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The effect of zinc addition in the production process of liquid organic fertilizer on the nutrient properties, P and Zn uptakes, and yields of sweet corn

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Abstract The effectiveness of liquid organic fertilizer (LOF) can be improved by incorporating micronutrient zinc (Zn) in its production process in order to increase the yields of organic vegetables such as sweet corn. This experiment was conducted to determine the effect of Zn amendment on LOF nutrient quality, nutrient uptakes, and sweet corn yields. Results indicated that Zn-enriched treatment during the production of LOF did not significantly affect N, P, and K contents, but significantly affected pH. There were also no significant effects on P and Zn contents in the leaves of sweet corn as well as those uptakes by the plants. However, the P contents in the leaves at a day before harvesting were significantly higher than 5 weeks after planting, while the Zn content showed a contrasting result. Moreover, the use of Zn-enriched LOF did not significantly affect the weights of husked and unhusked ears of sweet corn, but significantly decreased its sweetness. Future research should focus on the use of lower concentrations of Zn.

Keywords: Zinc amendment, Liquid organic fertilizer, Nutrient uptakes, Sweet corn

Introduction

The demand for organically grown vegetables such as sweet corn (*Zea mays* L. var. saccharata) has continued to increase since the 1990s (Thompson, 2000. Organic vegetables and fruits have been reported by Tanmay (2019) to be the largest and fastest-growing commodity in the global organic food market due to the increase in consumers' awareness of their health benefits. It was also associated with the willingness to pay more for organic foods because of the presence of fewer pesticides and their high nutritive values. This, therefore, means organic vegetables need to be continuously supplied to meet market demands without sacrificing the quality of land and water resources.

The use of solid organic fertilizer to produce sweet corn needs to be supplemented with other nutrient sources because it often requires a longer time to mineralize compared to the crop lifecycles. For example, the increased growth and yield experienced by sweet corn (Mukhlis and Lestari

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(2013) and maize (Maswar and Soelaeman, 2016; Khairuddin *et al*., 2018) was attributed to the addition of synthetic fertilizer, NPK. Muktamar *et al*. (2017) also showed there is a need to add liquid organic fertilizer through foliar application to increase sweet corn yields. Moreover, Hartz *et al.* (2010) concluded that the foliar application of nitrogen was required to compensate for the low availability of the element in organic soil in order to have a successful vegetable production. The CAPS research group in the Faculty of Agriculture, University of Bengkulu has developed liquid organic fertilizer (LOF) since 2010 using locally available materials to produce sweet corn in a closed agriculture production system. This involved designing a model to integrate organic farming by combining dairy cattle waste and local organic materials to produce solid and liquid organic fertilizers to grow vegetables. It is important to note that a closed production system has been defined by Brust *et al*. (2003) to be an integral organic agricultural practice involving the maintenance and sustainability of biodiversity, biological cycles, and soil biological activities. The group also addressed the technical development of LOF by identifying weeds as nutrient sources, decomposing bacteria and fungus, source of animal faeces, application methods, crop responses, nutrient stability in the rhizosphere, and nutrient uptakes by sweet corns. The production process involved the aerobic incubation of mixtures of cattle's faeces and urine, topsoil, green biomass, and effective microorganisms in a plastic container for four weeks (Fahrurrozi *et al*., 2016). There is, however, the need to continuously improve the effectiveness of the LOF by adding micronutrients during its production process.

Micronutrient of zinc (Zn) was considered very reasonable to be added during the production of LOF, since Zn plays significant roles in organic matter decomposition through its effects on activities of decomposing microbes, especially during the thermophilic phase (Chen *et al*., 1994). The enrichment of micronutrient to produce solid organic fertilizer has been documented by Zaccheo *et al.* (1996), Veeranagappa *et al.* (2010), and Duan *et al.* (2015) but there is no report on the incorporation of Zn in the production of LOF. If its addition is proven to increase nutrient contents, LOF production could incorporate natural organic wastes or green plants that have rich ZnO content. For example, a tropical plant native to India, *Moringa oleifera*, also commonly known as 'drumstick tree' or 'horseradish tree', is very nutritious and rich of Zn content (Gopalakrishnan *et al*., 2016). Other organic wastes are included fruit peels (Nava *et al*., 2016). Such organic materials could be added during the production of LOF to improve its nutrient contents, and eventually improve crop growth and development in organic production systems, including sweet corn.

This research was, therefore, aimed to determine the effect of adding Zn to LOF production process on the nutrients' quality, P and Zn uptakes as well as sweet corn yields.

Materials and methods

Series of experiments were conducted at Closed Agriculture Production System (CAPS) Research Station in Rejang Lebong highland, Bengkulu Province, Indonesia, elevated approximately 1.054 m above sea level and located on 3°, 27', 30.38" South Latitude and 102°. 36', 51.33'' East Longitude.

The effects of Zn addition on nutrient properties of liquid organic fertilizer

The experiment was conducted using a complete randomized design from July to August 2018 and treatments prepared include 0, 100, 200, 300, 400, and 500 ppm of Zn, with three replicates and added during the production of liquid organic fertilizer (LOF). Each treatment was produced by mixing 5 kg fresh cattle's faeces, 10 cattle's urine, 2.5 kg topsoil, 5 kg Tithonia diversifolia leaves, 10 L solution of 24-hour incubated 10 mL EM 4 + 0.125 kg white sugar in a blue plastic container. Water was added to these mixtures to reach a volume of 100 L, securely covered, and incubated for five weeks. All the containers were, however, placed in the production house to prevent direct sunlight and precipitation.

The proximate analysis of the LOF samples for nutrient contents including the pH, N-total (%), P-Bray (%), and K (%) with three replicates was conducted using the methods proposed by Yoshida *et al*. (1976) at the Laboratory of Soil Science University of Bengkulu. Meanwhile, samples to determine Zinc content were sent to the Laboratory of Soil Science and Land Resource, Bogor Agricultural University for analysis. The LOF pH was measured using pH meter (Konica Minolta) weekly after the sample has been thoroughly stirred. All data were subjected to analysis of variance using SAS at $P < 0.05$.

The effects of Zn addition on nutrient uptakes and sweet corn yields

A field experiment was conducted from late August to November 2018 to determine the uptakes of P and Zn by sweet corn using a complete randomized block design with three replicates. The treatments used include 0, 100, 200, 300, 400, and 500 ppm of Zn-enriched LOF. The land preparation process started with weed removals through ploughing and harrowing two weeks before planting. Meanwhile, the experimental site has been used for organic vegetable production since 2012 with 15 ton ha^{-1} of vermicompost applied every year. The plant used in this experiment was Paragon variety of sweet corn planted at 0.25 m x 0.70 m spacing in a 1.3 m x 3.0 m soil-bed and separated by 0.8 m within the block and 1.0 m among the blocks. Each concentration of LOF was uniformly applied to the sweet corn leaves using a total of 875 mL from each treatment comprising of 25, 50, 100, 150, 250, and 300 mL per plant, respectively from the second to the seventh week after planting. The plants were watered as necessary during the absence of precipitation for three consecutive days, weeds were removed at 25 and 45 days after planting while the soil surface around the stems was hilled up to maintain the crops' stands.

The wet destructive method was used to determine the plants' phosphorus and zinc contents (%) and this involved taking samples of third or fourth leaf of the uppermost fully developed leaves at five weeks after planting and one day before harvesting. The samples used for phosphorous tissue content analysis were sent to Soil Science Laboratory at the University of Bengkulu while those for zinc determination were sent to Soil Science and Land Resource Laboratory of Bogor Agricultural University. Moreover, the shoot dry weight for the sweet corn was calculated by weighing them after they have been dried and kept in the oven for 48 hours at 65 to 70 ℃ to obtain a constant value. Meanwhile, the phosphorus and zinc uptakes by sweet corn were calculated as PNC/100SDW, where PNC is plant nutrient contents (%) and SDW is shoot dry weight per plant (g). The weight of husked (g) and unhusked ears (g) were determined in fresh weight basis while the sweetness level (^{o}Brix) of the sweet corn was evaluated immediately after the unhusked ears were measured using a portable refractometer. The data obtained were subjected to a homogeneity test before analysis of variance using SAS at $P < 0.05$.

Results

Quality of liquid organic fertilizer

The results showed that after five weeks of incubation, adding Zn to LOF production process was found not to have a significant effect on N (P<F=0.6699), P (P<F=0.2552), K (P<F=0.3549), but did on Zn (P<F=0.0001) and pH (P<F=0.0309) contents. The average values recorded were 1.19 to 1.84 % for N, 0.28 to 0.48 % for P, and 0.52 to 0.60 % for K as shown in Figures 1A, 1B, and 1C respectively.

The results also showed the Zn amendment during LOF production process decreased the pH of enriched LOF with a linear relationship of $y=-0.002X+7.74$ ($R^2=0.8781$) as shown in Figure 2.

Effects on P and Zn uptakes by sweet corn

The results showed the use of Zn-enriched liquid organic fertilizer did not have significant effects on P and Zn contents in sweet corn leaves at five weeks after planting (P<F=0.6669 and P<F=0.4771, respectively) and at one day before harvesting (P<F=0.6129 and P<F=0.3839, respectively).

However, the P contents a day before harvesting was significantly higher than those at 5 weeks after planting (P<F=0.0300), meanwhile, the Zn content at a day before harvesting was significantly lower than those at 5 weeks after planting (P<F=0.0007) as shown in Figure 3.

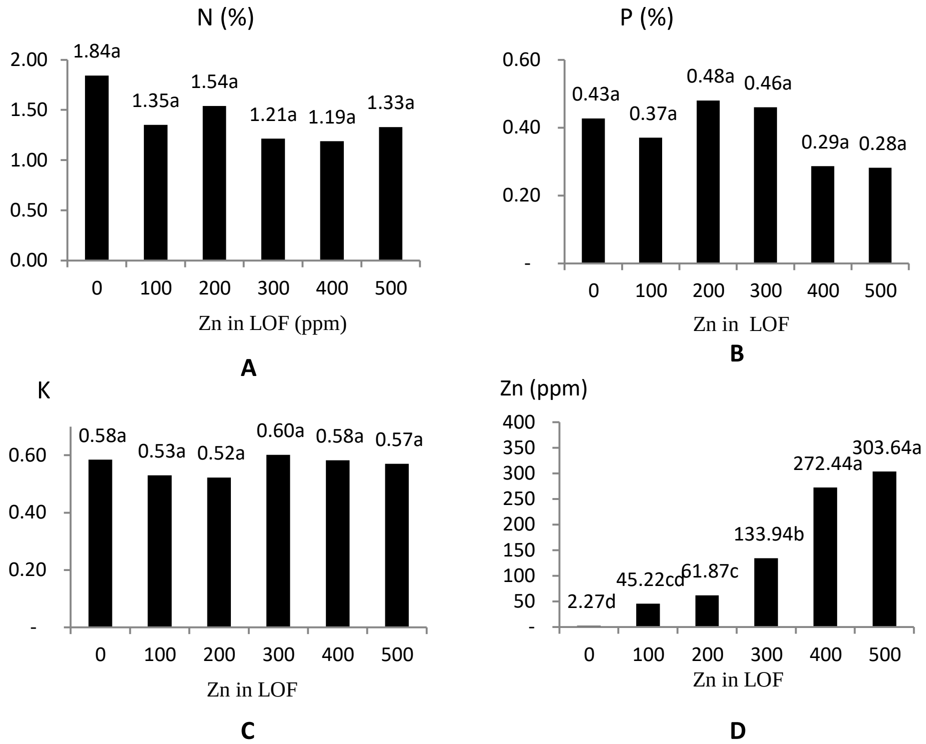


Figure 1. The effects of Zn amendment on N (A), P (B), K (C), and Zn (D)contents of liquid organic fertilizer. (*The mean values of treatments in each variable followed by the same letters are not significantly different at p < 0.05 according to Duncan's Multiple Range Test*)

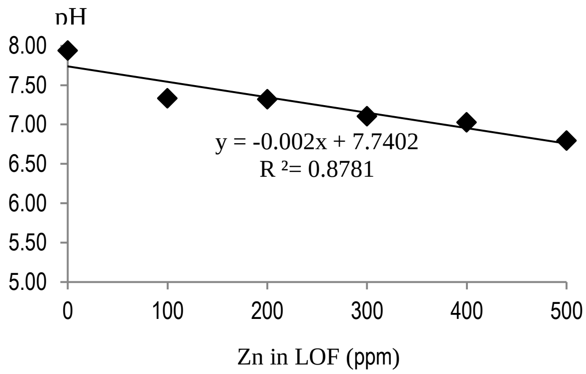
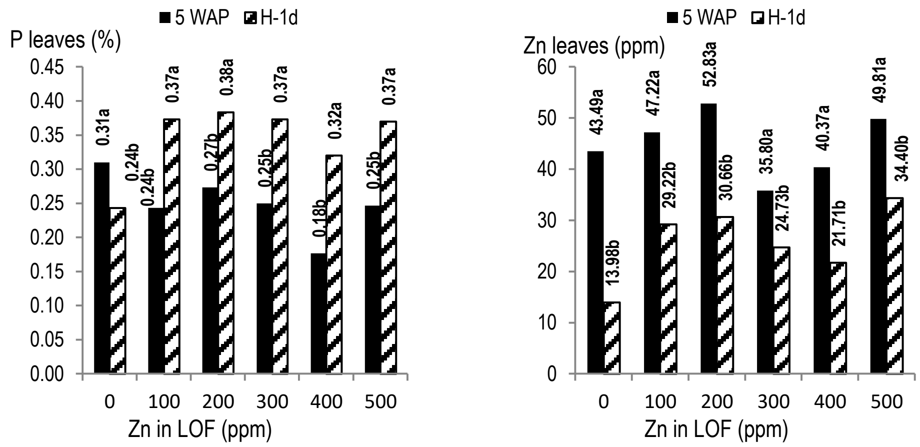


Figure 2. Effects of Zn amendment on pH of liquid organic fertilizer



[A] **[B]**

Figure 3. The effects of Zn amendment in LOF on P and Zn contents in sweet corn leaves at five weeks after planting (WAP) [A] and one day before harvesting (H-1)[B]. (*The mean values of treatments in each variable followed by the same letters are not significantly different at p < 0.05 according to the Least Significant Different*)

Applying Zn-enriched liquid organic fertilizer was also observed not to have a significant effect on P and Zn uptakes by sweet corn a day before harvesting (P<F=0.7718) and P<F=0.4746, respectively). The P was recorded to have ranged between 0.12 to 0.16 g/plant while Zn was 2.64 to 3.79 g/plant as shown in Figure 4. However, both P and Zn absorbed by sweet corn fertilized with non-Zn enriched LOF had the lowest nutrient uptakes compared to those grown with Zn-enriched ones.

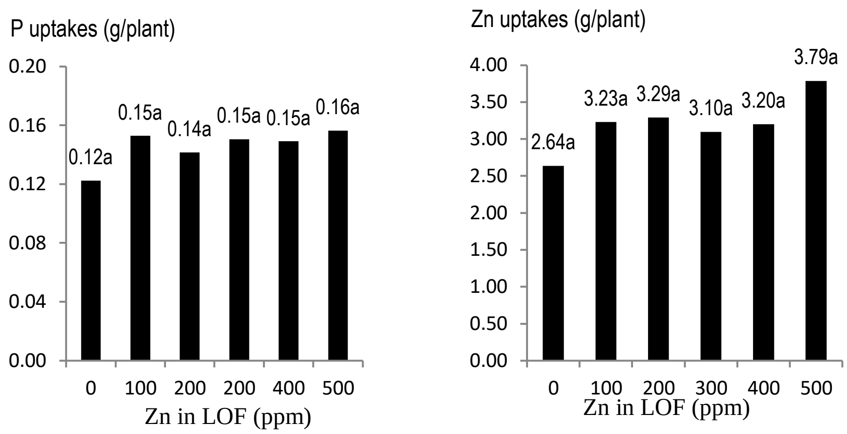


Figure 4. The effects of Zn amendment LOF on P uptakes (left) and Zn uptakes (right) by sweet corn at one day before harvesting

Sweet corn yields

The use of Zn-enriched LOF did not significantly affect the weights of both husked ears (P<F=0.3912) and unhusked ears (P<F=0.3070) of the sweet corn, respectively. Those grown without Zn-enriched LOF had the highest weights compared to those with the treatments but the difference was not significant as shown in Figure 5.

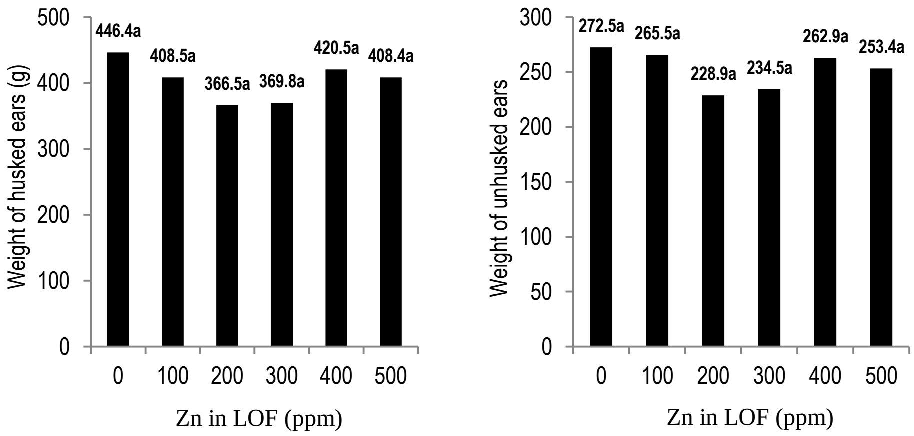


Figure 5. The effects of Zn amendment LOF on the weight of husked (left) and unhusked ears (right) of sweet corn

The treatments, however, significantly influenced the sweetness level of sweet corn (P<F=0.0154). This was evident in the reduction experienced at a linear relationship of $y = -0.0018x + 12.841$ (R^2=0.1758) as shown in Figure 6.

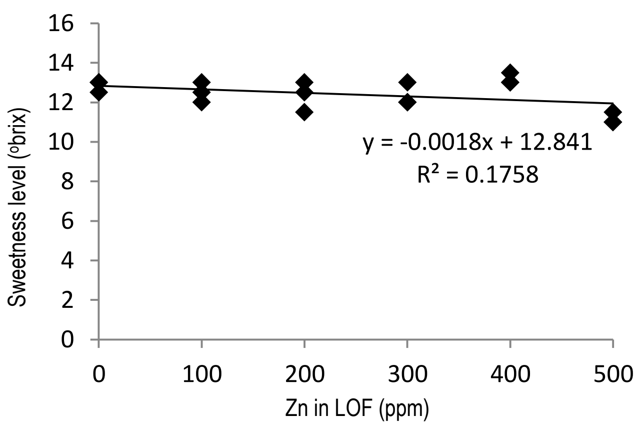


Figure 6. The effects of Zn amendment LOF on the sweetness of sweet corn

Discussion

The insignificant effects observed with the N, P, and K contents were least expected because Veeranagappa *et al*. (2010) and Duan *et al*. (2015) reported that Zn played important roles in organic matter decomposition by increasing the microbial activities of the decomposers. Moreover, the introduction of Zn in the LOF production process significantly increased its Zn contents as shown in Figure 1D and the addition of higher volume was observed to have led to an increase in the content. This was associated with the presence of an increased amount of Zn in decomposed materials during LOF production. However, the quantity in the LOF was much lower than those added and this means zinc mineral (ZnO) did not completely dissolve in water. Meanwhile, Li *et al*. (2010) stated that Zn is soluble in either acidic or alkaline condition. Surprisingly, the LOF produced without Zn also had a very small amount of the element as observed in the 2.27 ppm recorded and this shows Zn is naturally generated during the production process, probably from the soil used. According to Alloway (2008), the total mean Zn concentration in the soil is 55 ppm and this may vary with soil types and geographical regions. The natural occurrence of Zn can also be due to its release during the decomposition of green biomass and dairy cattle wastes.

The pH of LOF produced without Zn was 7.93 while those with 500 ppm had 6.79 as shown in Figure 2. This means Zn addition caused a significant release of protons (H^+) during the incubation and this was confirmed by a previous study that the dissolution of ZnO in water was able to discharge H^+ (Li *et al*., 2010). The amendment, however, should not be more than 400 ppm because the pH recorded at 500 ppm concentration was 6.79 which is lesser. Other treatments ranging from 100 to 400 ppm, however, had 7.33, 7.32, 7.10, and 7.02, respectively. This mean Zn is important to ensure LOF comply with market standard, but the addition should not exceed 400 ppm because a higher concentration has the ability to decrease the pH by increasing the organic acids supplied into the solution (Imtiaz *et al*., 2010).

The results also showed a higher P content in leaf tissues a day before harvesting compared to 5 weeks after transplanting and this means the sweet corn consumed a significant amount of P to support its generative growths. The element was presumably supplied by LOF as well as the rhizosphere. According to Marschner (2012), this nutrient stimulates flowering and hastens maturity in several plants. Sufficient phosphorus was observed to be important for the plant to maintain the quality of crop yields. Meanwhile, Hasani *et al*. (2012) concluded that the application of Zn insignificantly decreased the P concentrations in the pomegranate leaves.

The lower Zn content in leaf tissues a day before harvesting compared to 5 weeks after transplanting showed the sweet corn consumed less amount of this nutrient to support its generative growths. This is in line with Soltangheisi *et al*. (2013) findings that both Zn and P nutrients show contrasting effects in terms of uptakes and translocation. Li *et al*. (2007) and Fan *et al*. (2011) also showed excessive fertilization of P into the soil reduced the Zn availability. This antagonist trait showed the low Zn contents in the sweet corn leaves a day before harvesting was due to the Zn-P balance in the plant tissues. Hasani *et al*. (2012), however, concluded that the foliar application of Zn significantly increased its concentration in pomegranate leaves. Therefore, the fact that this study indicated the application of Zn-enriched LOF up to 200 ppm tended to increase Zn concentration in sweet corn leaves, but decreased at higher concentrations as shown in Figure 3B, means the concentration should be lowered during the production process.

The Zn amendment in the LOF did not significantly increase the P uptakes and this was probably associated with the high concentration of Zn applied into the LOF. Research conducted by Soltangheisi *et al*. (2013) concluded that low concentration of Zn (up to 20 ppm) has the ability to increase P uptakes in sweet corn. This, therefore, means the pronounced effect of Zn-enriched LOF would possibly be noticed at a lower concentration.

The weight of the Paragon sweet corn variety was found be to be between 371.31-431.49 g while the husked ranged 366.5-446.4 g and these are considered to have complied with the standard. The organic production systems being applied to the experimental site since 2010 have possibly dwindled the treatment effects. Nevertheless, the fresh weights of the ears were higher than 245.4 g previously reported by Ilker (2011) from eight sweet corn varieties after two years of experiments as well as the 225 g recorded by Kara (2011). The lower value was presumably attributed to the difference in the environmental conditions for the studies. Moreover, insignificant effects of LOF on sweet corn ears were also reported by Fahrurrozi *et al*. (2016, 2019) after they have both applied similar concentration and dosage of LOF for organic sweet corn production. However, the use of a lower LOF concentration needs to be evaluated in the future.

The sweetness level reflects the sugar content of sweet corn and those fertilized with 500 ppm Zn-enriched LOF had the lowest value with 11.17 ^{o}brix while those without Zn had 12.83 ^{o}brix. This linear relationship shows that every ppm of Zn included caused a decrease in the sweetness of the sweet corn as much as 0.000018 ^{o}brix. Meanwhile, the values for the varieties used in this experiment ranged from 11.47 to 11.77 ^{o}brix. These values were much higher than the sugar content of a promising sweet corn variety which is 9.3 ^{o}brix (Erdal *et al*., 2011). However, the differences in genetic capacity and agroecological conditions during the sweet corn production have contributed to such variations.

The experiment concluded that the addition of Zn to the LOF production process did not significantly affect N, P, K contents in LOF but decreased its pH. The use of Zn-enriched LOF also had no significant effects on P and Zn contents in sweet corn leaves, P and Zn uptakes, and weights of both husked ears and unhusked ears of sweet corn but significantly reduced the sweetness. Lower concentration of Zn addition in the process of LOF production needs to be evaluated in future research.

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