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ENVIRONMENTAL FACTORS AFFECTING PRODUCTIVITY OF TWO INDONESIAN VARIETIES OF BLACK PEPPER (*Piper nigrum* L.)

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ABSTRACT

Black pepper plantation area in Lampung province (the biggest producer area in Indonesia) has decreased from time to time, which might be related to unfavourable environmental condition. The aim of this study was to assess which environmental factors are positively or negatively correlated with productivity in particular yield of two local varieties of black pepper plant (Natar 1 and Natar 2) in Lampung province. Two observational studies were carried out i.e. phenological development and productivity of black pepper productivity in relation to various environmental factors. Our results showed that productivity of two varieties significantly affected rainfall, light intensity and micro humidity. Dry matter yield was positively correlated with rainfall, both in Natar 1 and Natar 2. It was concluded that among environmental factors affecting productivity of black pepper, rainfall intensity was the most influencing factor with a positive relationship with the productivity.

Keywords: black pepper, climate, cultivar, environment, Indonesia

INTRODUCTION

Black pepper (*Piper nigrum* L.) is a plant species that is widely used as spice and possesses a variety of medicinal properties, such as immunomodulatory, anti-oxidant, anti-asthmatic, anti-carcinogenic, anti-inflammatory, anti-ulcer and anti-amoebic effects (Ahmad *et al.,* 2012; Meghwal and Goswami 2013). In Indonesia, black pepper is one of the oldest cultivated plants, and up to date, it is an important non-oil export product after rubber, tea, palm oil and coffee. Indonesia had been the third biggest pepper producer in the world in 2004, both black and white pepper. With regard to black pepper only, Indonesia was the fourth biggest producer at that time, while it was the first for that of white pepper. Accordingly, black pepper plants are mainly cultivated by small-holder farmers. Main provinces or regions in Indonesia that produce black pepper in considerable amounts are Lampung, Bangka Belitung, West Kalimantan and East Kalimantan. Within the respective regions, Lampung province is the largest pepper producer and approximately 80% of black pepper export is originated from this province.

Successful cultivation of black pepper plant is affected by various environmental factors such as temperature and light intensity (Li *et al.*, 2010). In Lampung province, black pepper plantation area has decreased coinciding with its lower productivity from time to time. Productivity of black pepper in the province was 651 kg ha^{-1} in 2005 and declined to 461 kg ha^{-1} in 2011, whereas national black pepper productivity in 2011 in average was approximately 734 kg ha^{-1} (Estate Agency of Lampung Province, 2012). It has been hypothesized that such decline of black pepper productivity in Lampung province during the past decade is due to unfavourable environmental conditions especially related to a decline in soil fertility (Ann, 2012) and unsuitable weather (Kandiannan *et al.*, 2011). Apart from that, it may be also that cultivation area of black pepper in Lampung province does not fit the available black pepper varieties within the region in order to support sustainable production of the plant and in turn creates various productivity constraints. Selection of suitable land by considering a number of soil characteristics (e.g.

pH, physical properties, chemical composition, etc.,) for black pepper plantation is therefore essential (Tanaka *et al.*, 2009; Dinesh *et al.,* 2010).

Knowledge on the characteristics of black pepper varieties, environmental conditions, climate, and soil conditions where the pepper plants grow is a pivotal consideration in the cultivation of black pepper in Lampung. Through the respective knowledge, selection of land, cultivation practices, fertilization, and maintenance of black pepper plants could match with the specific needs for the success of black pepper cultivation in Lampung province. Therefore, this study is aimed to assess which environmental factors are positively or negatively correlated with productivity in particular yield of two local varieties of black pepper plant within the respective region.

MATERIALS AND METHODS

Research location

Lampung province was chosen as the study area since Lampung is the largest producer of black pepper in Indonesia. Four locations were chosen as the observation sites, i.e. Sekincau (West Lampung), Abung Barat (North Lampung), Margatiga (East Lampung) and Natar (South Lampung). Two observational studies were carried out in the present study. Observation on phenological development of black pepper was conducted at two locations, i.e. at Abung Barat and Natar. The duration of the experiment was 10 months, from December 2011 to September 2012. In the second observational study, environmental factors affecting productivity of black pepper was investigated from September 2011 to September 2012 (13 months), conducted at all sites, i.e. Sekincau, Abung Barat, Margatiga and Natar. In both studies, two Indonesian varieties of black pepper, i.e. Natar 1 and Natar 2 were used. A number of environmental variables were recorded at all observational sites. These comprised altitude, rainfall intensity, humidity, light intensity, ambient temperature, soil pH, C/N ratio and cation exchange capacity (CEC; Table 1).

Phenological observation

Three black pepper trees in each variety were observed for their phenological development. In each tree, 15 footstalks were randomly selected. Observation was done at three phenological development of black pepper, i.e. at flowering, fruiting and ripening stages as described by Figueiredo and Sazima (2007). The observed variables were the period of flowering, fruiting and ripening.

Productivity observation

A total of 100 black pepper trees for each study location were used as measurement objects, comprising 50 trees of Natar 1 variety and 50 trees of Natar 2 variety. Production variables of black pepper plant were measured, i.e. plant height, canopy width, weight of fruit (both wet and dry weight) per plant.

Table 1. Environmental variables of the experimental sites in Lampung province

Variable	Sekincau	Abung Barat	Margatiga	Natar
General				
Altitude (m)	1,191	180	114	72
Rainfall (mm month^{-1})	158	181	181	102
Local humidity (%)	93.6	83.0	79.8	81.5
Micro-climate				
Light intensity (lux)	912 ± 7.70	972 ± 7.10	990 ± 8.40	923 ± 8.10
Day temperature (°C)	26.0 ± 0.78	31.4 ± 0.54	31.4 ± 0.79	32.3 ± 0.67
Night temperature (°C)	17.3 ± 0.55	23.6 ± 0.18	23.7 ± 0.38	23.3 ± 0.66
Micro humidity (%)	92.9 ± 0.85	79.4 ± 0.74	78.4 ± 0.35	82.7 ± 0.53
Soil				
pH	4.96 ± 0.24	4.98 ± 0.11	5.16 ± 0.18	5.08 ± 0.18
C/N ratio	8.4 ± 0.35	9.4 ± 2.46	7.4 ± 0.17	7.9 ± 0.05
CEC	19.4 ± 2.69	12.1 ± 1.77	14.0 ± 1.47	11.6 ± 0.48

Remarks: CEC = cation exchange capacity

Data analysis

Canonical correspondence analysis (CCA) followed by ordistep analysis with 1000 permutation was performed to assess which environmental variables (as independent factor) influenced productivity related variables (dependent factor). Principal component analysis (PCA) was used to explore the relationship among variables observed. Here, productivity was represented only by dry matter yield. Extraction method of PCA was based on Eigen value higher than or equal to 1.0. However, only the first two principal components (PCs) were plotted into loading plot. The entire statistical analysis was conducted by using R statistical software (R Core Team, 2013).

RESULTS AND DISCUSSION

RESULTS

Environmental condition

Measurements of a number of environmental variables in various observational sites showed different characteristics in each location (Table 1). Sekincau was a high-land area and had the highest relative humidity among other locations. Average monthly rainfall at all locations was above 100 mm. In term of micro-climatic variables, Sekincau was also unique compared to other locations, in which light intensity and day and night temperature were lower. Other three locations, i.e. Abung Barat, Margatiga and Natar were closely similar for the respective micro-climatic variables. Abung Barat appeared to be more fertile compared to the others with regard to C/N ratio, while Sekincau had the highest cation exchange capacity (CEC) than that of Abung Barat, Margatiga and Natar experimental sites.

Phenological development

Periods of flowering, fruiting and ripening of two Indonesian varieties of black pepper, i.e. Natar 1 and Natar 2, at Abung Barat and Natar observational sites in Lampung province are presented in Table 2. Apparently, different locations determined flowering, fruiting and ripening period more than different varieties. Flowering and fruiting period of both Natar 1 and Natar 2 varieties in Abung Barat were longer than those in Natar experimental site. Conversely, ripening period of Natar 1 and Natar 2 in Abung Barat was shorter compared to that in Natar. Variation of flowering, fruiting and ripening period between Natar 1 and Natar 2 within each location was low. Despite such a low variation, Natar 1 appeared to have shorter flowering and fruiting period than that of Natar 2, while the ripening period of the two varieties was varied. Looking at phenotype appearance of both varieties, leaf of Natar 1 was thin and green, while the leaf in Natar 2 was thicker and possessed darker green than that in Natar 1. Natar 1 had no tentacle while the other varieties had tentacle (data not shown).

Table 2. The period of flowering, fruiting and ripening (days) of two Indonesian varieties of black pepper in Lampung province

Location	Variety	Flower-ing (d)	Fruit-ing (d)	Ripen-ing (d)
Abung Barat	Natar 1			
	Tree 1	28	174	10
	Tree 2	28	174	10
	Tree 3	28	174	10
	Natar 2			
	Tree 1	29	175	8
	Tree 2	29	175	8
	Tree 3	29	175	8
Natar	Natar 1			
	Tree 1	26	171	12
	Tree 2	26	170	13
	Tree 3	26	169	18
	Natar 2			
	Tree 1	27	172	15
	Tree 2	27	173	15
	Tree 3	27	171	12

Productivity of black pepper and its relationship with environmental variables

Wet weight and dry weight of black pepper were higher in Abung Barat and Margatiga compared to those in Sekincau and Natar (Table 3). Such patterns were closely similar in term of plant height and canopy diameter variables; higher weight was reflected by higher plant height and longer canopy diameter. With regard to black pepper variety used, it appeared that Natar 1 and Natar 2 were varied in the respective variables in all observation area.

Results on canonical correspondence analysis (CCA) showed that productivity of Natar 1 variety was significantly affected by light intensity, rainfall, micro humidity, local humidity, soil pH and day temperature (P<0.05), while CEC, altitude, night temperature and C/N ratio was not (Table 4). Variety of Natar 2 revealed closely similar pattern in term of influential environmental factors affecting its productivity although there were some dissimilarities; micro humidity, rainfall, light intensity, C/N ratio, local humidity and soil pH significantly affected productivity (P<0.05), while altitude, day temperature, CEC and night temperature did not (Table 5).

In Natar 1 variety and across all observational sites, as much as 65.1% and 22.5% of total variation could be explained by principal component 1 (PC1) and principal component 2 (PC2), respectively (Figure 1). Dry matter yield was positively correlated with rainfall but negatively correlated with C/N ratio. In Natar 2 variety, PC1 and PC2 explained 62.3% and 28.0% from total variation (Figure 2). Rainfall, micro humidity and C/N ratio were positively correlated with DM yield, whereas light intensity was negatively correlated with the DM yield.

Table 3. Observation of plant characteristics of two Indonesian varieties of black pepper in Lampung province

Location	Plant height (cm)		Canopy diameter (cm)		Wet weight /tree (kg)		Dry weight /tree (kg)	
	Natar 1	Natar 2	Natar 1	Natar 2	Natar 1	Natar 2	Natar 1	Natar 2
Sekincau	300	302	68	69	5.5	7.6	1.2	1.7
Abung Barat	506	372	114	111	11.1	6.0	2.5	2.0
Margatiga	504	463	112	108	7.1	6.7	2.7	2.3
Natar	303	288	83	101	3.9	5.5	1.4	1.9

Table 4. Influence of environmental variables on productivity of Natar 1 variety assessed by using canonical correspondence analysis (CCA)

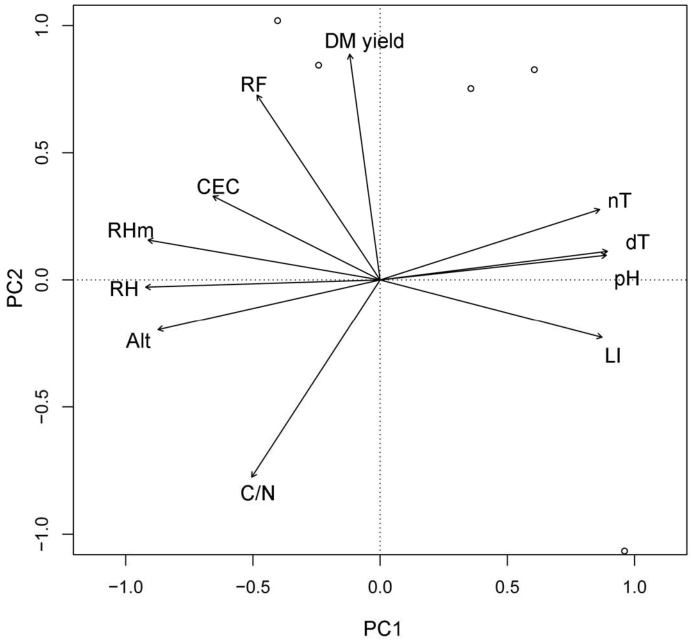
Variable	Df [1)]	AIC [2)]	F	N perm [3)]	P-value
Light intensity	1	11.11	20.08	999	<0.001
Rainfall	1	8.43	28.69	999	0.002
Micro humidity	1	11.17	19.90	999	0.002
Local humidity	1	16.00	9.22	999	0.014
Soil pH	1	17. 92	6.20	999	0.024
Day temperature	1	19.08	4.65	999	0.047
CEC [4)]	1	19.76	3.82	999	0.062
Altitude	1	20.49	2.99	999	0.096
Night temperature	1	21.16	2.28	999	0.132
C/N ratio	1	23.54	0.10	999	0.746

Remarks: [1)] degree of freedom; [2)] Akaike Information Criteria; [3)] Number of permutation; [4)] Cation Exchange Capacity

Table 5. Influence of environmental variables on productivity of Natar 2 variety assessed by using canonical correspondence analysis (CCA)

Variable	Df [1)]	AIC [2)]	F	N perm [3)]	P-value
Micro humidity	1	5.62	26.18	999	<0.001
Rainfall	1	5.84	25.43	999	<0.001
Light intensity	1	6.45	23.48	999	0.004
C/N ratio	1	14.38	6.24	999	0.020
Local humidity	1	13.57	7.44	999	0.021
Soil pH	1	15.17	5.15	999	0.049
Altitude	1	18.94	1.02	999	0.260
Day temperature	1	18.95	1.01	999	0.283
CEC [4)]	1	19.21	0.78	999	0.389
Night temperature	1	19.40	0.62	999	0.405

Remarks: [1)] degree of freedom; [2)] Akaike Information Criteria; [3)] Number of permutation; [4)] Cation Exchange Capacity



Remarks: Alt = altitude; CEC = cation exchange capacity; DM = dry matter; dT = day temperature; LI = light intensity; nT = night temperature; RF = rainfall; RH = local humidity; RHm = micro humidity

Figure 1. Loading plot of principal component 1 (PC1; 65.1% from total variation) and principal component 2 (PC2; 22.5% from total variation) of Natar 1 variety

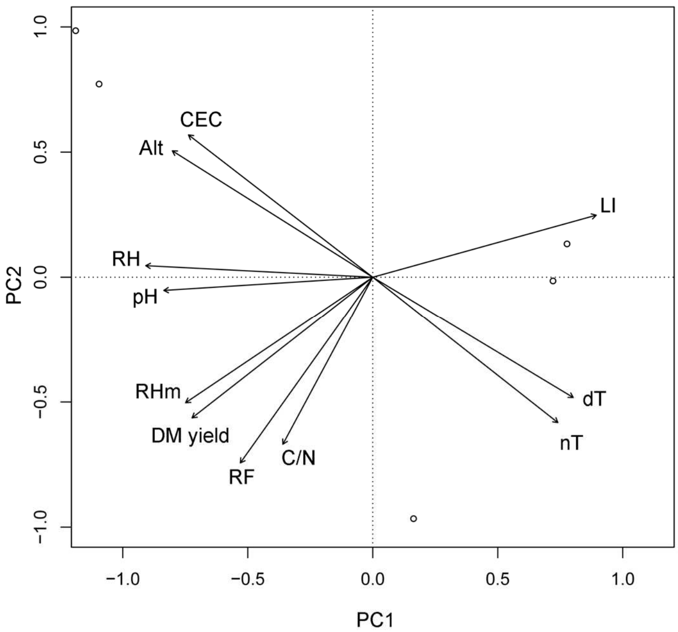


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Figure 2. Loading plot of principal component 1 (PC1; 62.3% from total variation) and principal component 2 (PC2; 28.0% from total variation) of Natar 2 variety

DISCUSSION

Among all environmental factors measured in the study, it appears that rainfall, micro humidity and light intensity play important roles and influence most productivity of black pepper in Lampung province. Rainfall is the most important environmental factor affecting black pepper productivity (as shown by CCA analysis) with a positive correlation between both variables (as shown by PCA analysis) irrespective of different varieties of the plant.

Black pepper is a high-demanding nutrient plant species (Ann, 2012), and it requires plenty of water (Rosman *et al.*, 1996). A desired level of rainfall for the optimum growth of black pepper ranged from 2000 to 3000 mm year^{-1} with an average of 2300 mm year^{-1}, and without dry months with rainfall less than 60 mm month^{-1}. The growth of black pepper begins to hamper when the monthly rainfall is less than 90 mm month^{-1} (Rosman *et al.*, 1996). All observational sites in this study, i.e Sekincau, Abung Barat, Margatiga and Natar showed rainfall higher than 100 mm month^{-1}, which implied that there was no obstacle of rainfall or water requirement for the growth of black pepper in the respective area. However, higher rainfall intensity within the observed range led to higher productivity of black pepper in term of wet and dry weight, as well as plant height and canopy diameter. The result is in accordance with Hao *et al.*, (2012) who observed that precipitation of the wettest month was identified as a highly effective factor in the distribution of black pepper in Asia and could possibly account for the black pepper distribution pattern. Further, black pepper productivity showed a decreasing trend due to lower rainfall and higher temperature concomitantly (Krishnamurthy *et al.*, 2011).

Apart from providing water as an essential nutrient for the growth of black pepper, rainfall may affect macro and micro climatic conditions which are also important for the plant. Rainwater affects the availability of ground water, soil physical and chemical properties, micro temperature and micro humidity in black pepper plantation area. Changes in environmental conditions may trigger the growth of the bud and early flowering of the plant; high variation of rainfall will certainly affect the ability of black pepper during the growth period and the development of flower buds. Black pepper plant requires a lot of rainfall in addition to a warm climate and sufficient light intensity (Rosman *et al.*, 1996).

Intensity of sunlight is necessary for maintaining photosynthesis activity of plants. Plants transform light energy into chemical energy in the form of ATP and NADPH through the process of photosynthesis. This molecule then provides energy to bind CO_2 atmosphere and in the synthesis of carbohydrates, of which 80 to 90% dry weight of the plant comes from the carbohydrates (Noggle and Fritz, 1979). Furthermore, light intensity affects the absorption of nutrients for plants (Eriksen and Whitney, 1981). Light intensity also affects the microclimate such as temperature micro, micro air humidity and soil moisture content. However, if the light intensity is too high, it may cause respiratory rate greater than the rate of photosynthesis which in turn may decrease the yield. In this study, light intensity appeared to be conversely related to black pepper productivity, i.e. the DM yield especially for Natar 2 variety. It might be that the level of light intensity in all observation sites is already high and, therefore, leads to a counter-productive effect on the yield of black pepper. It is confirmed that pepper plants require a moderate light intensity (not too low and not too high) in accordance with the character as a protected plant (sciophyta) with C_3 photosynthetic pathway (Das *et al.*, 1976). Further, Wahid (1984) stated that the pepper plants need a light intensity of 50 to 75% in order to grow well. Therefore, pepper plants need to be managed by pruning to obtain sufficient light intensity.

CONCLUSION

Among a number of environmental factors affecting the productivity of black pepper in Lampung province, Indonesia, apparently rainfall intensity is the most important factor. Accordingly, rainfall has a positive correlation with black pepper productivity; higher rainfall leads to higher productivity. This information is important for the policy of further development of black pepper plantation area, not only in the country but also in other parts of the world. However, production of black pepper will be facing an uncertainty in the context of climate change driven by global warming in the future. As precipitation may be significantly lower at simultaneously higher environmental temperature, the productivity as well as the extent of black pepper production is under threat. Development of a certain varieties that are adapted to such environment may provide a solution for the future of black pepper agriculture.

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MATERIALS AND METHODS

Research location

Lampung province was chosen as the study area since Lampung is the largest producer of black pepper in Indonesia. Four locations were chosen as the observation sites, i.e. Sekincau (West Lampung), Abung Barat (North Lampung), Margatiga (East Lampung) and Natar (South Lampung). Two observational studies were carried out in the present study. Observation on phenological development of black pepper was conducted at two locations, i.e. at Abung Barat and Natar. The duration of the experiment was 10 months, from December 2011 to September 2012. In the second observational study, environmental factors affecting productivity of black pepper was investigated from September 2011 to September 2012 (13 months), conducted at all sites, i.e. Sekincau, Abung Barat, Margatiga and Natar. In both studies, two Indonesian varieties of black pepper, i.e. Natar 1 and Natar 2 were used. A number of environmental variables were recorded at all observational sites. These comprised altitude, rainfall intensity, humidity, light intensity, ambient temperature, soil pH, C/N ratio and cation exchange capacity (CEC; Table 1).

Phenological observation

Three black pepper trees in each variety were observed for their phenological development. In each tree, 15 footstalks were randomly selected. Observation was done at three phenological development of black pepper, i.e. at flowering, fruiting and ripening stages as described by Figueiredo and Sazima (2007). The observed variables were the period of flowering, fruiting and ripening.

Productivity observation

A total of 100 black pepper trees for each study location were used as measurement objects, comprising 50 trees of Natar 1 variety and 50 trees of Natar 2 variety. Production variables of black pepper plant were measured, i.e. plant height, canopy width, weight of fruit (both wet and dry weight) per plant.

Table 1. Environmental variables of the experimental sites in Lampung province

Variable	Sekincau	Abung Barat	Margatiga	Natar
General				
Altitude (m)	1,191	180	114	72
Rainfall (mm month^{-1})	158	181	181	102
Local humidity (%)	93.6	83.0	79.8	81.5
Micro-climate				
Light intensity (lux)	912 ± 7.70	972 ± 7.10	990 ± 8.40	923 ± 8.10
Day temperature (°C)	26.0 ± 0.78	31.4 ± 0.54	31.4 ± 0.79	32.3 ± 0.67
Night temperature (°C)	17.3 ± 0.55	23.6 ± 0.18	23.7 ± 0.38	23.3 ± 0.66
Micro humidity (%)	92.9 ± 0.85	79.4 ± 0.74	78.4 ± 0.35	82.7 ± 0.53
Soil				
pH	4.96 ± 0.24	4.98 ± 0.11	5.16 ± 0.18	5.08 ± 0.18
C/N ratio	8.4 ± 0.35	9.4 ± 2.46	7.4 ± 0.17	7.9 ± 0.05
CEC	19.4 ± 2.69	12.1 ± 1.77	14.0 ± 1.47	11.6 ± 0.48

Remarks: CEC = cation exchange capacity

Data analysis

Canonical correspondence analysis (CCA) followed by ordistep analysis with 1000 permutation was performed to assess which environmental variables (as independent factor) influenced productivity related variables (dependent factor). Principal component analysis (PCA) was used to explore the relationship among variables observed. Here, productivity was represented only by dry matter yield. Extraction method of PCA was based on Eigen value higher than or equal to 1.0. However, only the first two principal components (PCs) were plotted into loading plot. The entire statistical analysis was conducted by using R statistical software (R Core Team, 2013).

RESULTS AND DISCUSSION

RESULTS

Environmental condition

Measurements of a number of environmental variables in various observational sites showed different characteristics in each location (Table 1). Sekincau was a high-land area and had the highest relative humidity among other locations. Average monthly rainfall at all locations was above 100 mm. In term of micro-climatic variables, Sekincau was also unique compared to other locations, in which light intensity and day and night temperature were lower. Other three locations, i.e. Abung Barat, Margatiga and Natar were closely similar for the respective micro-climatic variables. Abung Barat appeared to be more fertile compared to the others with regard to C/N ratio, while Sekincau had the highest cation exchange capacity (CEC) than that of Abung Barat, Margatiga and Natar experimental sites.

Phenological development

Periods of flowering, fruiting and ripening of two Indonesian varieties of black pepper, i.e. Natar 1 and Natar 2, at Abung Barat and Natar observational sites in Lampung province are presented in Table 2. Apparently, different locations determined flowering, fruiting and ripening period more than different varieties. Flowering and fruiting period of both Natar 1 and Natar 2 varieties in Abung Barat were longer than those in Natar experimental site. Conversely, ripening period of Natar 1 and Natar 2 in Abung Barat was shorter compared to that in Natar. Variation of flowering, fruiting and ripening period between Natar 1 and Natar 2 within each location was low. Despite such a low variation, Natar 1 appeared to have shorter flowering and fruiting period than that of Natar 2, while the ripening period of the two varieties was varied. Looking at phenotype appearance of both varieties, leaf of Natar 1 was thin and green, while the leaf in Natar 2 was thicker and possessed darker green than that in Natar 1. Natar 1 had no tentacle while the other varieties had tentacle (data not shown).

Table 2. The period of flowering, fruiting and ripening (days) of two Indonesian varieties of black pepper in Lampung province

Location	Variety	Flower-ing (d)	Fruit-ing (d)	Ripen-ing (d)
Abung Barat	Natar 1			
	Tree 1	28	174	10
	Tree 2	28	174	10
	Tree 3	28	174	10
	Natar 2			
	Tree 1	29	175	8
	Tree 2	29	175	8
	Tree 3	29	175	8
Natar	Natar 1			
	Tree 1	26	171	12
	Tree 2	26	170	13
	Tree 3	26	169	18
	Natar 2			
	Tree 1	27	172	15
	Tree 2	27	173	15
	Tree 3	27	171	12

Productivity of black pepper and its relationship with environmental variables

Wet weight and dry weight of black pepper were higher in Abung Barat and Margatiga compared to those in Sekincau and Natar (Table 3). Such patterns were closely similar in term of plant height and canopy diameter variables; higher weight was reflected by higher plant height and longer canopy diameter. With regard to black pepper variety used, it appeared that Natar 1 and Natar 2 were varied in the respective variables in all observation area.

Results on canonical correspondence analysis (CCA) showed that productivity of Natar 1 variety was significantly affected by light intensity, rainfall, micro humidity, local humidity, soil pH and day temperature ($P<0.05$), while

CEC, altitude, night temperature and C/N ratio was not (Table 4). Variety of Natar 2 revealed closely similar pattern in term of influential environmental factors affecting its productivity although there were some dissimilarities; micro humidity, rainfall, light intensity, C/N ratio, local humidity and soil pH significantly affected productivity ($P<0.05$), while altitude, day temperature, CEC and night temperature did not (Table 5).

In Natar 1 variety and across all observational sites, as much as 65.1% and 22.5% of total variation could be explained by principal component 1 (PC1) and principal component 2 (PC2), respectively (Figure 1). Dry matter yield was positively correlated with rainfall but negatively correlated with C/N ratio. In Natar 2 variety, PC1 and PC2 explained 62.3% and 28.0% from total variation (Figure 2). Rainfall, micro humidity and C/N ratio were positively correlated with DM yield, whereas light intensity was negatively correlated with the DM yield.

Table 3. Observation of plant characteristics of two Indonesian varieties of black pepper in Lampung province

Location	**Plant height (cm)**		**Canopy diameter (cm)**		**Wet weight /tree (kg)**		**Dry weight /tree (kg)**	
	Natar 1	**Natar 2**	**Natar 1**	**Natar 2**	**Natar 1**	**Natar 2**	**Natar 1**	**Natar 2**
Sekincau	300	302	68	69	5.5	7.6	1.2	1.7
Abung Barat	506	372	114	111	11.1	6.0	2.5	2.0
Margatiga	504	463	112	108	7.1	6.7	2.7	2.3
Natar	303	288	83	101	3.9	5.5	1.4	1.9

Table 4. Influence of environmental variables on productivity of Natar 1 variety assessed by using canonical correspondence analysis (CCA)

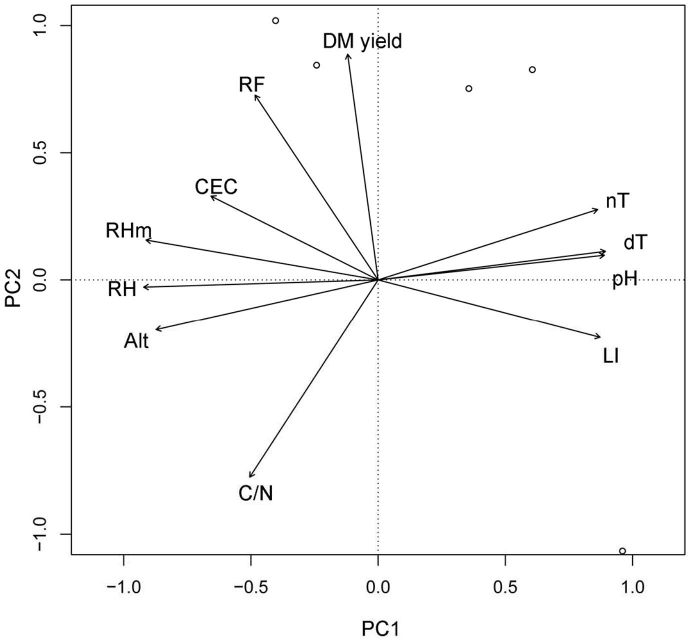
Variable	**Df [1)]**	**AIC [2)]**	**F**	**N perm [3)]**	**P-value**
Light intensity	1	11.11	20.08	999	<0.001
Rainfall	1	8.43	28.69	999	0.002
Micro humidity	1	11.17	19.90	999	0.002
Local humidity	1	16.00	9.22	999	0.014
Soil pH	1	17. 92	6.20	999	0.024
Day temperature	1	19.08	4.65	999	0.047
CEC [4)]	1	19.76	3.82	999	0.062
Altitude	1	20.49	2.99	999	0.096
Night temperature	1	21.16	2.28	999	0.132
C/N ratio	1	23.54	0.10	999	0.746

Remarks: [1)] degree of freedom; [2)] Akaike Information Criteria; [3)] Number of permutation; [4)] Cation Exchange Capacity

Table 5. Influence of environmental variables on productivity of Natar 2 variety assessed by using canonical correspondence analysis (CCA)

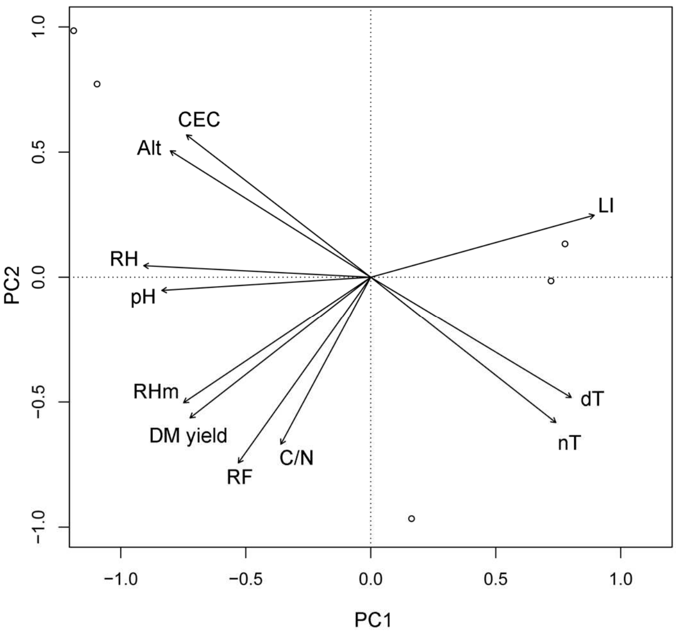
Variable	**Df [1)]**	**AIC [2)]**	**F**	**N perm [3)]**	**P-value**
Micro humidity	1	5.62	26.18	999	<0.001
Rainfall	1	5.84	25.43	999	<0.001
Light intensity	1	6.45	23.48	999	0.004
C/N ratio	1	14.38	6.24	999	0.020
Local humidity	1	13.57	7.44	999	0.021
Soil pH	1	15.17	5.15	999	0.049
Altitude	1	18.94	1.02	999	0.260
Day temperature	1	18.95	1.01	999	0.283
CEC [4)]	1	19.21	0.78	999	0.389
Night temperature	1	19.40	0.62	999	0.405

Remarks: [1)] degree of freedom; [2)] Akaike Information Criteria; [3)] Number of permutation; [4)] Cation Exchange Capacity



Remarks: Alt = altitude; CEC = cation exchange capacity; DM = dry matter; dT = day temperature; LI = light intensity; nT = night temperature; RF = rainfall; RH = local humidity; RHm = micro humidity

Figure 1. Loading plot of principal component 1 (PC1; 65.1% from total variation) and principal component 2 (PC2; 22.5% from total variation) of Natar 1 variety



Remarks: Alt = altitude; CEC = cation exchange capacity; DM = dry matter; dT = day temperature; LI = light intensity; nT = night temperature; RF = rainfall; RH = local humidity; RHm = micro humidity

Figure 2. Loading plot of principal component 1 (PC1; 62.3% from total variation) and principal component 2 (PC2; 28.0% from total variation) of Natar 2 variety

DISCUSSION

Among all environmental factors measured in the study, it appears that rainfall, micro humidity and light intensity play important roles and influence most productivity of black pepper in Lampung province. Rainfall is the most important environmental factor affecting black pepper productivity (as shown by CCA analysis) with a positive correlation between both variables (as shown by PCA analysis) irrespective of different varieties of the plant.

Black pepper is a high-demanding nutrient plant species (Ann, 2012), and it requires plenty of water (Rosman *et al.*, 1996). A desired level of rainfall for the optimum growth of black pepper ranged from 2000 to 3000 mm $year^{-1}$ with an average of 2300 mm $year^{-1}$, and without dry months with rainfall less than 60 mm $month^{-1}$. The growth of black pepper begins to hamper when the monthly rainfall is less than 90 mm $month^{-1}$ (Rosman *et al.*, 1996). All observational sites in this study, i.e Sekincau, Abung Barat, Margatiga and Natar showed rainfall higher than 100 mm $month^{-1}$, which implied that there was no obstacle of rainfall or water requirement for the growth of black pepper in the respective area. However, higher rainfall intensity within the observed range led to higher productivity of black pepper in term of wet and dry weight, as well as plant height and canopy diameter. The result is in accordance with Hao *et al.*, (2012) who observed that precipitation of the wettest month was identified as a highly effective factor in the distribution of black pepper in Asia and could possibly account for the black pepper distribution pattern. Further, black pepper productivity showed a decreasing trend due to lower rainfall and higher temperature concomitantly (Krishnamurthy *et al.*, 2011).

Apart from providing water as an essential nutrient for the growth of black pepper, rainfall may affect macro and micro climatic conditions which are also important for the plant. Rainwater affects the availability of ground water, soil physical and chemical properties, micro temperature and micro humidity in black pepper plantation area. Changes in environmental conditions may trigger the growth of the bud and early flowering of the plant; high variation of rainfall will certainly affect the ability of black pepper during the growth period and the development of flower buds. Black pepper plant requires a lot of rainfall in addition to a warm climate and sufficient light intensity (Rosman *et al.*, 1996).

Intensity of sunlight is necessary for maintaining photosynthesis activity of plants. Plants transform light energy into chemical energy in the form of ATP and NADPH through the process of photosynthesis. This molecule then provides energy to bind CO_2 atmosphere and in the synthesis of carbohydrates, of which 80 to 90% dry weight of the plant comes from the carbohydrates (Noggle and Fritz, 1979). Furthermore, light intensity affects the absorption of nutrients for plants (Eriksen and Whitney, 1981). Light intensity also affects the microclimate such as temperature micro, micro air humidity and soil moisture content. However, if the light intensity is too high, it may cause respiratory rate greater than the rate of photosynthesis which in turn may decrease the yield. In this study, light intensity appeared to be conversely related to black pepper productivity, i.e. the DM yield especially for Natar 2 variety. It might be that the level of light intensity in all observation sites is already high and, therefore, leads to a counter-productive effect on the yield of black pepper. It is confirmed that pepper plants require a moderate light intensity (not too low and not too high) in accordance with the character as a protected plant (sciophyta) with C_3 photosynthetic pathway (Das *et al.*, 1976). Further, Wahid (1984) stated that the pepper plants need a light intensity of 50 to 75% in order to grow well. Therefore, pepper plants need to be managed by pruning to obtain sufficient light intensity.

CONCLUSION

Among a number of environmental factors affecting the productivity of black pepper in Lampung province, Indonesia, apparently rainfall intensity is the most important factor. Accordingly, rainfall has a positive correlation with black pepper productivity; higher rainfall leads to higher productivity. This information is important for the policy of further development of black pepper plantation area, not only in the country but also in other parts of the world. However, production of black pepper will be facing an uncertainty in the context of climate change driven by global warming in the future. As precipitation may be significantly lower at simultaneously higher environmental temperature, the productivity as well as the extent of black pepper production is under threat. Development of a certain varieties that are adapted to such environment may provide a solution for the future of black pepper agriculture.

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