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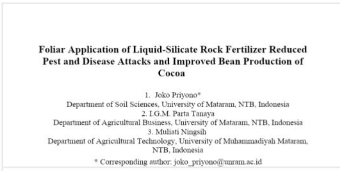
**Foliar Application of Liquid-Silicate Rock Fertilizer Reduced Pest and Disease Attacks and Improved Bean Production of Cocoa**

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# Foliar Application of Liquid-Silicate Rock Fertilizer Reduced Pest and Disease Attacks and Improved Bean Production of Cocoa

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**Abstract:** Besides the lack of soil fertilization, the primary biotic stressor limiting the production of cocoa (*Theobroma cacao L.*) in Indonesia is pest and disease attacks (PDAs). As a part of the efforts to find out the appropriate solution for the farming constraints, a field trial was carried out for 14 months (2015 – 2016) in Genggelang - North Lombok Regency, Indonesia. The main objective of the experiment was to identify the effects of the use of locally-available materials, i.e., liquid-silicate rock fertilizer (LSRF), botanical pesticide (BP) of *neem*, and black ants (BA) of *Doliccoderus thoracic*, on PDAs, bean production, and polyphenol and lignin contents of cocoa pod shell. A randomized complete block design was laid out in three blocks, and the treatments were LSRF, LSRF+BP, LSRF+BA, BA, and control. Results reveal that the application of those materials reduced the intensity of pest and disease attacks (e.i., respectively, 6 - 24 % and 3 - 9 % lower than for that of the control), increased 18 – 119 % of bean production, and improved the polyphenol and lignin contents of pod shell. The highest increase (119 %) of bean production was due to the foliar application of LSRF. The positive effect of the treatments, especially the use of LSRF, associated with the improvement of the resistance of cocoa to PDAs and appropriate supply of plant-essential nutrients. Therefore, the foliar application of LSRF may be promoted as a proper method to improve the production of cocoa, especially of that grown on less fertile soils.

**Keywords:** botanical pesticide, black ants, defence system, lignin, polyphenol, plant resistance, silicate.

## 1. Introduction

Cocoa (*Theobroma cacao L.*) is an important cash crop in the world, and Indonesia currently is the 3rd largest cocoa-producing country after Côte d'Ivoire and Ghana [1]. During the last several years, however, the production of cocoa in Indonesia has declined. In 2012/2014, the production of cocoa in Indonesia was about 430 tons, but in 2015/2016, it was only about 220 tons [2]. The most suspected cause of the declining of cocoa production was pest and disease attacks (PDAs) or/and the lack of fertilizer application. Efforts are required to find out an appropriate method to handle those farming constraints effectively.

The conventional methods for handling the PDAs are based on the basic concept that the organisms of insect pests and pathogens are considered as the farmers' enemy. Consequently, the population of those organisms in farming areas must be suppressed, and the simplest way to do so is by applying synthetic pesticides. However, the use of synthetic pesticides potentially induces the resistance of pests and negatively impacts various ecological aspects [3, 4, 5, 6, 7] including human health [8]. Moreover, the use of synthetic pesticides is incompatible with the standard of producing organic cocoa [7] and not suitable for most smallholder farmers due to its high cost [4, 9, 10]. Responding to the case, many plant pathologists recommend the use of preventive measures by growing the resistant varieties and applying ethical farming practices [7], botanical pesticides [11, 12, 13], or by employing natural pest-predators such as black ants [14, 15]. Integrated pest management (IPM), combining several possible preventive and curative measures, is currently promoted worldwide [15]. However, in most cases, implementing IPM on-farm level is too complicated for most smallholder farmers.

Suppressing the population of pests and pathogens by applying whatever appropriate methods, may directly contribute to the improvement of cocoa production. Nevertheless, soil fertility may also become a significant limiting factor of cocoa production [16], which such condition occurred in cocoa farming in Papua New Guinea [17]. Accordingly, to significantly improve the productivity of cocoa farming, the actions for combating PDAs should be integrated with appropriate soil fertilization, especially for cocoa grown on infertile soils. Importantly, the integrated method should be technically applicable for smallholders with their various land condition.

Another acceptable view is that the plant receiving sufficient and proportional supply of plant-essential nutrients in a suitable environmental condition will grow and produce optimum yield. A healthy plant can perform its highest natural-defence system [18]. Moreover, many researchers [e.g., 19, 20, 21, 22, 23] reported that applying Si-based fertilizers improves the resistance of the plant to biotic (e.g., PDAs) and abiotic stressors. Therefore, it is reasonable to postulate that applying the Si-based fertilizers containing all essential nutrients, with or without suppressing the population pests in the farming areas, may reduce PDAs or minimize the damaging impact of PDAs on the cocoa beans and at the same time improve the bean production. The other possible-appropriate method is by combining the application of the Si-based fertilizers with botanical pesticides or pest-enemies such as black ants. Field tests are required to identify the most effective method to improve cocoa production.

The main objective of this field research was to identify the effects of applying the locally available materials, i.e., liquid-silicate rock fertilizer (LSRF), the botanical pesticide (BP) of *neem* leaf, and black ants (BA) of *Doliccoderus thoracic* on the intensity of PDAs, bean production, and polyphenol and lignin content of cocoa pod shell.

## 2. Materials and Method

### 2.1. Description of Experiment Site

This experiment was conducted in a farmer's cocoa farming land in Genggelang village, North Lombok Regency, Indonesia (8°20'37.9" S, 116°14'13.1" E). The land was at about 335-m above sea level with the moderately deep-sandy textured soil (Arenic Eutrundepts) developed from pumice stone on undulating physiography (4 – 8 % sloping). The soil pH was 6 – 6.5, moderate C-organic content (1.5 – 2.2 %), relatively low contents of N (< 0.01 %) and Bray-extractable P (2 - 5 $mg.kg^{-}$), cation exchange capacity (4.8 $cmol.kg^{-}$), and exchangeable Ca, Mg, and K (respectively 4.8, 1.4, and 0.58 $cmol.kg^{-}$).

### 2.2. Experimental Materials, Design, and Management

The primary materials used in this experiment were liquid-silicate rock fertilizer (LSRF), botanical pesticide (BP) of *neem*, and black ants (BA) of *Doliccoderus thoracicus*, which were prepared as follows:

- The LSRF was produced from basaltic silicate rocks, containing (w/v) of 6.4 % Si, 4.04 % N, 3.22 % $P_2O_5$, 3.36 % $K_2O$, 0.32 % Ca, 0.40 % Mg, 0.12 % S, 40 $mg.L^{-}$ Fe, 122 $mg.L^{-}$ Mn, 260 $mg.L^{-}$ Zn, 10 $mg.L^{-}$ Cu, 3.0 $mg.L^{-}$ B, 0.1 $mg.L^{-}$ Co, and 1.2 $mg.L^{-}$ Mo.
- The botanical pesticide (BP) was made from *neem* leaf (*Azadirachta indica*). A kilogram of fresh *neem* leaf was crushed into < 2 mm, incubated for 24 hours with 2-L fresh water in a closed plastic container. The suspension was filtered, and the filtrate (BP) was stored in another closed plastic container. The BP was freshly prepared a week before application.
- Black ants (BA) of *Doliccoderus thoracicus* were collected from the surrounding area of the experiment site. A plastic bag was filled with an amount of dry banana leaf sprayed with a sugar solution to attract black ants to house in the bag. The population of the trapped black ants in each bag was about 200 ants at the starting time of this experiment.

This experiment was laid out in a randomized complete block design with the treatments consisting of LSRF, LSRF+BP, LSRF+BA, BA, and control, and those were triplicated (in 3 blocks). Each plot contained 10-productive cocoa trees of about 7-year old. The experiment was run for 14 months (September 2015 – December 2016).

For the application of LSRF, 300-mL LSRF was diluted with freshwater into 30 L and then sprayed evenly onto the leaf of cocoa trees in an experimental unit containing ten cocoa trees. For an experimental unit of the treatment of LSRF + BP, 300-mL LSRF and 40-mL BP were mixed and diluted with freshwater into 30 L and was sprayed evenly onto the leaf of cocoa trees. The treatments of LSRF and LSRF + BP were applied fortnightly. For the treatments of LSRF + BA and BA, each bag of black ants described above was hanged on a branch of each cocoa tree.

### 2.3. Data Collection and Statistical Analysis

The primarily collected data were (1) the intensity-incident of PDAs, (2) the annual-bean production, and (3) the polyphenol and lignin contents of the pod shell.

The number of pods attacked by pests or/and diseases in each plot was observed monthly, started from November 2015 (a month after the first application of the treatments) up to the end of the experiment (December 2016). The intensity incident of PDAs (%) was calculated on the besis of sum of cocoa pods of 14-month observations:

$$\text{PDAs (\%)} = \frac{\Sigma \text{ pods attacked by pests or/and diseases}}{\Sigma \text{ whole pods}} \times 100$$

The ripe pods were harvested weekly for 14 months, and then the beans were oven-dried at 40° C to reach a constant weight (after 7 – 10 days of drying). The dry beans and pod shells, harvested at the end of June - August 2016), were sampled for the measurements of polyphenol and lignin contents using the colorimetric methods [24, 25].

All collected data were subjected to the analysis of variance (ANOVA) to identify the effects of the treatments on each observed parameter as described above and followed with the analysis of least significant difference ($LSD_{\alpha = 0.05}$) for the parameters that were significantly affected by the treatments.

**3. Results**

The effects of the treatments on the incident-intensity of PDAs, annual-bean production, and polyphenol and lignin contents of pod shell are presented in Table 1. It was noted that the observed pests attacking cocoa pods during the experiment were *Hellopeltis* and *Conopomorpha cramerella*, and the diseases were cocoa-black pod (CBP) caused by *Phytophthora palmivora* and *Colletotrichum gloeosporioides*.

Table 1. The effects of liquid-silicate rock fertilizer (LSRF), botanical pesticide (BP), and black ants (BA) on the incident-intensity of pest and disease attacks, annual-bean production, and polyphenol and lignin contents of cocoa pod shell.

| Treatments | Pest Attacks (%) | Disease Attacks (%) | Bean Production ($kg.plot^{-}.y^{-}$) | Polyphenol Content (%) | Lignin Content (%) |
|---|---|---|---|---|---|
| Control | 75.7 b | 11.8 d | 4.98 a | 5.70 a | 20.25 a |
| LSRF | 62.3 a | 5.6 b | 10.42 d | 7.12 b | 28.03 b |
| LSRF+BP | 70.7 b | 3.1 a | 8.41 c | 9.33 c | 29.28 b |
| LSRF+BA | 62.7 a | 8.9 c | 7.05 b | 7.61 b | 20.54 a |
| BA | 57.9 a | 5.8 b | 5.89 a | 10.18 d | 23.04 a |
| $LSD_{\alpha = 0.05}$ | 7.6 | 0.3 | 1.06 | 0.78 | 0.96 |

The values in the same column, followed by the same letter are not significantly different based on $LSD_{\alpha=0.05}$.

A specific observation was carried out to the pods that were attacked by pests (*Hellopeltis* and *Conopomorpha cramerella*). Result of the visual observation showed that most of the beans in the pods of the cocoa trees treated with LSRF, LSRF + BP, or LSRF + BA were still in good condition. In contrast, more than 60

% of the beans of the attacked pods of the control trees were in a damaged condition – flatty and dark-coloured (data are not shown in this paper). Thus, the attacks of *Hellopeltis* or/and CBP on the pods of the treated cocoa trees damaged only the outmost part of pod shell, injuring only a minor part of the beans inside the pods.

## 4. Discussion

As shown in Table 1, the intensities of pest and disease attacks for the cocoa trees treated with LSRF, LSRF+BP, LSRF+BA, and BA were significantly lower than of that for the control. The decreases of pest and disease attacks due to those treatments, respectively, ranged from 6 to 18 % and from 3 to 6 %. Inversely, the treatments significantly increased bean production with the order of the treatments, based on its quantity of bean production, was LSRF > LSRF+BP > LSRF+BA > BA > control. The bean production for the control was about 5 kg.plot$^{-}$.y$^{-}$ (~ 550 kg.ha$^{-}$.y$^{-}$), whereas for the treated cocoa trees was 6 to 10.5 kg.plot$^{-}$.y$^{-}$ (~ 650 to 1,100 kg.ha$^{-}$.y$^{-}$). In other words, the treatments increased about 18 to 109 % of bean production, and the highest increase (109 % over that of the control) was gained by foliar application of LSRF.

The identification of polyphenol and lignin contents of the pod shell was aimed to explain if the treatments affect the resistance of cocoa to PDAs. Polyphenol has essential roles due to its antioxidant capacity being beneficial to human health [26] and contributes to the improvement of the defense system of the plant to PDAs [27]. Lignin, as an essential part of the cell structure, also has a substantial role in the defense system of the plant to PDAs, including in reducing the damaging impact of CPB or Phytophthora attacks on cocoa pods. Lignification could provide more strength and rigidity to the cell wall of the plant [29].

In this present research, the applications of LSRF, LSRF+BP, or LSRF+BA significantly increased polyphenol and lignin contents of the cocoa pod shell. The enrichment of those substances in the pod shell may improve the resistance of cocoa pod to PDAs (especially of *Hellopeltis* or/and CBP). Moreover, the result of visual observation as described in earlier section proved that the application of LSRF (a Si-containing fertilizer) alone or in combination with BP or BA strengthened the cell wall of cocoa pods, avoiding the injuring impact of PDAs to cocoa bean in the pods. Therefore, the application of LSRF significantly increased cocoa bean production through the mechanism of improving the defence system and satisfying the plant with essential nutrients.

## 5. Conclusion

The applications of liquid-silicate rock fertilizer (LSRF), the combination of it with botanical pesticide (LSRF + BP) or with black ants (LSRF + BA), and BA alone provided several positive effects on cocoa. Those effects included the reduction of pest and disease attacks (PDAs), the increases of annual-bean production and the polyphenol and lignin contents in the cocoa pod shell. The highest gain of the annual-bean yield of cocoa was due to the application of LSRF. The use of the fertilizer (LSRF) stimulated the optimum defense system of cocoa to PDAs and provided a sufficient supply of essential nutrients to the plant. Thus, using LSRF may be promoted as an appropriate method to improve cocoa farming productivity, especially in less fertilize soils, in Indonesia.

**Acknowledgement**

We thank and appreciate the World Cocoa Foundation (WCF) for its funding to this research. Special thanks to MS. Virginia Sofila and Mr Ben Breman for their help in the project administration and implementation

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DOI: https://doi.org/10.32861/jac.65.68.72

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**Article History**
**Received:** April 6, 2020
**Revised:** April 30, 2020
**Accepted:** May 9, 2020
**Published:** May 11, 2020



## Abstract

Besides the lack of soil fertilization, the primary biotic stressor limiting the production of cocoa (*Theobroma cacao L.*) in Indonesia is pest and disease attacks (PDAs). As a part of the efforts to find out the appropriate solution for the farming constraints, a field trial was carried out for 14 months (2015 – 2016) in Genggelang - North Lombok Regency, Indonesia. The main objective of the experiment was to identify the effects of the use of locally-available materials, i.e., liquid-silicate rock fertilizer (LSRF), botanical pesticide (BP) of *neem*, and black ants (BA) of *Doliccoderus thoracic*, on PDAs, bean production, and polyphenol and lignin contents of cocoa pod shell. A randomized complete block design was laid out in three blocks, and the treatments were LSRF, LSRF+BP, LSRF+BA, BA, and control. Results reveal that the application of those materials reduced the intensity of pest and disease attacks (e.i., respectively, 6 - 24 % and 3 - 9 % lower than for that of the control), increased 18 – 119 % of bean production, and improved the polyphenol and lignin contents of pod shell. The highest increase (119 %) of bean production was due to the foliar application of LSRF. The positive effect of the treatments, especially the use of LSRF, associated with the improvement of the resistance of cocoa to PDAs and appropriate supply of plant-essential nutrients. Therefore, the foliar application of LSRF may be promoted as a proper method to improve the production of cocoa, especially of that grown on less fertile soils.

**Keywords:** Botanical pesticide; Black ants; Defence system; Lignin; Polyphenol; Plant resistance; Silicate.

## 1. Introduction

Cocoa (*Theobroma cacao L.*) is an important cash crop in the world, and Indonesia currently is the 3$^{rd}$ largest cocoa-producing country after Côte d'Ivoire and Ghana [1]. During the last several years, however, the production of cocoa in Indonesia has declined. In 2012/2014, the production of cocoa in Indonesia was about 430 tons, but in 2015/2016, it was only about 220 tons [2]. The most suspected cause of the declining of cocoa production was pest and disease attacks (PDAs) or/and the lack of fertilizer application. Efforts are required to find out an appropriate method to handle those farming constraints effectively.

The conventional methods for handling the PDAs are based on the basic concept that the organisms of insect pests and pathogens are considered as the farmers' enemy. Consequently, the population of those organisms in farming areas must be suppressed, and the simplest way to do so is by applying synthetic pesticides. However, the use of synthetic pesticides potentially induces the resistance of pests and negatively impacts various ecological aspects [3-7] including human health [8]. Moreover, the use of synthetic pesticides is incompatible with the standard of producing organic cocoa [3] and not suitable for most smallholder farmers due to its high cost [4, 9, 10]. Responding to the case, many plant pathologists recommend the use of preventive measures by growing the resistant varieties and applying ethical farming practices [3], botanical pesticides [11-13], or by employing natural pest-predators such as black ants [14, 15]. Integrated pest management (IPM), combining several possible preventive and curative measures, is currently promoted worldwide [5]. However, in most cases, implementing IPM on-farm level is too complicated for most smallholder farmers.

Suppressing the population of pests and pathogens by applying whatever appropriate methods, may directly contribute to the improvement of cocoa production. Nevertheless, soil fertility may also become a significant limiting factor of cocoa production [16], which such condition occurred in cocoa farming in Papua New Guinea [17]. Accordingly, to significantly improve the productivity of cocoa farming, the actions for combating PDAs should be integrated with appropriate soil fertilization, especially for cocoa grown on infertile soils. Importantly, the integrated method should be technically applicable for smallholders with their various land condition.

Another acceptable view is that the plant receiving sufficient and proportional supply of plant-essential nutrients in a suitable environmental condition will grow and produce optimum yield. A healthy plant can perform its highest natural-defence system [18]. Moreover, many researchers [19-23] reported that applying Si-based fertilizers improves the resistance of the plant to biotic (e.g., PDAs) and abiotic stressors. Therefore, it is reasonable to postulate that applying the Si-based fertilizers containing all essential nutrients, with or without suppressing the population pests in the farming areas, may reduce PDAs or minimize the damaging impact of PDAs on the cocoa beans and at the same time improve the bean production. The other possible-appropriate method is by combining the application of the Si-based fertilizers with botanical pesticides or pest-enemies such as black ants. Field tests are required to identify the most effective method to improve cocoa production.

The main objective of this field research was to identify the effects of applying the locally available materials, i.e., liquid-silicate rock fertilizer (LSRF), the botanical pesticide (BP) of *neem* leaf, and black ants (BA) of *Doliccoderus thoracic* on the intensity of PDAs, bean production, and polyphenol and lignin content of cocoa pod shell.

# 2. Materials and Method

## 2.1. Description of Experiment Site

This experiment was conducted in a farmer's cocoa farming land in Genggelang village, North Lombok Regency, Indonesia (8$^o$20'37.9" S, 116$^o$14'13.1" E). The land was at about 335-m above sea level with the moderately deep-sandy textured soil (Arenic Eutrundepts) developed from pumice stone on undulating physiography (4 – 8 % sloping). The soil pH was 6 – 6.5, moderate C-organic content (1.5 – 2.2 %), relatively low contents of N (< 0.01 %) and Bray-extractable P (2 - 5 mg.kg$^-$), cation exchange capacity (4.8 cmol.kg$^-$), and exchangeable Ca, Mg, and K (respectively 4.8, 1.4, and 0.58 cmol.kg$^-$).

## 2.2. Experimental Materials, Design, and Management

The primary materials used in this experiment were liquid-silicate rock fertilizer (LSRF), botanical pesticide (BP) of *neem*, and black ants (BA) of *Doliccoderus thoracicus*, which were prepared as follows:

- The LSRF was produced from basaltic silicate rocks, containing (w/v) of 6.4 % Si, 4.04 % N, 3.22 % $P_2O_5$, 3.36 % $K_2O$, 0.32 % Ca, 0.40 % Mg, 0.12 % S, 40 mg.L$^-$ Fe, 122 mg.L$^-$ Mn, 260 mg.L$^-$ Zn, 10 mg.L$^-$ Cu, 3.0 mg.L$^-$ B, 0.1 mg.L$^-$ Co, and 1.2 mg.L$^-$ Mo.
- The botanical pesticide (BP) was made from *neem* leaf (*Azadirachta indica*). A kilogram of fresh *neem* leaf was crushed into < 2 mm, incubated for 24 hours with 2-L fresh water in a closed plastic container. The suspension was filtered, and the filtrate (BP) was stored in another closed plastic container. The BP was freshly prepared a week before application.
- Black ants (BA) of *Doliccoderus thoracicus* were collected from the surrounding area of the experiment site. A plastic bag was filled with an amount of dry banana leaf sprayed with a sugar solution to attract black ants to house in the bag. The population of the trapped black ants in each bag was about 200 ants at the starting time of this experiment.

This experiment was laid out in a randomized complete block design with the treatments consisting of LSRF, LSRF+BP, LSRF+BA, BA, and control, and those were triplicated (in 3 blocks). Each plot contained 10-productive cocoa trees of about 7-year old. The experiment was run for 14 months (September 2015 – December 2016).

For the application of LSRF, 300-mL LSRF was diluted with freshwater into 30 L and then sprayed evenly onto the leaf of cocoa trees in an experimental unit containing ten cocoa trees. For an experimental unit of the treatment of LSRF + BP, 300-mL LSRF and 40-mL BP were mixed and diluted with freshwater into 30 L and was sprayed evenly onto the leaf of cocoa trees. The treatments of LSRF and LSRF + BP were applied fortnightly. For the treatments of LSRF + BA and BA, each bag of black ants described above was hanged on a branch of each cocoa tree.

## 2.3. Data Collection and Statistical Analysis

The primarily collected data were (1) the intensity-incident of PDAs, (2) the annual-bean production, and (3) the polyphenol and lignin contents of the pod shell. The number of pods attacked by pests or/and diseases in each plot was observed monthly, started from November 2015 (a month after the first application of the treatments) up to the end of the experiment (December 2016). The intensity incident of PDAs (%) was calculated on the besis of sum of cocoa pods of 14-month observations:

$$\text{PDAs (\%)} = \frac{\Sigma \text{ pods attacked by pests or/and diseases}}{\Sigma \text{ whole pods}} \text{ x } 100$$

The ripe pods were harvested weekly for 14 months, and then the beans were oven-dried at 40$^o$ C to reach a constant weight (after 7 – 10 days of drying). The dry beans and pod shells, harvested at the end of June - August 2016), were sampled for the measurements of polyphenol and lignin contents using the colorimetric methods [24, 25].

All collected data were subjected to the analysis of variance (ANOVA) to identify the effects of the treatments on each observed parameter as described above and followed with the analysis of least significant difference ($LSD_{\alpha = 0.05}$) for the parameters that were significantly affected by the treatments.

# 3. Results

The effects of the treatments on the incident-intensity of PDAs, annual-bean production, and polyphenol and lignin contents of pod shell are presented in Table 1. It was noted that the observed pests attacking cocoa pods during the experiment were *Hellopeltis* and *Conopomorpha cramerella*, and the diseases were cocoa-black pod (CBP) caused by *Phytophthora palmivora* and *Colletotrichum gloeosporioides*.

**Table-1.** The effects of liquid-silicate rock fertilizer (LSRF), botanical pesticide (BP), and black ants (BA) on the incident-intensity of pest and disease attacks, annual-bean production, and polyphenol and lignin contents of cocoa pod shell

| Treatments | Pest Attacks (%) | Disease Attacks (%) | Bean Production (kg.plot$^{-}$.y$^{-}$) | Polyphenol Content (%) | Lignin Content (%) |
|---|---|---|---|---|---|
| Control | 75.7 b | 11.8 d | 4.98 a | 5.70 a 7.12 b | 20.25 a 28.03 b |
| LSRF | 62.3 a | 5.6 b | 10.42 d | 9.33 c 7.61 b | 29.28 b 20.54 a |
| LSRF+BP | 70.7 b | 3.1 a | 8.41 c | 10.18 d | 23.04 a |
| LSRF+BA | 62.7 a | 8.9 c | 7.05 b | | |
| BA | 57.9 a | 5.8 b | 5.89 a | | |
| LSD $_{\alpha = 0.05}$ | 7.6 | 0.3 | 1.06 | 0.78 | 0.96 |

The values in the same column, followed by the same letter are not significantly different based on LSD$_{\alpha=0.05}$.

A specific observation was carried out to the pods that were attacked by pests (*Hellopeltis* and *Conopomorpha cramerella*). Result of the visual observation showed that most of the beans in the pods of the cocoa trees treated with LSRF, LSRF + BP, or LSRF + BA were still in good condition. In contrast, more than 60 % of the beans of the attacked pods of the control trees were in a damaged condition – flatty and dark-coloured (data are not shown in this paper). Thus, the attacks of *Hellopeltis* or/and CBP on the pods of the treated cocoa trees damaged only the outmost part of pod shell, injuring only a minor part of the beans inside the pods.

# 4. Discussion

As shown in Table 1, the intensities of pest and disease attacks for the cocoa trees treated with LSRF, LSRF+BP, LSRF+BA, and BA were significantly lower than of that for the control. The decreases of pest and disease attacks due to those treatments, respectively, ranged from 6 to 18 % and from 3 to 6 %. Inversely, the treatments significantly increased bean production with the order of the treatments, based on its quantity of bean production, was LSRF > LSRF+BP > LSRF+BA > BA > control. The bean production for the control was about 5 kg.plot$^{-}$.y$^{-}$ (~ 550 kg.ha$^{-}$.y$^{-}$), whereas for the treated cocoa trees was 6 to 10.5 kg.plot$^{-}$.y$^{-}$ (~ 650 to 1,100 kg.ha$^{-}$.y$^{-}$). In other words, the treatments increased about 18 to 109 % of bean production, and the highest increase (109 % over that of the control) was gained by foliar application of LSRF.

The identification of polyphenol and lignin contents of the pod shell was aimed to explain if the treatments affect the resistance of cocoa to PDAs. Polyphenol has essential roles due to its antioxidant capacity being beneficial to human health [26] and contributes to the improvement of the defense system of the plant to PDAs [27]. Lignin, as an essential part of the cell structure, also has a substantial role in the defense system of the plant to PDAs, including in reducing the damaging impact of CPB or Phytophthora attacks on cocoa pods. Lignification could provide more strength and rigidity to the cell wall of the plant [28].

In this present research, the applications of LSRF, LSRF+BP, or LSRF+BA significantly increased polyphenol and lignin contents of the cocoa pod shell. The enrichment of those substances in the pod shell may improve the resistance of cocoa pod to PDAs (especially of *Hellopeltis* or/and CBP). Moreover, the result of visual observation as described in earlier section proved that the application of LSRF (a Si-containing fertilizer) alone or in combination with BP or BA strengthened the cell wall of cocoa pods, avoiding the injuring impact of PDAs to cocoa bean in the pods. Therefore, the application of LSRF significantly increased cocoa bean production through the mechanism of improving the defence system and satisfying the plant with essential nutrients.

# 5. Conclusion

The applications of liquid-silicate rock fertilizer (LSRF), the combination of it with botanical pesticide (LSRF + BP) or with black ants (LSRF + BA), and BA alone provided several positive effects on cocoa. Those effects included the reduction of pest and disease attacks (PDAs), the increases of annual-bean production and the polyphenol and lignin contents in the cocoa pod shell. The highest gain of the annual-bean yield of cocoa was due to the application of LSRF. The use of the fertilizer (LSRF) stimulated the optimum defense system of cocoa to PDAs and provided a sufficient supply of essential nutrients to the plant. Thus, using LSRF may be promoted as an appropriate method to improve cocoa farming productivity, especially in less fertilize soils, in Indonesia.

# Acknowledgement

We thank and appreciate the World Cocoa Foundation (WCF) for its funding to this research. Special thanks to MS. Virginia Sofila and Mr Ben Breman for their help in the project administration and implementation

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