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Research Article
Response of Physiological Characteristics, Seed Yield and Seed Quality of Quinoa under Difference of Nitrogen Fertilizer Management

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Abstract
Background and Objective: Quinoa (*Chenopodium quinoa* Willd.), a pseudocereal is a new introduction in Thailand. The production of high grain quality and quantity which depending on various growth factor. This study focusing on planting location, nitrogen management and cultivars. This experiment was aimed to evaluate the physiological characteristics, yield and seed quality of quinoa responses to different nitrogen fertilizer rates in Thailand climate condition. **Methodology:** The experimental design was split-split plot in Randomized Complete Block Design (RCBD) with four replications. Main plot was planting locations (Pang-Da Research Station, Chiang Mai, Thailand (PD) and Prabathuaytom Royal Project Development Center Plant, Lamphun, Thailand (PB). Sub-plot was nitrogen fertilizer rate (0, 93.75, 187.5 and 312.5 kg N ha^{-1}) and sub-sub plot was quinoa cultivar (Moradas and Verdes). **Results:** The study found that at PD location showed higher of Leaf Area Index (LAI), Leaf Area Ratio (LAR), seed yield and 1,000 seed weight (1.47, 31.97 cm^2 g^{-1}, 2144.20 kg ha^{-1} and 3.00 g, respectively) over than PB location. On the other hand, PB location showed higher of seed germination (97%), germination index (7.86) and low of mean germination time (3.12 days) when compared with PD location. Furthermore, nitrogen fertilizer rate at 93.75, 187.5 and 312.5 kg N ha^{-1} showed highest of Leaf Area Index (LAI) (1.04, 1.21 and 1.14, respectively) and Crop Growth Rate (CGR) (1.87, 1.85 and 1.48 mg cm^{-2} day^{-1}, respectively). Then, nitrogen fertilizer rate at 93.75 and 187.5 kg N ha^{-1} showed highest of Relative Growth Rate (RGR) (35.54 and 32.59 mg g^{-1} day^{-1}, respectively). Additionally, nitrogen fertilizer rate at 93.75, 187.5 and 312.5 kg N ha^{-1} resulted higher of seed yield (1872.00, 1726.70 and 1822.20 kg ha^{-1}, respectively) than those control. Nitrogen fertilizer rate at 187.5 kg N ha^{-1} revealed higher of 1,000 seed weight at (3.02 g) than 93.75 kg N ha^{-1} and control. Therefore, Verdes cultivar provided the good physiological responses than those Moradas cultivar. Verdes cultivar showed higher of CGR (1.87 mg cm^{-2} day^{-1}), RGR (31.80 mg g^{-1} day^{-1}), seed yield (1892.80 kg ha^{-1}) and 1,000 seed weight (2.97 g) over than Moradas cultivar. **Conclusion:** Finally, it could be concluded that at PD research station was high responded to that nitrogen fertilizer rates and cultivars for increased crop physiological growth and improved seed yield of quinoa production in Thailand.

Key words: Crop physiology, physiological characteristic, growth and development, nitrogen response, nitrogen fertilizer management, seed yield, seed quality, quinoa

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) was native plant of South America which was currently cultivated in other interesting areas such as Europe, America and Asia[1]. Quinoa was usually consumed as pseudocereal. The grain has contained high nutritional value especially essential amino acids and protein content twice more than common cereal grains. Those protein was highly quality and quantity close to the Food and Agriculture Organization (FAO) standard of human nutrition requirement[2]. Quinoa was annual crop, tap root system and penetrating as deep as 1.5 m below the surface, which protects against drought conditions, with broad leaved. The inflorescence in panicle is 15-70 cm length and rising from the top of the plant and axils of lower leaves, usually standing about 1-2 m. Quinoa seeds was small with diameter about 1-2.5 mm and 1,000 seed weight was 1.4-4.3 g according to Shams[2] and Bhargava *et al.*[1]. The production of high grain quality and quantity depends on various growth factors such as genetics and environments. The environmental factors affected to plant growth, development and yield potential, which were light, temperature, humidity, air, soil, pest, disease and nutrient. Nitrogen fertilizer was important for crop growth during vegetative stage and affected to quantity and quality of grain yield. It is also a component of amino acids, proteins and chlorophyll content. Kaveeta *et al.*[3] and Oelke *et al.*[4] reported that nitrogen fertilizer rates enhance vegetative growth and affect grain yield of quinoa. Basra *et al.*[5] reported nitrogen fertilizer rates at 75 kg N ha^{-1} showed highest Crop Growth Rate (CGR) in quinoa significantly higher than other treatment. Erley *et al.*[6] reported that nitrogen fertilizer rates at 80 and 120 kg N ha^{-1} had significant increased quinoa grain yield for 3,083 and 3,495 kg ha^{-1}, respectively. Ainika *et al.*[7] found that nitrogen fertilizer rates at 150 kg N ha^{-1} incresed Leaf Area Index (LAI) in grain amaranth at 18.1 significantly higher than control. Moreover, nitrogen fertilizer rates at 50 and 100 kg N ha^{-1} showed highest of grain amaranth seed yield at 1,497 and 1,449 kg ha^{-1}, respectively. This is consisted with Pospisil *et al.*[8] reported that nitrogen fertilizer rates at 50 and 100 kg N ha^{-1} had the highest *Amaranthus* spp., yield for 1,434 and 1,525 kg ha^{-1}, which correlate to increase of 1,000 seed weight for 0.747 and 0.750 g, respectively. However, the cultivation area is in the Northern part of Thailand. The area was found lower nutrients. Thus, it need to improve soil qualities for higher productivity of crops. In addition, lack of information of quinoa cultivation in Thailand was studies. Moreover, there are no experimental data was done to understand the quinoa responses to nitrogen application rate on growth, yield and their seed qualities. And to gain better understanding of quinoa production as a new crop in Thailand. The selection of cultivated area, climatic analogue with the original area was necessary. New cultivated area should be similar to origin. Thus, the experiment was aimed to evaluate the physiological characteristics, seed yield and seed quality responses of quinoa under difference of nitrogen fertilizer rates in Thailand climate condition.

MATERIALS AND METHODS

The experiment was conducted in split-split plot in RCBD with 4 replications. Main plot was planting location (Pang-Da Research Station ((18°51'21.73'' N, 98°45'31.63'' E), PD) and Prabathuaytom Royal Project Development Center Plant ((17°43'45.69'' N, 98°56'33.96'' E), PB). Sub-plot was nitrogen fertilizer rate (0, 93.75, 187.5 and 312.5 kg N ha^{-1}) and sub-sub plot was quinoa cultivar (Moradas and Verdes). The experimental areas were located at average elevation of 720 for PD location and 500 for PB location meters above sea level, respectively. The climate characteristics and soil properties of both the research station was showed in Table 1-3, respectively. The experiment was done during November-March, 2015. Quinoa seed were hand sown on 5th and 6th December, 2014 in PD location and PB location, respectively. Quinoa was grown by row board casting method in 50 cm apart row with 2-3 cm depth. Plants were thinned to 10 cm intra spacing at 2 weeks after planted. The plant were irrigated by sprinkler method by 1 week interval. The water supply was stopped at 2-3 weeks before harvesting.

Table 1: Climate characteristics of both research stations

	Temperature (°C)					
	Maximum		Minimum		Average	
Months	PD	PB	PD	PB	PD	PB
December	33.2	33.8	12.6	11.2	23.5	22.9
January	33.0	33.6	14.1	12.4	22.3	21.8
February	37.1	37.5	13.9	12.8	24.3	24.3
March	39.5	40.9	17.8	17.1	27.9	28.1
Mean	35.7	36.5	14.6	13.4	24.5	24.3

PD: Pang-Da, PB: Phabaghuaytom

Table 2: Climate characteristics of both research stations

	Total precipitation (mm)		Relative humidity (%)	
Months	PD	PB	PD	PB
December	nd	nd	71	74
January	78.9	62.2	69	71
February	nd	nd	58	59
March	27.5	48.2	55	56
mean	53.2	55.2	63.3	65

PD: Pang-Da, PB: Phabaghuaytom, nd: No detected

Table 3: Result of soil properties tested before growing at both research stations

	Planting lacations	
Soil properties	Pang-Da	Phabadhuaytom
pH	7.3	6
Sand (%)	45	73
Silt (%)	33	19
Clay (%)	23	9
Soil texture	L	SL
Organic matter	2.29 (medium)	0.58 (very low)
Nitrogen (%)	0.1	0.02
Phosphorus (mg kg^{-1})	109 (very high)	27 (high)
Potassium (mg kg^{-1})	152 (very high)	30 (very low)
Calcium (mg kg^{-1})	3,459 (high)	281 (low)
Magnesium (mg kg^{-1})	169 (high)	31 (low)

L: Loamy soil, SL: Sandy loam soil

Phosphorus and potassium fertilizers were applied for 187.5 kg ha^{-1}, while nitrogen fertilizer was applied at 20, 40 and 60 days after planting. The weed was controlled by manpower method for twice time. Harvesting time was usually begins when the seed can barely be dented with a fingernail and plants had turned a pale yellow or red color and leaves have dropped. After harvesting quinoa panicle was tied into bundle and sundried for a week and then seed separated from panicle was done by manpower method and rice miller. After that quinoa seed will be cleaning was done by air blower (Seedburo equipment company). Finally, quinoa seed was kept in plastic sealed bag which was stored in the refrigerator to control the temperature for 12±2°C.

Crop physiological characteristics: Crop physiological characteristics were recorded according to Hunt[9] as following, Leaf Area Index (LAI) were calculated by Eq. 1:

$$\text{LAI} = \frac{\text{LA}}{\text{G}} \quad (1)$$

Where:
LA = Leaf area
G = Ground area

Leaf Area Ratio (LAR) were calculated by Eq. 2:

$$\text{LAR} = \frac{\text{LA}}{\text{W}} \quad (2)$$

Where:
LA = Leaf area
W = Dry matter yield

Net Assimilation Rate (NAR) were calculated by Eq. 3:

$$\text{NAR} = (1/\text{LA})\times(\text{dW/dt}) \quad (3)$$

Where:
LA = Leaf area
W = Dry matter yield
t = Time

Crop Growth Rate (CGR) were calculated by Eq. 4:

$$\text{CGR} = (1/\text{G})\times(\text{dW/dt}) \quad (4)$$

Where:
G = Ground area
W = Dry matter yield
t = Time

Relative Growth Rate (RGR) were calculated by Eq. 5:

$$\text{RGR} = (1/\text{W})\times(\text{dW/dt}) \quad (5)$$

Where:
W = Dry matter yield
t = Time

Seed yield: The quinoa seed of all the crops of each plot were bulked, after threshing by manpower methods and rice millers and quinoa seed will be cleaning by air blower, weighed and the seed yield per plant was then converted to kilogram per hectare.

Seed quality analysis: The seed quality was done as followed, ISTA[10] were 1,000 seed weight: A sample of 100 seeds from the bulked seed of each plot was weighed with 8 replication and then converted to 1000 seeds.

Standard germination test: Seed germination test was done using between of paper method, 100 seeds were randomly selected in four replication each 25 seeds. Then the germination paper with see was pushed in germinator set at 20°C and the germination data was collected in 4 and 7 days after the start of the experiment. Germination index and mean germination time followed by Munir *et al*.[11].

Germination Index (GI) were calculated by Eq. 6:

$$\text{GI} = \frac{\text{No. of germinated seed}}{\text{Days of first count}} + \cdots + \frac{\text{No. of germinated seed}}{\text{Days of first count}} \quad (6)$$

Mean Germination Time (MGT) were calculated by Eq. 7:

$$\text{MGT} = \frac{\sum \text{Dn}}{\sum \text{n}} \quad (7)$$

Where:

n = Total germinated seed count on day

D = No. of days counted from the day on which germination started

Statistical analysis: The analysis of variance (ANOVA) was carried out using the Statistix software package version 8.0. Then, the mean comparison was done by Fisher's LSD methods at $p<0.05$.

RESULTS AND DISCUSSION

Crop physiological characteristics: The experimented found that PD location showed higher of LAI and LAR (1.47 and 31.97 cm^2 g^{-1}, respectively) than PB location, while NAR, CGR and RGR were not significantly different (Table 4). It might be the effect of differences of soil fertility between those two locations. The PD soil contained higher of nitrogen, phosphorus, potassium, calcium and magnesium over than PB soil, which revealed higher of organic matter for 2.29% over than PB soil (Table 3). On the other hand, nitrogen fertilizer rate at 93.75, 187.5 and 312.5 kg N ha^{-1} showed highest of LAI (1.04, 1.21 and 1.14, respectively), CGR (1.87, 1.85 and 1.48 mg cm^{-2} day^{-1}, respectively) and nitrogen fertilizer rate at 93.75, 187.5 kg N ha^{-1} showed highest of RGR (35.54 and 32.59 mg g^{-1} day^{-1}, respectively). The values obtained correspond to those reported by Ainika *et al.*[7] and Basra *et al.*[5] that nitrogen fertilizer had promoting vegetative growth and Kineber[12] reported that nitrogen application enhance vegetative growth as well as the metabolism process in the plant and increase in dry matter accumulation. The LAR and NAR were not significantly different (Table 4). Moreover, Verdes cultivar provided higher of CGR (1.87 mg cm^{-2} day^{-1}) and RGR (31.80 mg g^{-1} day^{-1}) than Moradas cultivar. The LAI, LAR and NAR were not significantly different among cultivars (Table 4).

The study of interaction between planting locations, nitrogen fertilizer rates and cultivars found that LAR, NAR and CGR were significantly different, while LAI and RGR were not significantly different (Table 4). Verdes cultivar grown at PD location applied with nitrogen fertilizer 93.75 kg N ha^{-1} showed higher of LAR (44.38 cm^2 g^{-1}) than other treatments but no significant different when compare with Moradas cultivar was grown at PD location applied with nitrogen fertilizer for 0 and 187.5 kg N ha^{-1} and no significant different when compare with Verdes cultivar was grown at PD location applied with nitrogen fertilizer for 0 kg N ha^{-1}. Moradas cultivar grown at PD location applied with nitrogen fertilizer 187.5 kg N ha^{-1} showed higher of NAR (3.88 mg cm^{-2} day^{-1}) than other treatments but no significant different when compare with Moradas cultivar was grown at PD location applied with nitrogen fertilizer for 93.75 kg N ha^{-1} and no significant different when compare with Verdes cultivar was grown at PB location applied with nitrogen fertilizer for 93.75 and 187.5 kg N ha^{-1}. Verdes cultivar grown at PD location applied with nitrogen fertilizer for 312.5 kg N ha^{-1} showed higher of CGR (3.29 mg cm^{-2} day^{-1}) than other treatments but no significant different when compare with Moradas cultivar was grown at PD location applied with nitrogen fertilizer for 93.75 kg N ha^{-1} and no significant different when compare with Verdes cultivar was grown at PD location applied with nitrogen fertilizer for 187.5 kg N ha^{-1} (Table 5).

Table 4: Effect of planting locations, nitrogen rates and cultivars on Leaf Area Index (LAI), Leaf Area Ratio (LAR), Net Assimilation Rate (NAR), Crop Growth Rate (CGR), and Relative Growth rate (RGR) of quinoa

Treatments	LAI	LAR (cm^2 g^{-1})	NAR (mg cm^{-2} day^{-1})	CGR (mg cm^{-2} day^{-1})	RGR (mg g^{-1} day^{-1})
Planting locations (A)					
Pang-Da	1.47^a	31.97^a	1.27	1.85	31.03
Phabadhuaytom	0.50^b	12.72^b	2.20	1.10	23.92
Nitrogen rates (B)					
0	0.55^b	22.95	1.20	0.71^b	21.21^b
93.75	1.04^a	22.61	2.25	1.87^a	35.54^a
187.5	1.21^a	22.54	2.30	1.85^a	32.59^a
312.5	1.14^a	21.28	1.18	1.48^a	20.58^b
Cultivars (C)					
Moradas	0.88	21.48	1.67	1.08^b	23.16^b
Verdes	1.09	23.21	1.80	1.87^a	31.80^a
F-test					
A×B	ns	ns	ns	ns	ns
A×C	ns	ns	ns	ns	ns
B×C	ns	ns	ns	ns	ns
A×B×C	ns	*	*	*	ns
CV (%)	56.54	51.41	88.44	58.62	41.06

[a,b]Mean within a column followed by the same letter do not significantly different to LSD at $p<0.05$, ns: Not significantly different, *Significantly at $p<0.05$

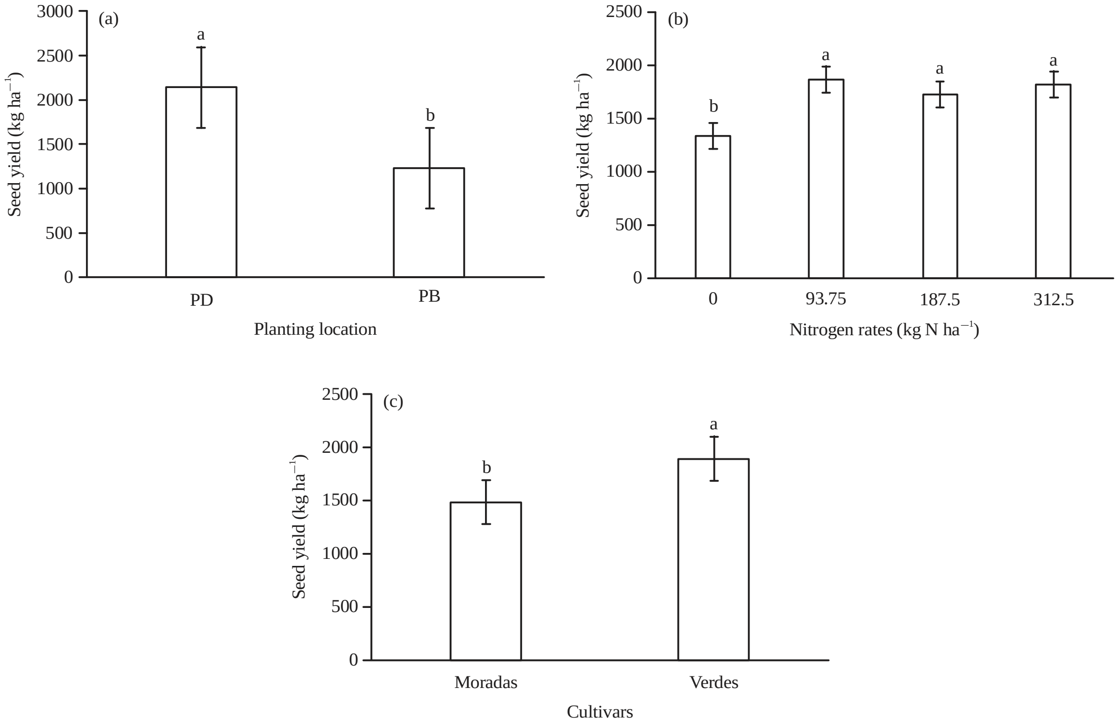

Fig. 1(a-c): Effect of (a) Planting locations, (b) Nitrogen rates and (c) Cultivars on seed yield

Table 5: Effect interaction of planting location, nitrogen rates and cultivars on Leaf Area Ratio (LAR), Net Assimilation Rate (NAR) and Crop Growth Rate (CGR)

Planting locations	Nitrogen rates	Cultivars	LAR (cm^2 g^{-1})	NAR	CGR
				-----------(mg cm^{-2} day^{-1})--------------	
Pang-Da	0.00	Moradas	36.10^{ab}	-0.37^{c}	0.37^{d}
		Verdes	35.25^{ab}	1.51^{b}	1.87^{bc}
	93.75	Moradas	15.65^{cd}	3.22^{ab}	2.64^{ab}
		Verdes	44.38^{a}	1.05^{b}	1.85^{bc}
	187.50	Moradas	40.33^{ab}	0.57^{b}	1.13^{cd}
		Verdes	25.62^{bc}	1.66^{b}	2.52^{ab}
	312.50	Moradas	27.20^{bc}	0.98^{b}	1.15^{cd}
		Verdes	31.23^{b}	1.51^{b}	3.29^{a}
Phabadhuaytom	0.00	Moradas	11.76^{d}	1.64^{b}	0.06^{e}
		Verdes	8.68^{d}	2.03^{b}	0.54^{d}
	93.75	Moradas	17.04^{cd}	1.58^{b}	0.91^{cd}
		Verdes	13.38^{cd}	3.16^{ab}	2.07^{bc}
	187.50	Moradas	10.90^{d}	3.88^{a}	1.51^{bc}
		Verdes	13.31^{cd}	3.07^{ab}	2.27^{b}
	312.50	Moradas	12.87^{cd}	1.86^{b}	0.90^{cd}
		Verdes	13.84^{cd}	0.36^{b}	0.59^{cd}
SE			5.7442	0.7662	0.4336

SE: Standard error of a mean, ^{a,b}Mean within a column followed by the same letter do not significantly different to LSD at p<0.05

Seed yield and seed quality analysis: The PD location showed higher of seed yield and 1,000 seed weight (2144.20 kg ha^{-1} (Fig. 1a) and 3.00 g, respectively) than PB location because at PD location had higher of LAI and LAR than PB location. Therefore, it had increased ability for photosynthesis and transport photosynthate to grain. On the other hand, at PB location showed higher seed germination (97%), germination index (7.8568) and the low of mean germination time (3.12 days) when compared with PD location because the weather at PD location where high humidity were found. Those weather may induce the decrease of seed deterioration rate, which affected to seed viability, germination potential and germination percentage[13]. On the other hand, nitrogen fertilizer rate of 93.75,187.5 and 312.5 kg N ha^{-1} results on higher of seed yield than those control (1336.80, 1872.00 and 1726.70 kg ha^{-1}, respectively) (Fig. 1b). Nitrogen fertilizer rate of 187.5 kg ha^{-1} revealed higher of 1,000 seed weight than 93.75 kg N ha^{-1} and

Table 6: Effect of planting locations, nitrogen rates and cultivars on seed yield, 1,000 seed weight, germination percentage, Germination Index (GI) and Mean Germination Time (MGT) of quinoa

Treatments	Seed yield	1,000 seed weight (g)	Germination (%)	GI	MGT (days)
Planting locations (A)					
Pang-Da	2144.20[a]	3.00[a]	61[b]	4.26[b]	3.74[a]
Phabadhuaytom	1234.60[b]	2.88[b]	97[a]	7.86[a]	3.12[b]
Nitrogen rates (B)					
0	1336.80[b]	2.87[b]	80	6.04	3.51
93.75	1872.00[a]	2.93[b]	79	6.11	3.39
187.5	1726.70[a]	3.02[a]	77	5.89	3.49
312.5	1822.20[a]	2.94[ab]	80	6.21	3.34
Cultivars (C)					
Moradas	1486.00[b]	2.91[b]	78	6.03	3.42
Verdes	1892.80[a]	2.97[a]	80	6.09	3.44
F-test					
A×B	*	*	ns	ns	ns
A×C	*	*	ns	ns	ns
B×C	ns	ns	ns	ns	ns
A×B×C	ns	ns	ns	ns	ns
CV (%)	22.90	3.23	13.02	13.62	7.39

[a,b]Mean within a column followed by the same letter do not significantly different to LSD at p<0.05, ns: Not significantly different, *Significantly at p<0.05

control by 3.02 g. The values obtained correspond to those reported by Erley *et al.*[6] that nitrogen fertilizer rates at 80 and 120 kg N ha^{-1} had the highest of quinoa grain yield at 3,083 and 3,495 kg ha^{-1}, respectively. And related to Oelke *et al.*[4], Basra *et al.*[5], Carlsson *et al.*[14], Thanapornpoonpong[15], Shams[16], Gomaa[17] and Geren[18] reported that nitrogen fertilizer rates affected grain yield of quinoa because nitrogen fertilizer had promoting vegetative growth. Therefore had increased ability for photosynthesis and photosynthate translocation to promote grain and these results agreed with Thanapornpoonpong[15] who noticed that seed yield per plant increased with increasing nitrogen fertilizer rates, while germination percentage, GI and MGT were not significantly different. The values obtained correspond to those reported by Kansomjet *et al.*[19] and there are several factors that effect to the emergence percentage such as photoperiod and temperature[20]. Moreover, Verdes cultivar provided higher of seed yield (1892.80 kg ha^{-1}) and 1,000 seed weight (2.97 g) than Moradas (Fig. 1c), while germination percentage, GI and MGT were not significantly different (Table 6).

The study of interaction between planting locations and nitrogen fertilizer rates found that seed yield and 1,000 seed weight were significantly different, while germination percentage, GI and MGT were not significantly different. Furthermore, the study of interaction between planting locations and cultivars found that seed yield and 1,000 seed weight were significantly different, while germination percentage, GI and MGT were not significantly different. On the other hand, the study of interaction between nitrogen fertilizer rates, cultivars and interaction between planting locations, nitrogen fertilizer rates and cultivars found that seed yield, 1,000 seed weight, germination percentage, GI and MGT were not significantly different (Table 6).

Table 7: Influence of planting locations and nitrogen rates on seed yield and 1,000 seed weight

Planting locations	Nitrogen rates	Seed yield (kg ha^{-1})	1,000 seed weight (g)
Pang-Da	0.00	2043.10[b]	2.96[b]
	93.75	2641.70[a]	3.06[a]
	187.50	1698.90[c]	3.01[ab]
	312.50	2193.20[b]	2.96[b]
Phabadhuaytom	0.00	630.40[f]	2.78[c]
	93.75	1102.30[e]	2.79[c]
	187.50	1754.40[c]	3.03[ab]
	312.50	1451.10[d]	2.92[b]
SE		99.38	0.0374

SE: Standard error of a mean, [a,b]Mean within a column followed by the same letter do not significantly different to LSD at p<0.05

Quinoa grown at PD location applied with nitrogen fertilizer for 93.75 kg N ha^{-1} showed highest of seed yield (2641.70 kg ha^{-1}), while at quinoa grown at PD location applied with nitrogen fertilizer for 93.75 kg N ha^{-1} showed higher of 1,000 seed weight (3.0637 g) than other treatments but no significant different when compare with quinoa was grown at PD location applied with nitrogen fertilizer for 187.5 kg N ha^{-1} and no significant different when compare with quinoa was grown at PB location applied with nitrogen fertilizer for 187.5 kg N ha^{-1} (Table 7).

Furthermore, Verdes cultivar grown at PD location showed highest of seed yield and 1,000 seed weight (2479.80 kg ha^{-1} and 3.0880 g, respectively) (Table 8).

Correlation between physiological characteristics: The study of correlation between physiological characteristics showed that the LAI had positively high correlation with the distribution of LAR (Fig. 2a). The LAI correlated with a number

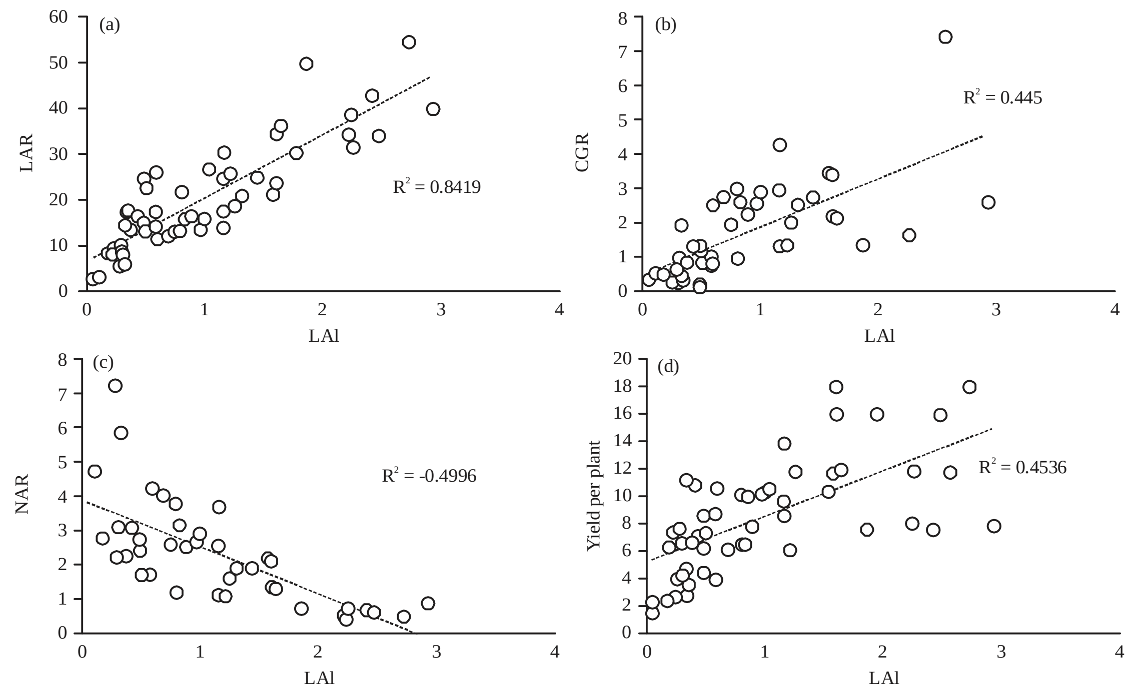

Fig. 2(a-d): Correlation analysis of LAI on (a) LAR, (b) CGR, (c) NAR and (d) Seed yield

Table 8: Influence of planting locations and cultivars on seed yield and 1,000 seed weight

Planting locations	Cultivars (kg ha^{-1})	Seed yield	1,000 seed weight (g)
Pang-Da	Moradas	1808.70^{b}	2.91^{b}
	Verdes	2479.80^{a}	3.09^{a}
Phabadhuaytom	Moradas	1163.30^{c}	2.91^{b}
	Verdes	1305.80^{c}	2.85^{c}
SE		96.73	0.0238

SE: Standard error of a mean, ^{a,b}Mean within a column followed by the same letter do not significantly different to LSD at p<0.05

of leaves when LAI was high the number of leaves was increased. The high number of leaves can increased the distribution of leaves on plant which high correlated with high number of LAR. Figure 2b showed LAI had positively high correlated with CGR because when the plant had high of leaf area which could increased ability for photosynthesis and photosynthate translocation, which was important substance for crop growth, development and especially dry matter accumulation as well. However, value of high leaf area may not increased seed yield (Fig. 2d). The shading effect resulted the decrease of total photosynthesis or NAR. Figure 2c showed the negatively correlation between LAI and NAR which may indicated the leaves shaded cloud not provided the optimum of light interception. The total photosynthesis may decrease, then photosynthate did not translocated to only the primary sink (quinoa seed) but its also translocated to support the parasitic sink (shaded leaves), finally quinoa seed yield may decreased. The result were correlated to Basra *et al*.[5] and Kansomjet *et al*.[21].

CONCLUSION

Quinoa have high potential to produce in Thailand and Pang-Da research station location was highly responded to that nitrogen rate and cultivars for increased crop physiological growth and improved seed yield. Quinoa was grown with nitrogen fertilizer for 93.75 kg ha^{-1} was suitable for quinoa seed production which provide high LAI, CGR, RGR and seed yield.

SIGNIFICANCE STATEMENT

Quinoa (*Chenopodium quinoa* Willd.) was contained high nutritional value especially essential amino acids and protein content twice more than common cereal grains. Those protein was highly quality and quantity close to the Food and Agriculture Organization (FAO) standard of human nutrition requirement quinoa is new crop in Thailand. Although there are many crop like rice, corn, soybean and mung bean but it's quality nutritive value in quinoa is much higher compare with other crops. Also It grown in the area where the other crops cannot perform well.

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REFERENCES

1. Bhargava, A., S. Shukla and D. Ohri, 2006. *Chenopodium quinoa*-an Indian perspective. Indus. Crops Prod., 23: 73-87.
2. Shams, A., 2011. Combat degradation in rain fed areas by introducing new drought tolerant crops in Egypt. Int. J. Water Resour. Arid Environ., 1: 318-325.
3. Kaveeta, L., M. Nanakorn, S. Suwanwong and S. Tantiwiwat, 2009. Plant Physiology. Kasetsart University Press, Bangkok, Pages: 261.
4. Oelke, E.A., D.H. Putnam, T.M. Teynor and E.S. Oplinger, 1992. Quinoa. Alternative Field Crops Manual. http://www.hort.purdue.edu/newcrop/afcm/quinoa.html
5. Basra, S.M.A., S. Iqbal and I. Afzal, 2014. Evaluating the response of nitrogen application on growth, development and yield of quinoa genotypes. Int. J. Agric. Biol., 16: 886-892.
6. Erley, G.S.A., H.P. Kaul, M. Kruse and W. Aufhammer, 2005. Yield and nitrogen utilization efficiency of the pseudocereals amaranth, quinoa and buckwheat under differing nitrogen fertilization. Eur. J. Agron., 22: 95-100.
7. Ainika, J.N., B.M. Auwalu and A.U. Yusuf, 2011. Response of grain amaranth (*Amaranthus cruentus* L.) to nitrogen and farmyard manure rates in Northern Guinea and Sudan savanna ecological zones of Nigeria. World J. Eng. Pure Applied Sci., 1: 46-49.
8. Pospisil, A., M. pospisil, B. Varga and Z. Svecnjak, 2006. Grain yield and protein concentration of two amaranth species (*Amaranthus* spp.) as influenced by the nitrogen fertilization. Eur. J. Agron., 25: 250-253.
9. Hunt, R., 1978. Plant Growth Analysis. Edward Arnold Ltd., London, UK., ISBN-13: 978-0713126969, Pages: 67.
10. ISTA., 2011. International Rules for Seed Testing. The International Seed Testing Association, Bassersdof, Switzerland, Pages: 540.
11. Munir, H., S.M.A. Basra, M.A. Cheema and A. Wahid, 2011. Phenotypic flexibility in exotic quinoa (*Chenopodium quinoa* Willd.) germplasm for seedling vigor and viability. Pak. J. Agric. Sci., 48: 255-261.
12. Kineber, M.E.A., 1991. Evaluation of some new promising flax varieties in relation to yield and quality. M.Sc. Thesis, Faculty of Agriculture, Zagazig University, Egypt.
13. Shu, Y.J., S. Wang, Y. Tao, L.R. Song, L.Y. Huang, Y.L. Zhou and H. Ma, 2014. [Effects of high temperature and humidity stress at the physiological maturity stage on seed vigor, main nutrients and coat structure of spring soybean]. J,. Applied Ecol., 25: 1380-1386, (In Chinese).
14. Carlsson, R., P. Hanczakowski and T. Kaptur, 1984. The quality of the green fraction of leaf protein concentrate from *Chenopodium quinoa* Willd. grown at different levels of fertilizer nitrogen. Anim. Feed Sci. Technol., 11: 239-245.
15. Thanapornpoonpong, S., 2004. Effect of nitrogen fertilizer on nitrogen assimilation and seed quality of amaranth (*Amaranthus* spp.) and quinoa (*Chenopodium quinoa* Willd.). Ph.D. Thesis, Georg-August-Universityof Gottingen, Phayao, Thailand.
16. Shams, A.S., 2012. Response of quinoa to nitrogen fertilizer rates under sandy soil conditions. Proceedings of the 13th International of Agronomy Conference, September 9-10, 2012, Benha University, Egypt, pp: 195-205.
17. Gomaa, E.F., 2013. Effect of nitrogen, phosphorus and biofertilizers on quinoa plant (*Chenopodium quinoa*). J. Applied Sci. Res., 9: 5210-5222.
18. Geren, H., 2015. Effects of different nitrogen levels on the grain yield and some yield components of quinoa (*Chenopodium quinoa* Willd.) under Mediterranean climatic conditions. Turk. J. Field Crops, 20: 59-64.
19. Kansomjet, P., P. Thobunluepop, N. Tonmukayakul, P. Boonkorkaew and P. Junhaeng *et al*., 2014. Harvesting time and nitrogen management on yield and seed quality of quinoa. Agric. Sci. J., 45: 93-96.
20. Bertero, H.D., 2001. Effects of photoperiod, temperature and radiation on the rate of leaf appearance in quinoa (*Chenopodium quinoa* Willd.) under field conditions. Ann. Bot., 87: 495-502.
21. Kansomjet, P., P. Thobunluepop, N. Tonmukayakul, P. Boonkorkaew and P. Junhaeng *et al*., 2014. Nitrogen rate and cultivars on physiology and seed quality of quinoa. Agric. Sci. J., 45: 481-484.