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Research Article

Growth and yield of wheat (*Triticum aestivum*) adapted to lowland Lombok Island as an alternative food crop for dryland

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Abstract: Wheat is not currently grown as a commercial crop in Indonesia, however since the consumption of wheat in Indonesia is steadily increasing and alternative of dry season crops are required for farming system diversification, wheat becomes an important crop to be adapted in dry land areas of Indonesia, one of them is dry land area of Lombok Island. The aims of this experiment is to adapt and screen wheat varieties including national and introduced Australian varieties in lowland Lombok Island. In future, wheat is expected to be an alternative crop for degraded lands. The experimental method used to evaluate growth and yield of 10 wheat varieties to look at the adaptability on the lowland of 200 m asl (Pringgarata) and on higher land of 400 m asl (Aik Bukak). The results showed that at a lower altitude (Pringgarata), wheat growth is slower than in Aik Bukak, which can be caused by the temperature at 200 m asl has exceeded the tolerance limit for grain growth (supra optimal temperature). Wheat can give good yields on 400 m asl, but the yield is decreased at 200 m asl (average 1.68 t/ha vs 0.82 t/ha). This low yield is mainly due to sterility indicated by the low number of grain/spikelet (<2 grain/spikelet). There is genetic variation of wheat crop responses adapted to the lowlands. Nias, Dewata, Mace and Estoc give good yields (> 2 t/ha), higher than other varieties .

***Keywords**: adaptation, dryland, Lombok Island, lowland, wheat*

Introduction

Wheat (*Triticum aestivum*) is a sub-tropical cereal commonly grown at latitudes 25 ° N / LS to 50 ° N / LS, but the cultivation of wheat to the tropics has been started up to latitude 15 ° N / S (Music and Porter, 1990). In Indonesia, wheat consumption has increased rapidly lately that wheat imports in 2012 reached 7.4 million tons (Siregar, 2012). The development of instant noodles, bread and snacks are very fast, especially for the urban areas encouraged flour consumption in Indonesia is high. To meet the needs of those made with wheat flour brought from wheat producing countries, such as Australia. Given the high number of the population, consumption increase of wheat flour and the advice of the government and needed to promote the diversification of sources of carbohydrates. Therefore, it is necessary to dig the potential of the wheat crop in Indonesia, including wheat crop adaptation efforts in areas that are potential for development, such as on the Island of Lombok.

Lombok Island (8.5ºS, 116ºE) has good potential areas for the development of wheat plants (Gusmayanti et al., 2006). Although most of the area is rain-fed, but wheat can adapt well on dry land where rice cannot well survive. Lombok island topography varies with the edges around the lowland islands and highlands in the north-central part of the Mt. Rinjani as the highest peak. Wheat plants can be used as an option to enrich the diversity of food crops on less irrigated land and is expected as an alternative crop in degraded lands. Previous experiments conducted in 2010 and 2011 showed that the Australian wheat crop could produce well with a yield of about 3 t / ha when planted at an altitude of about 1000 m above sea level (Zubaidi et al., 2011). Efforts of extending through the expansion of the wheat planting area to lower ground needs to be done, considering the plateau should be more suitable for the cultivation of wheat is an area that has long been used for the cultivation of vegetables and other horticultural crops. For that also needs to be tested wheat varieties suitable lowland. This study was aimed to select wheat varieties that are adapted to agroecology of Lombok in order to develop optimum wheat production. This study is expected to set the location of the minimum altitude for planting wheat with adequate results and the selection of appropriate varieties.

Materials and Methods

Determination of the locations used in this study is based on the altitude from the sea level: ± 200 m above sea level (Pringgarata, District Pringgarata Central Lombok) and ≥400 m above sea level (Aik Bukak, Batukliang District of North Central Lombok). Two wheat varieties from Indonesia (Nias and Bali) and eight wheat varieties from Australia (Axe, Gladius, Correl, Estoc, Espada, Mace, Scout and Cobra) were used for this study of each site. All wheat varieties from Australia used for this study were the spring types that do not require a cold treatment (vernalisation) for flowering. Each wheat variety was grown on a 1.5x4 m plot. Seeds were planted in five rows with 30 cm distance between rows. In each plot, 1000 seeds were planted or 250 seeds per row. The ten treatments (two wheat varieties from Indonesia, and eight wheat varieties from Australia) were arranged in a randomized block design with three replicates. Tillage was done by plowing and harrowing twice and then leveled the experimental blocks that consisting of 30 experimental plots at each experimental location. Planting was done on July 2, 2013 in Pringgarata and July 4, 2013 in Aik Bukak. Plant maintenance included fertilization, weed control and pest control, but disease control was not conducted. Plant harvest was conducted when 80% of the population of plants in experimental plots reached harvest criteria that are characterized by physiological ripe panicles, yellowish stems and leaves, and yellow and hard grains.

Observations were made on growth phase, number of leaves, leaf growth rate and phylochron, plant height, number of total tiller, number of productive tillers, flowering date, harvest date, number of panicles, number of spikelet per panicle, number of seeds, number of seeds per spikelet, weight 1000 grains, grain weight per m^2, yield, harvest index, and vulnerability index (susceptibility index). Growth phase was measured using Zadoks scale (Zadoks et al, 1974), while number of leaves was measured using Haun scale (Haun, 1973). Harvest index was calculated by comparing the results of economic crops (beans) with biological results (stover dry weight). Susceptibility index indicates the amount of yield loss caused by non-ideal environment (e.g. altitude) of a genotype relatively compared with all genotypes tested at the same stress index (Fischer and Maurer, 1978).

The experiment was conducted at two independent that are not related with one to another, then the data at each site were analyzed separately. Data were analyzed using Statistical Package GENSTAT (VSN International Ltd. United Kingdom). Least Significant Difference test was performed to differentiate the average varieties. Comparison of plant responses between the two experiments was shown by calculating the average of varieties and standard error of means.

Results and Discussion

The growth and development of plants

The growth of wheat leaves in Pringgarata was slower than that in Aik Bukak. On average, 0.15 parts of leaves grew daily in Pringgarata, while in Aik Bukak the leaves only grew 0.16 parts daily. Time required to grow one leaf (phylochron) in Pringgarata was 6.6 (± 0.11) days, while that in Aik Bukak was 6.2 (± 0.11) days. All varieties planted in Pringgarata tended to grow slower than that planted in Aik Bukak. This slow leaf growth might indicate the presence of high temperature stress (Midmore et al., 1984). However, the number of leaves in the two sites was not significantly different (Table 1). In general, wheat growth is driven by an increase in ambient temperature (Slafer and Rawson, 1994b). The temperatures in Pringgarata seem already beyond the limit of tolerance adaptation of wheat varieties studied. This made the growth became slower (Summerfield et al., 1991).

Growth of plant height in Aik Bukak and Pringgarata did not differ. The difference in growth occurring between varieties indicated that genetic factors were more influential than environmental factors. There were no differences in the growth of the wheat crop and Pringgarata and Aik Bukak, except for varieties with slow growth (Scout, Cobra and Estoc). The growth of plants in Pringgarata was slower than in Aik Bukak (Figure 1). The growth of wheat crop in Mataram at lower elevations (± 10 m above sea level) is even slower than Pringgarata (Anugrahwati and Zubaidi, 2012). The growth of each of the varieties in Pringgarata showed a similar trend with that in Aik Bukak. This indicates that varieties with the development phase of rapid growth in Aik Bukak also showed rapid growth in Pringgarata, except that the varieties with slow growth in Aik Bukak became slower in Pringgarata. In the second week, plant development at the seed growth phase was almost similar (Zadoks Scale / SZ dozen).

Table 1. Number of leaves, leaf growth and Phylochron at Pringgarata (PR) and Aik Bukak (AB) of ten varieties of wheat.

Variety	Number of Leaves		Leaf Growth (leaf/day)		Phylochron (day/leaf)	
	AB	PR	AB	PR	AB	PR
Axe	6.3	6.2	0.188	0.174	5.3	5.7
Nias	7.3	7.4	0.157	0.152	6.4	6.6
Gladius	7.2	7.0	0.153	0.149	6.5	6.7
Mace	7.4	7.2	0.156	0.146	6.4	6.8
Cobra	7.1	7.3	0.153	0.142	6.5	7.0
Correll	7.7	7.3	0.163	0.147	6.1	6.8
Dewata	7.4	7.4	0.158	0.153	6.3	6.5
Espada	7.3	7.2	0.156	0.149	6.4	6.7
Scout	7.8	7.4	0.162	0.152	6.2	6.6
Estoc	7.6	7.6	0.161	0.156	6.2	6.4
Mean	7.3	7.2	0.161	0.152	6.2	6.6
SEM	0.13	0.12	0.0032	0.0027	0.11	0.11

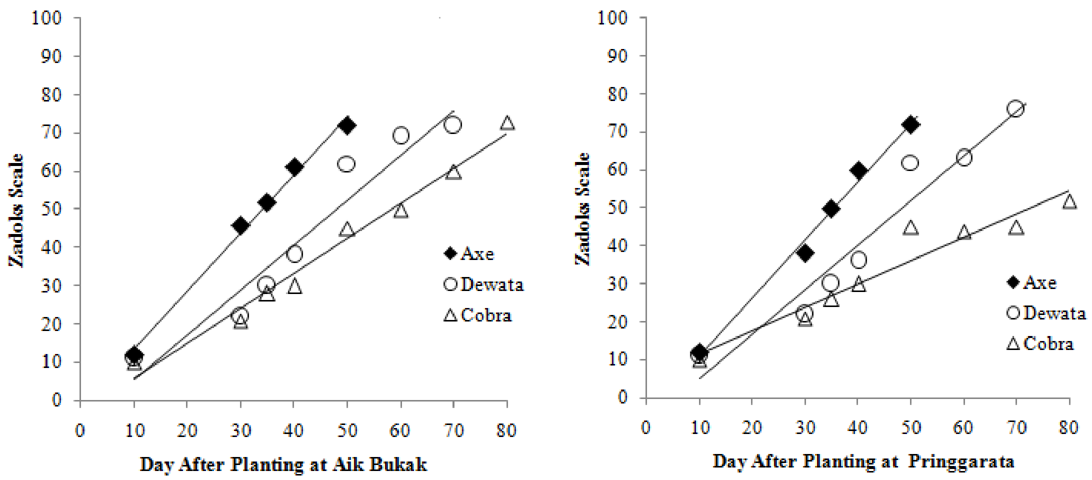

Figure 1. The rate of development of wheat plants (in the Zadoks scale) in Aik Bukak (400 m above sea level) and Pringgarata (200 m above sea level). The trend line for Axe (♦), Dewata (○) and Cobra (Δ) are shown to represent the speed of growth. Cobra line slope that is flatter than Aik Pringgarata Bukak indicating that the speed of development in Pringgarata Cobra was slower. There was no difference for the Axe and the Dewata.

At 28 days, the development of Axe variety exceeded the development of other varieties, when the Axe variety reached the phase of stem elongation (SZ 30s), either in Aik Bukak or in Pringgarata, while other varieties were still in the phase of seedling growth (tillering / SZ 20s). At six weeks, the development of plants varied according to the speed of their development. The ten varieties can be grouped into 3 groups, i.e. rapid (Axe and Nias), medium (Gladius, Mace, Espada, Dewata, Correll), and slow (Scout, Cobra, Estoc). It should be noted that although Cobra variety is characterized to have rapid to moderate growth (short to mid-season), in this study Cobra variety showed slow development growth. This indicates the existence of genetic variation in response of plants to high temperature stress in Lombok. Summerfield et al. (1991) suggested that the growth of wheat plants when grown in areas with temperatures above the tolerance threshold (supra-optimal temperature) would show a decrease in growth rate. This was also found in long-lived varieties (Cobra and Scout).

Phenology

Phenology is an important character in the adaptation of plants to environmental changes that may occur naturally or is conditioned on the particular environment. Phenology is associated with phases of growth (development), flowering, and harvest. The three main characters that affect plant responses to the environment are vernalization, photoperiod, and the need for the vegetative phase (Earlyness or Basic Vegetative Phase / BVP) (Kosner and Pankova, 1998; Slafer and Rawson, 1994; Snape et al., 2001).

In this study, there was no difference in days of flowering between Pringgarata and Aik Bukak except for the varieties having the slow rate of development, i.e. Estoc, Scout and Cobra, that were flowering about 5 days slower than in Aik Pringgarata Bukak (Table 2). There were significant differences between varieties. Axe and Nias are wheat varieties having rapid flowering age, whereas Estoc, Scout and Cobra are varieties with slow flowering age, and other varieties are between them.

Table 2. Age of flowering, harvesting and grain filling period of wheat crop at Pringgarata (PR) and Aik Bukak (AB)

Variety	**Age of Flowering (day)**		**Age of Harvesting (day)**		**Grain Filling Period (day)**	
	AB	**PR**	**AB**	**PR**	**AB**	**PR**
Axe	42	42	77	78	35	36
Nias	45	44	77	78	32	34
Gladius	56	59	92	91	36	32
Mace	63	68	92	91	29	23
Cobra	67	72	110	108	43	36
Correll	57	59	92	91	35	32
Dewata	51	51	92	91	41	40
Espada	57	61	92	91	35	30
Scout	70	75	110	108	40	33
Estoc	63	68	110	108	47	40
Mean	57	60	94	94	37	34
SEM	2.9	3.6	3.9	3.6	1.7	1.6

Despite the difference in age of flowering in some varieties, grain-filling period of varieties tested also showed no difference in the two sites, and the grain-filling period was not correlated with the yield.

Yield and yield components

All overall wheat varieties grown in Aik Bukak yielded higher than those grown Pringgarata, i.e. 1.68 t / ha in Aik Bukak and 0.82 t / ha in Pringgarata. The higher yield in Aik Bukak was supported by all the yield components observed, such as number of stems (tillers), stover dry weight, number of seeds, number of seeds / spikelet, weight and individual seed as well as Harvest Index. Although wheat varieties planted in Pringgarata generally had longer panicles, as shown the high number of spikelet per panicle, but they could not support high yield (Table 3). This was due to the low number of seeds / spikelet.

The introduced Estoc variety was able to produce almost similar to the National variety of Dewata with the highest yield was in Aik Bukak

(2.17 t / ha). The yield performed by Estoc in this experiment was quite high and similar to its origin, Australia. The high yield of Estoc in Aik Bukak was a combination of two components, i.e. the high number of seeds / m^2 and the high number of seeds / spikelet. Dewata is a wheat variety with the longest panicle or has the highest number of spikelet per panicle. This character supports the Dewata to produce high yield. Nias, Gladius and Mace also produced quite good yield which was close to the yield of the Dewata. Although Axe had many tillers and panicles, this variety did not produce a good yield. This was probably because Axe has short panicles and low number of grains / spikelet (Table 4). Wheat grain yields in Pringgarata were lower than in Aik Bukak. However, Estoc also had the highest yield in Pringgarata (1.42 t / ha) (Table 4). The highest number of seeds produced and the high number of seeds in a spikelet (2.1 grains / spikelet) supported the high yield of Estoc. The lowest yield observed for Axe (0.35 t / ha) was because Axe had short panicles (7.8 spikelet / panicle) and the low success of seed formation (0.9 seeds / spikelet) (Table 4).

Wheat yields in this study were quite good at Aik Bukak (400 m above sea level) was 1.68 t / ha (ranging from 0.9 to 2.17 t / ha) and low in Pringgarata (200 m above sea level), 0.83 t / ha (ranging from 0:35 to 1:42 t / ha). For comparison, Zubaidi et al (2011) reported the yield of 1 t / ha for wheat planted at below 200 m above sea level and about 2 t / ha for that planted at about 500 m above sea level. Handoko (2007) also reported that the yield of 2 t / ha could be obtained from the crops planted at an elevation of 500 m above sea level. As the low areas plains have high temperature, the low yields at 200 m above sea level is because the temperature of above tolerance limits growth and production of wheat (Summerfield et al. 1991).

Table 3. Comparison of yield and yield components at Pringgarata (PR) and Aik Bukak (AB), Values in parentheses indicate the Standard Error of Means

Loca-tion	**Yield (t/ha)**	**Number of Tillers**	**Biomass (g/m^2)**	**Spikelet/ panicle**	**Number of Seeds**	**Seed /spikelet**	**Yield Index**	**Weight of 1000 seeds (g)**
PR	0.83	254.0	369.4	12.8	3988	1.5	33.2	31.4
	(±0.085)	(±18.82)	(±26.28)	(±0.97)	(±428)	(±0.1)	(±2.43)	(±1.27)
AB	1.68	340.0	500.3	10.8	5780	1.9	39.56	34.6
	(±0.083)	(±15.44)	(±23.36)	(±0.41)	(±336)	(±0.08)	(±1.45)	(±1.04)

Data presented in Table 5 show evidence that there was genetic variation of plant response to high temperature stress. Calculation of Susceptibility Index (S) (Fischer and Maurer, 1978) indicated that Nias, Dewata, Mace, and Estoc had a value of $0.5 < S < 1$, which means those varieties have medium degree of adaptation to the stress conditions, while other varieties are the varieties that could not adapt well or less adaptable.

In line with that indicated by the value of S, Nias, Dewata, Mace and Estoc varieties had a percentage of yield decrease in Pringgarata ranged from 30-40% compared to Aik Bukak, and that for other varieties was greater than 50%.

The low yield in Pringgarata compared to Aik Bukak could be caused by a failure in pollination because of high temperature stress. It is assumed that the lower plane has a higher temperature range than the area on higher land, which means that Pringgarata has an average temperature that is higher than Aik Bukak, and thus the failure probability of pollination in Pringgarata is higher than Aik Bukak. This was indicated by the lower number of seeds formed on a spikelet in Pringgarata than in Aik Bukak (1.5 vs. 1.9 seeds / spikelet). The low number of seeds / spikelet in this experiment (<2.0 seeds / spikelet) indicates the low quality of pollination in both locations. The occurrence of sterility is a phenomenon observed by many wheat researchers at high temperature stress (Saini and Aspinall, 1982; Wheeler et al., 1996, Tashiro and Wardlaw, 1990). It was also evidenced that the yield was strongly influenced by the number of seeds / spikelet ($r = 0.64$ / Aik Bukak, and $r = 0.86$ / Pringgarata, $n = 53$, $P = 0.05$ level). Other yield components that affected wheat yields in this study were the dry biomass, number of spikelet per panicle, number of seeds, number of seeds / spikelet and Harvest Index. The significant correlation with the yield shows the importance of these yield components. Hence, the plant growth phases that determine the growth of these components should be of concern.

Table 4. Average yield and yield components of ten wheat varieties tested in Aik Bukak (altitude 400 m above sea level) and Pringgarata (altitude 200 m dpl)

Variety	Yield (t/ha)		Number of Tillers		Biomass (g/m^2)		Spikelet/ panicle		Number of Seeds		Seed / spikelet		Yield Index		Weight of 1000 seeds (g)	
	AB	**PR**	**AB**	**PR**	**AB**	**PR**	**AB**	**PR**	**AB**	**PR**	**AB**	**PR**	**AB**	**PR**	**AB**	**PR**
Axe	0.91	0.35	405	126.5	361.3	220.8	10.3	7.8	5311	1747	1.6	0.9	43.51	24.8	29.9	30.1
Nias	1.86	1.20	356	217.7	565.6	442.5	11.2	14.6	7567	6240	2.3	1.9	44.58	42.0	33.0	29.0
Gladius	1.85	0.75	407	236.0	582.4	241.0	9.1	11.2	6494	2687	1.9	1.5	44.25	38.7	39.4	32.7
Mace	1.89	1.12	322	231.0	532.9	286.8	12.7	11.7	6482	3767	1.8	1.7	45.66	42.7	37.7	30.5
Cobra	1.06	0.24	233	169.8	321.8	257.6	11.0	10.9	3523	1261	1.7	1.3	29.12	14.4	27.1	29.4
Correll	1.29	0.66	364	330.8	507.9	372.9	7.7	10.8	3059	2819	1.3	1.0	28.57	28.3	41.7	38.7
Dewata	2.13	1.12	265	252.0	605.7	553.9	13.7	15.1	6804	5831	2.0	1.8	41.36	38.5	36.6	36.2
Espada	1.74	0.69	369	313.0	558.6	373.7	11.6	20.0	5677	4303	1.7	1.2	40.32	40.8	39.9	32.9
Scout	1.89	0.79	293	246.0	484.1	437.6	11.0	16.1	5491	3897	2.0	1.4	36.13	29.4	32.7	32.0
Estoc	2.17	1.42	384	417.4	482.8	507.3	9.7	9.9	7387	7332	2.2	2.1	42.09	32.5	27.4	22.6
Mean	1.68	0.83	340	254.0	500.3	369.4	10.8	12.8	5780	3988	1.9	1.5	39.56	33.2	34.6	31.4
LSD	0.213	0.318	ns	72.83	ns	133.48	3.17	ns	2366.7	1927.1	ns	0.59	10.39	ns	5.36	ns

Table 5. Comparison of yield Pringgarata done to Aik Bukak Vulnerability to stress index and percent decrease

Variety	Yield (t/ha)		S Value	% Decrease
	AB	PR		
Axe	0.91	0.35	1.2	61.5
Nias	1.86	1.20	0.7	35.5
Gladius	1.87	0.71	1.2	62.0
Mace	1.92	1.09	0.8	43.2
Cobra	1.06	0.24	1.5	77.4
Correll	1.29	0.62	1.0	51.9
Dewata	2.13	1.12	0.9	47.4
Espada	1.74	0.69	1.2	60.3
Scout	1.89	0.75	1.2	60.3
Estoc	2.17	1.42	0.7	34.6

Conclusion

There was a genetic variation in wheat varieties response if they were adapted to the lowland areas. Growth and yield of wheat in high area (400 m above sea level), was better than at 200 m above sea level. Growth at areas having high temperature exceeding the limit of tolerance (supra-optimal), were slowed down. When grown at high temperature, wheat (in this case Cobra variety) underwent changing of the nature of the growth from medium (mid-season) to slow (late). Varieties with medium growth rate (mid-season variety), i.e. Nias, Dewata, Estoc and Mace produced higher yield (> 2 t / ha) that yield of other varieties. Environmental conditions that affect the success of pollination / fertilization should be considered to obtain a better yield with high number of seeds / spikelet.

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