the role with the government fully support will bring sustainability. Therefore, it is necessary to continue making efforts to socialize and educate the public about this promising method, further research on large applications and economic value, including market research of this compost product. So it will not only give advantages for environmental sustainability but also economically beneficial.

573

574 **ABBREVIATIONS**

<i>ANOVA</i>	Analysis of Variance
<i>C</i>	Carbon
<i>C / N ratio</i>	Carbon to nitrogen ratio
<i>D</i>	Decimal reduction time
<i>DDT</i>	Dichloro Diphenyl Trichloroethane
<i>E. coli</i>	Escherichia coli
<i>EDTA</i>	Ethylenediaminetetraacetic acid
FeCl_3	Ferric chloride
<i>GI</i>	Germination Index
<i>LDPE</i>	Low-Density Polyethylene
<i>MPN</i>	Most Probable Numbers
<i>N</i>	Nitrogen
NH_3	Ammonia
NH_4	Ammonium
<i>S. platensis</i>	<i>Spirulina platensis</i>

<i>P</i>	Polybag
<i>PP</i>	Polypropylene
<i>P-value</i>	Probability value
<i>PVC</i>	Polyvinyl Chloride
<i>R</i>	Reactor
<i>RSG</i>	Relative Seed Germination
<i>SAP</i>	Super Absorbent Polymer
<i>SG</i>	Seed Germination
<i>SNi</i>	Standar Nasional Indonesia
<i>ZA</i>	Zwavelzure ammoniak/ Amonium Sulfate

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576

577 **Declarations**

578 **Availability of data and materials**

579 The dataset supporting the conclusions of this article is available in the Mendeley

580 Data repository at <https://data.mendeley.com/datasets/r4329wpzvf/1>.

581

582 **Competing interests**

583 The authors declare they have no competing interests.

584

585 **Funding**

586 This work funded by the Ministry of Finance of the Republic of Indonesia through

587 Lembaga Pengelola Dana Pendidikan (LPDP). The scholarship numbers:

588 KET-1460/LPDP.3/2018.

589

590 **Authors' contributions**

591 Diana Indah Kusumawati: Conceptualization, performed the literature review, formal

592 analysis, investigation, writing-original draft, visualization, administration, obtaining

593 funding. Sarwoko Mangkoedihardjo: Conceptualization, methodology, supervision.

594 critical revision of the manuscript for important intellectual content.

595 All authors read and approved the final manuscript.

596

597 **Acknowledgements**

598 The authors would like to thank the Department of Environmental Engineering,

Faculty of Civil, Planning and Geo-Engineering at Institut Teknologi Sepuluh
Nopember (ITS) and Department of Environment of Pasuruan Regency for providing
the support to conduct the above research.

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Table 1. Characteristics of Feedstock Materials and Compost

Parameter	Initial Characteristics of				Characteristics of			
	Feedstock Materials				Compost			
	R1	R2	R3	R4	R1	R2	R3	R4
pH	6,3	6,2	6,0	6,2	7,0	6,0	5,5	5,8
Temperature (°C)	29,3	29,7	30,0	31,0	29,0	29,0	28,7	29,0
Organic C	63,2	63,3	63,2	63,3	62,3	54,5	53,3	51,5
Total N	2,11	2,12	2,11	2,12	1,75	2,45	2,51	2,58
C/N Ratio	29,95	29,86	29,95	29,86	35,60	22,24	21,24	19,96
Moisture Content	73,3	74,6	75	75	49,7	52,1	51,2	50,1
E.coli (MPN/g)	> 1600	> 1600	> 1600	> 1600	79	< 1,8	26	< 1,8

747 **Table 2.** Interparameter Relations

R1	pH	Temperature	Moisture	C	N	C/N Ratio	E. coli
pH	1						
Temperature	-0,26	1					
Moisture content	-0,36	0,86	1				
C	-0,25	0,01	0,22	1			
N	-0,33	0,86	0,99	0,28	1		
C/N Ratio	0,32	-0,88	-0,99	-0,21	-1,00	1	
E. coli	-0,33	0,61	0,63	0,10	0,71	-0,69	1
R2	pH	Temperature	Moisture	C	N	C/N Ratio	E. coli
pH	1						
Temperature	-0,20	1					
Moisture content	0,07	0,84	1				
C	-0,27	0,59	0,75	1			
N	0,35	-0,46	-0,64	-0,98	1		
C/N Ratio	-0,31	0,55	0,72	1,00	-0,99	1	
E. coli	-0,31	0,93	0,76	0,49	-0,38	0,46	1
R3	pH	Temperature	Moisture	C	N	C/N Ratio	E. coli
pH	1						
Temperature	-0,04	1					
Moisture content	0,52	0,73	1				
C	0,07	0,62	0,80	1			
N	-0,07	-0,46	-0,72	-0,98	1		
C/N Ratio	0,08	0,57	0,78	1,00	-0,99	1	
E. coli	0,07	0,94	0,74	0,52	-0,37	0,48	1
R4	pH	Temperature	Moisture	C	N	C/N Ratio	E. coli
pH	1						
Temperature	0,06	1					
Moisture content	0,20	0,65	1				
C	-0,09	0,60	0,78	1			
N	0,005	-0,54	-0,74	-0,99	1		
C/N Ratio	-0,04	0,59	0,79	1,00	-0,99	1	
E. coli	-0,20	0,84	0,71	0,51	-0,39	0,49	1

Table 3. The compost quality compared to the Indonesian Regulatory Standard

Parameter	Compost	The Decree of the Minister of Agriculture 261/KPTS/SR.310/M/4/2019	SNI 19-7030-2004
pH	5,8	4-9	6,8-7,5
Temperature (°C)	29,0	-	groundwater temperature
Organic C	51,5	> 15	9,8-32
Total N	2,58	-	0,4
C/N Ratio	19,96	' <u>≤</u> 25	10-20
Moisture Content	50,1	10 – 25	50
E.coli (MPN/g)	< 1,8	< 1 x 10 ²	-

Figures

Figure 1

Composting reactor with lid and aeration pipe

Figure 2

Temperature and pH during composting

Figure 3

Organic-C, Total N, and C / N Ratio during composting

Figure 4

Log N vs Composting Time

Figure 5

RSG for maize and cayenne pepper