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7 **Wheat (*Triticum aestivum*) Adaptation to Lombok Island Indonesia**

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ABSTRACT

1 Wheat is a temperate crop; therefore, effort is needed in adapting it to tropical areas. Lombok Island is suggested to be a potential wheat growing area. To investigate the feasibility of wheat production on Lombok and the adaptation of wheat to the current cropping systems, field experiments were carried out at six sowing times in 2010 and three sowing times in 2011 at three different sites up to 1000 meters above sea level (m asl) to represent low, medium and high elevation areas. 1)ght Australian and two Indonesian wheat varieties were selected to represent a range in maturity types. Six sowing dates in 2010 were arranged two weeks apart, from 19 April to 27 June, and three sowing 1)ne in 2011 were from 20 May to 19 June. Plant development was rapid at this continuously high temperature environment with flowering occurring 40-70 days after sowing (DAS). Wheat productivity was influenced by elevation and sowing date, at lowland, yields were about 1 t ha⁻¹ or less, whereas at 500 m asl and above ranged from 2-3 t ha⁻¹. Mid-season varieties were higher yielding than earlier or later flowering varieties. The optimum sowing time was from mid-May to early-June.

5 INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of world's major sources of dietary 1) calories and protein. It is a temperate cereal that is grown over a wide range of precipitation and temperature conditions, mostly in the range from 25° to 50° latitudes. However, wheat production has expanded into tropical and subtropical areas, to less than 15° latitude due in part to the availability of more widely adapted semi-dwarf germplasm (Musick & Porter, 1990) as well as the growing demand for wheat-based products in these regions. In these tropical and subtropical environments, wheat is grown during the cool season and often at high altitude to minimize the adverse effects of high temperature.

3) Currently, wheat is not produced in Indonesia, but Indonesia is the 3) largest importer of wheat in South East Asia. Indonesia is the largest single importer of wheat in the region with a 10.5 Mt of grain imported in 2016 (FAO, 2018). This trend is likely to continue as the per capita consumption of wheat-based products continues to increase. The need to

provide feed grain to support increased production of eggs, dairy and meat products is also likely to increase the demand for cereal grains. Increased production of wheat in Indonesia would help to ease the dependence on imported wheat for the country. However, improvement in the adaptation of wheat to tropical environments is needed to achieve this goal. Wheat is a winter cereal that evolved in temperate environments and tropical conditions are not favorable for wheat production. However, there is variation in rainfall and temperature during the year as well as topography that can be exploited to improve the growing environment for wheat.

Temperature and photoperiod are two environmental factors that greatly influence wheat development, growth and yield. Yield is affected by time of sowing and location because of the differences in temperature and photoperiod 8) during the year and among different locations. Changes in sowing date can alter the duration of some developmental stages significantly, and to different degrees depending on cultivars (Uddin, Islam, Ullah, Hore, & Paul, 2016). However in tropical countries

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such as Indonesia, variation in photoperiod is small and it is likely that temperature will be a major factor influencing crop development and productivity.

Lombok Island in Indonesia (8.5°S, 116.3°E) has a hot and humid climate with distinct wet and dry seasons. The wet season stretches from October to April with 1295 mm of rainfall (average 215 mm per month) while the dry season lasts from May to September when only 219 mm is received (average 36 mm per month). Temperatures on Lombok are higher than those experienced in many other regions where wheat is grown. The average maximum temperature is 30.9 °C during the day and minimum temperature is 22 °C at night in the lowland areas, but temperatures are 5-10 °C cooler in the upland areas in the centre of the island. The lowest maximum temperatures occur in July-August, while the lowest rainfall occurs during July-September (WMO, 2016) (Fig. 1).

The cropping system on Lombok consists of two rice and one non-rice crop, mainly peanut and soybean or sometimes maize. In drier areas, there is only one rice crop during the rainy season (October–January) followed by one non-rice crop and then a fallow until the next rainy season. An alternative crop to replace the fallow may help farmers diversify their cropping systems in these areas. Wheat is proposed as one of the non-rice options in the cropping system, which could be planted immediately after the second rice crop to use stored water in the soil for early growth and harvested before the start of rainy season in October. During this period, wheat will be growing at a time when temperatures are lowest and rainfall is declining (Fig. 1).

Time of sowing and the maturity type of the variety will be important on Lombok to allow crop

growth and development to match seasonal changes in temperature and rainfall and allow wheat to be integrated into the current agricultural systems. In many environments, sowing outside the ideal time can result in the loss of yield, which is related to reduction in germination or crop establishment and growth components such as dry matter accumulation and leaf area index (Baloch, Shah, Nadim, Khan, & Khakwani, 2010). Time of sowing can also determine the length of the crop growth cycle and the timing of key stages of development in relation to the determination of the major yield components, grain number and thousand grain weight (Hakim, Hossain, Teixeira da Silva, Zvolinsky, & Khan, 2012; Tahir, Nakata, Yamaguchi, Nakano, & Ali, 2009). The importance of sowing time to wheat yield on Lombok is not known.

Elevation may influence wheat performance because of its influence on temperature, especially in the tropics, and may be important for the adaptation of wheat in tropical environments. Investigations on the influence of elevation on wheat growth and yield in tropical and subtropical areas have generally shown substantial increases in yield at higher altitudes. Elevation influence wheat sensitive parameters of growth and yields greatly (Zhang et al., 2017). There is a large variation in elevation on Lombok and it is anticipated this will have a substantial influence on wheat yield.

The aim of this work was to examine the effects of sowing time and maturity type on the yield of wheat at sites with different elevations. Through these studies the feasibility of wheat production on Lombok and the integration of wheat into the current cropping systems would be better understood.

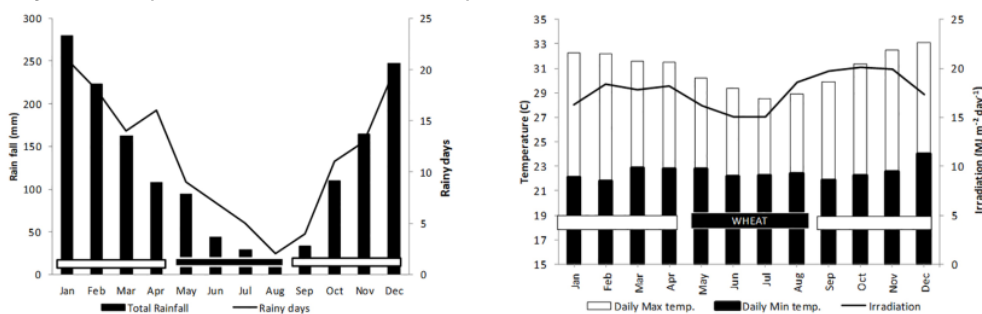


Fig. 1. Long term average of daily maximum and minimum temperature and total rainfall and rainy days for Lombok Island (WMO, 2016), and Irradiation of closed area Denpasar (Morrison & Sudjito, 1992). Closed bars indicate growing season in which wheat is proposed, during the coolest month May to August and the open bars represent the current rice growing seasons

MATERIALS AND METHODS

Plant Material

Plant material consisted of 8 Australian and 2 Indonesian bread wheat varieties. The varieties were selected to represent a range in maturity types. The varieties grown were Axe, Silverstar (early flowering), Mira, Gladius, Hartog, Janz (midseason), Sunvale and Yitpi (late flowering). The two Indonesian varieties used were Nias and Dewata. These 10 varieties were grown in 2010, but in 2011 only Axe, Gladius, Nias and Dewata were grown as they showed the most promising results in 2010 and they represented a range in maturity types that was considered suited to Lombok (early and midseason).

Sites and Time of Sowing

Three sites were chosen in each year to represent 3 different elevations. Experiments were conducted at Sembalun (1000 m above sea level (m asl)), Narmada (100 m asl) and Gunung Sari (10 m asl) in 2010 and at Lekok (10 m asl), Senaru (500 m asl) and Sembalun in 2011.

Sowing occurred within 1-2 days of each other at the three sites. Treatments consisted of a combination of 6 sowing dates and 10 varieties at each site. The sowing dates at Gunung Sari were 19 April, 3 May, 17 May, 31 May, 15 June, 28 June; at Narmada 17 April, 1 May, 14 May, 29 May, 12 June, 26 June; and at Sembalun 18 April, 2 May, 16 May, 30 May, 13 June and 27 June. In 2011, only three sowing dates were selected to represent early, mid season and late sowing dates. Sowing dates were: Lekok, 20 May, 2 June, 20 June; Senaru, 21 May, 6 June, 18 June; and Sembalun 22 May, 7 June and 19 June.

At planting a basal compound fertilizer NPK (15-15-15) was applied at the rate of 300 kg ha⁻¹. Urea was applied at the rate of 135 kg N ha⁻¹ and was split into 3 times of application: planting, 21 DAS and 35 DAS.

Experimental Designs

An objective of the 2010 experiment was to span a wide range of sowing times at the three sites to characterise the responses to sowing time. However, because of the limited supplies of seed and the small areas available in the farmers' fields, the varieties were grown in non-replicated plots at each sowing time and multiple plant samples were taken from each plot to provide an estimate

of variation associated with each treatment. Each sowing time was sown in a block with varieties randomly allocated within a block. In 2011, with fewer sowing times and larger quantities of seed, the experiments were designed as randomised complete blocks, with 3 replicates.

Measurements of Plant Growth and Development

Data were collected on individual plants in each plot, ten plants were chosen randomly from the middle row of each plot and tagged in 2010. In 2011, samples were taken from a half meter two adjacent rows. Crop development stage (Zadoks, Chang, & Konzak, 1977) and tiller number were measured on the tagged samples during the growing season at each sowing date. Time to flowering, when 50 % of ears had reached anthesis (Zadoks growth stage 65), was recorded. At maturity quadrat samples were taken to estimate yield components, [ear number, spikelets number and grain per spikelet, harvest index (HI) and 1000 grain weight] and from the remaining half of each plot all the ears were harvested, sun dried and threshed to recover grains, and grains were weighed to estimate grain yield.

Data Analysis

Data were analyzed as a multisite trial to examine the interactions between site, variety and sowing date. To examine the importance of maturity more so than individual varieties, varieties were also classified as early (Axe, Nias, Silverstar), midseason (Dewata, Gladius, Hartog, Janz, Mira) and late (Sunvale, Yitpi) and maturity grouping was used as a fixed effect in the analysis of variance. All data were analyzed with GenStat statistical program. Differences between mean values were compared by 5 % least significant differences (LSD) and relationships between variables were examined using simple linear correlations and regression.

RESULTS AND DISCUSSION

Adapting of wheat into tropical environments such as Lombok Island needs to consider the environmental limitations and the prevailing farming systems in the area. Soil and weather, including temperature and rainfall, are among the environmental factors that could have a large influence on wheat growth and development. The trends in grain yields on Lombok were similar to widely published research which shows higher yield at sites with greater elevation (Handoko, 2007; Zhang et al., 2017). In Handoko's trials on

1 Java Island, Indonesia (6-8°S; 106-112°E), Dewata (originally DWR 162) achieved a yield of 5.7 t ha⁻¹ at high elevation (1650 m asl) (Handoko, 2007). At elevations of 1000 m or lower on Lombok Island (8°S; 116°E), yields were about 100 g m⁻² higher compared to those reported by Handoko (2007) but the effect of changes in elevation on yield was very similar. The difference in yield may be associated with difference in solar radiation, because there is a significant transition from west to east in solar radiation in the Indonesian archipelago (Morrison & Sudjito, 1992). There is higher solar radiation and a higher proportion of clear days in the eastern islands compared to Java, which may promote growth and yield in the eastern islands such as Lombok. Nevertheless, the yield data shows that wheat could be a viable crop on Lombok, especially at medium to high elevations of around 500 m asl and above.

Plant Development

20 Plant development in general was rapid as warm temperatures increased the rate of phenological development (Hatfield & Prueger, 2015) but there were differences among the different maturity groups and locations. Table 1 shows the average times to stem elongation, flowering and

maturity for the four varieties that were common to both years. In 2010 time to the start of stem elongation (GS31) was 7-10 days later at Sembalun compared to Gunung Sari. The early varieties (Axe and Nias) reached GS31 5-7 days before the midseason varieties (Gladius and Dewata). Crops flowered, on average, between 40 and 60 days after sowing with the two earlier varieties flowering 7-10 days before the midseason varieties. There was relatively little difference between the sites in the time to flower. Crops at Sembalun reached maturity 7-10 days later than at Gunung Sari.

In 2011, time to GS31 was similar at the lowland sites (Gunung Sari and Lekok) and at Sembalun and at both sites the time was comparable to those recorded in 2010. Time to flowering was also similar to 2010 at the lowland sites (Gunung Sari and Lekok), but it was 10-20 days later at Sembalun. The mid-altitude site at Senaru was similar to Lekok for the time to GS31 and flowering, but was intermediate between Lekok and Sembalun for the time to maturity. As in 2010, the two early maturing varieties reached GS31 5-7 days earlier than the midseason varieties and reached flowering about 10 days earlier.

Table 1. Times to the beginning of stem elongation (ZGS 31), flowering (ZGS 65) and maturity of 4 varieties of bread wheat on Lombok Island. Data are the averages \pm sem over all sowing times at each site

Site	Variety	Days to:		
		GS31	50% flowering	Maturity
2010 (n = 6)				
Gunung Sari	Axe	28.6 \pm 1.3	44.2 \pm 3.4	78.2 \pm 2.8
	Gladius	35.6 \pm 2.8	59.8 \pm 2.8	97.2 \pm 7.7
	Nias	33.0 \pm 2.5	51.8 \pm 3.6	88.8 \pm 7.6
	Dewata	39.4 \pm 3.8	66.2 \pm 3.4	102.0 \pm 5.0
Sembalun	Axe	32.0 \pm 1.0	49.8 \pm 1.2	94.3 \pm 2.2
	Gladius	39.3 \pm 1.7	59.3 \pm 0.9	109.5 \pm 2.1
	Nias	34.3 \pm 2.2	51.3 \pm 2.2	97.5 \pm 1.0
	Dewata	41.8 \pm 1.6	66.0 \pm 2.0	109.5 \pm 2.1
2011 (n = 3)				
Lekok	Axe	21.1 \pm 2.1	39.7 \pm 2.2	76.7 \pm 5.8
	Gladius	30.3 \pm 1.5	51.3 \pm 1.5	98.0 \pm 2.5
	Nias	27.3 \pm 1.8	43.0 \pm 0.6	87.7 \pm 2.3
	Dewata	33.3 \pm 1.7	54.3 \pm 1.9	98.3 \pm 2.7
Senaru	Axe	25.3 \pm 2.7	41.3 \pm 1.2	91.3 \pm 4.3
	Gladius	31.7 \pm 4.4	53.7 \pm 1.5	105.0 \pm 0.6
	Nias	28.0 \pm 4.0	45.0 \pm 1.2	93.3 \pm 2.8
	Dewata	32.7 \pm 4.7	55.0 \pm 0.6	105.0 \pm 0.6
Sembalun	Axe	32.7 \pm 1.3	57.7 \pm 1.7	108.7 \pm 1.9
	Gladius	40.0 \pm 2.0	68.3 \pm 0.9	120.7 \pm 2.7
	Nias	34.3 \pm 2.3	62.7 \pm 1.2	112.7 \pm 4.6
	Dewata	39.7 \pm 2.3	70.3 \pm 1.5	120.7 \pm 2.7

Table 2. Average yield, total dry matter at maturity and yield components of varieties grown at three sites in Experiment 1 in 2010, grouped according to maturity type. Data are the means across six sowing times

Maturity type ^A	Yield (g m ⁻²)	DM (g m ⁻²)	Ears per m ²	Grain per m ²	Spikelet per ear	Grains per spikelet	TGW (g)	HI (%)
Gunung Sari								
Site mean	18	265	307	2251	10.8	0.6	21.5	17.3
Early	66 a	256	310 b	2762 a	10.4 b	0.8 a	25.0 a	22.7 a
Midseason	45 b	280	318 b	2204 b	11.6 a	0.6 b	21.2 b	16.1 b
Late	33 c	252	401 a	1850 b	9.4 c	0.5 c	17.4 c	13.3 c
LSD.	8	ns	26.5	387	0.25	0.09	1.33	2.09
Narmada								
Site mean	78	284	313	3819	10.5	1.3	28.5	20.5
Early	68 b	208 c	225 a	2956 c	10.4 b	1.4 a	22.7 a	31.5 a
Midseason	94 a	337 a	313 b	4547 a	11.6 a	1.3 a	20.9 b	29.1 b
Late	51 c	314 b	425 a	3384 b	9.7 c	0.9 b	14.9 c	17.2 c
LSD.	4	21.4	19.4	358	0.48	0.11	0.99	2.33
Sembalun								
Site mean	323	848	507	11280	12.2	2.0	38.5	28.6
Early	293 b	760 b	477 b	10471 b	11.5 b	2.0 a	28.2 b	39.2 a
Midseason	344 a	888 a	482 b	11567 a	13.0 a	2.0 a	29.6 a	39.0 a
Late	307 b	875 a	614 a	11754 a	11.2 b	1.9 b	26.4 c	35.7 b
LSD.	0.27	70.0	32.5	852	0.32	0.04	0.6	1.52

Remarks: ^AEarly: Axe, Silverstar, Nias; Midseason: Mira, Gladius, Hartog, Janz, Dewata; Late: Sunvale, Yitpi

Difference in maturity among the sites were greater in 2011, with crops grown at Sembalun reaching maturity up to 30 days later than at Leko. The post anthesis period (flowering to harvest ripe) ranged from 30-40 days in 2010 and 30-50 days in 2011 (Table 1). In 2010, sowing at the earliest dates at Gunung Sari delayed flowering, which was associated with very high temperatures, while at Sembalun no effect of time of sowing on flowering time was observed.

Grain Yield and Yield Components (2010)

Average grain yields in 2010 were 48 g m⁻² at Gunung Sari, 78 g m⁻² at Narmada and 323 g m⁻² at Sembalun (Table 2). High yields at Sembalun were achieved because dry matter production, ear production, grain set, thousand grain weight and HI were higher than at Gunung Sari and Narmada (Table 2). Maturity type influenced yield at the three sites. At Gunung Sari, average yields were highest among the early maturing varieties, while at Narmada and Sembalun midseason varieties produced the highest yields (Table 2). Late flowering varieties produced low yields at all sites. The effect of maturity on yield reflected differences in pre-anthesis growth (ear number, spikelets per ear) and consequently the number of grains per m², more than post-anthesis growth. The late maturity varieties produced smaller grains than the early and

midseason varieties at all sites.

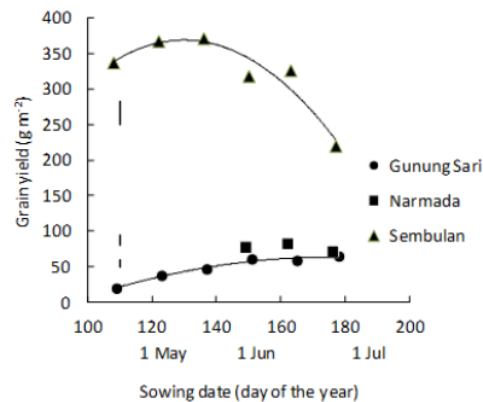


Fig. 2. The average responses to sowing time of wheat sown at three sites on Lombok Island, Indonesia in 2010. The LSD ($P = 0.05$) for comparisons among sowing dates at each site are shown as vertical bars. The predicted optimum sowing date for Sembalun is 10 May (day 130). Grain yield from three sowing dates was only available at Narmada because of water logging at the first three sowing times

Average responses to sowing time varied among sites (Fig. 2). At Gunung Sari grain yields

increased with later sowing dates, while at Sembalun there was an optimum sowing date of 10 May after which yields declined. There were too few sowing dates at Narmada to indicate a general pattern in the response to time of sowing, but among the three sowing dates harvested, there was no effect of time of sowing on yield. Yields at these three sowing times at Narmada were similar to those measured at the lowland site at Gunung Sari. Similar types of yield responses were seen with flowering time: at Gunung Sari yield increased at later anthesis dates, while at Sembalun yield decreased with later anthesis date, with an optimum flowering time of 8 July. Among both sites and sowing dates, grain yield was more strongly related to grains per m² than to thousand grain weight. The two Indonesian varieties, Nias and Dewata, were high yielding at each site. At Gunung Sari, the early flowering Indonesian variety Nias produced the highest yield of all 10 varieties (110 g m⁻²) while at Sembalun, Dewata and Nias were the two highest yielding varieties (494 g m⁻² and 359 g m⁻² respectively). At Narmada they produced average yields (Nias: 81 g m⁻² and Dewata: 90 g m⁻²). Of the Australian varieties Gladius produced the highest yield at Narmada

(126 g m⁻²) and produced a similar yield to Nias at Sembalun (349 g m⁻²). The variation in yields among varieties was largely associated with the production of grains per m² (Table 3).

Yield and Yield Components (2011)

Grain yields were highest at Sembalun followed by Senaru and least at Lekok (Table 3). Crops at Sembalun produced the highest dry matter, grains.m⁻² and kernel weights (Table 3). There was no significant interaction between sowing time and variety at any of the sites. However, the response to sowing time differed significantly among the three sites with two different responses to sowing date (Table 4). At Lekok lowest yields were obtained from the first time of sowing with no significant difference between the two later sowings in June. In contrast, at Senaru and Sembalun, grain yields at the first two sowing dates did not differ significantly from one another, with the third sowing date producing the lowest yield. The responses in yield to sowing time reflected the responses in total dry matter and grains.m⁻² and consequently yield was strongly associated with grain number. Thousand grain weights increased with later sowing and were highest at Sembalun and lowest at Lekok.

Table 3. Average yield and yield components of crops at different time of sowing in Experiment 2010

TOS	Yield (g m ⁻²)	DM (g m ⁻²)	Ears per m ²	Spikelet per head	Grain per m ²	Grains per spikelet	HI (%)	TGW (g)
Gunung Sari								
6 19-Apr	20	153	193	9.3	962	0.5	13.5	20.1
3-May	38	247	283	11.2	1535	0.5	14.5	23.2
17-May	47	275	328	11.0	1913	0.6	16.2	24.0
31-May	61	317	320	11.5	2740	0.7	19.0	22.7
15-Jun	59	282	328	10.8	2979	0.9	21.0	20.6
28-Jun	65	318	391	10.8	3487	0.8	19.7	18.7
LSD	9.6	29.7	39.9	0.5	444.1	0.1	2.43	1.52
Narmada								
29-May	78	268	259	11.0	3512	1.3	28.7	21.5
12-Jun	83	328	337	10.9	4287	1.3	27.2	20.4
26-Jun	72	279	318	10.3	3716	1.2	27.1	19.0
LSD	ns	38.3	35.8	ns	618.0	ns	ns	1.87
Sembalun								
6 18-Apr	337	971	551	12.2	12059	1.8	35.5	27.8
2-May	367	979	492	13.2	12396	2.0	37.6	29.4
16-May	371	914	455	12.8	11602	2.1	40.4	31.8
30-May	318	747	432	12.2	10109	2.1	42.9	31.8
13-Jun	326	843	584	11.1	12732	2.1	39.4	25.5
27-Jun	220	635	528	11.5	8825	1.8	35.2	25.4
LSD	32.7	78.2	41.8	0.66	1047	0.09	1.99	1.31

Table 4. The responses to sowing date among varieties of bread wheat sown at three sites on Lombok Island in 2011. Grain yield is based on bulk harvest of half the plot while grain number and thousand grain weight as derived from quadrat samples

Sowing date	Site			Mean
	Lekok	Senaru	Semalun	
	Grain yield (g m ⁻²)			
20 - 22 May ^A	56	262	301	206
2 - 7 June	149	249	364	254
18 - 20 June	147	160	285	198
Mean	117	224	317	
LSD		Site 45; Sowing time 45 Site x Sowing time 79		
	Total dry weight (g m ⁻²)			
20 - 22 May	221	664	844	576
2 - 7 June	493	761	824	693
18 - 20 June	559	415	787	587
Mean	424	613	818	
LSD		Site 108; Sowing time 108 Site x Sowing time 186		
	Grains m ⁻²			
20 - 22 May	3048	8473	11610	7710
2 - 7 June	6567	9826	11880	9424
18 - 20 June	6601	6149	9731	7494
Mean	5406	8149	11073	
LSD		Site 1316; Sowing time 1316 Site x Sowing time 2279		
	Thousand grain wt (g)			
20 - 22 May	26.7	33.8	35.2	31.9
2 - 7 June	31.2	35.0	35.2	33.8
18 - 20 June	29.8	34.5	36.7	33.7
Mean	29.2	34.4	35.7	
LSD		Site 1.61; Sowing time 1.61 Site x Sowing time NS		

Remarks: ^A Range of sowing times among the three sites**Crop Development and Yield**

The influence of different phases of growth on grain yield, grains per m² and thousand grain weights was examined using simple linear correlations. The data for the lowland sites (Gunung Sari and Lekok) were examined separately from the upland sites (Semalun and Senaru) because of the marked difference in yield; however in both cases yield was strongly correlated with grains per m² and only weakly with thousand grain weights. At the two lowland sites, late flowering and a long period between the start of stem elongation and flowering were associated with low grain number and yields. However a long post-flowering period was associated with high thousand grain weight and yield. In contrast, at the upland sites, the duration of the post-flowering period was not associated with yield, but instead high yields were associated with late flowering and a long pre-flowering period.

Effect of Elevation

Grain yield was influenced by elevation, which was associated with variation in growing season temperature. Regression analysis suggested that average grain yield increased by 25 g m⁻² per 100 m increase in elevation (Fig. 3a). The data also suggested an optimum average daily temperature for the growing season is 19.5 °C (Fig. 3b). The effect of elevation on the yield of the Indonesian variety Dewata is consistent with the previous analysis of Handoko (2007) on Java Island, with an average yield increase of 34 g m⁻² per 100 m increase in elevation, which was not significantly different to the 37 g m⁻² per 100 m derived from the work of Handoko (2007) (Fig. 3c). However the temperature response data for Dewata did not show an optimum on Java, while the results from Lombok suggest an optimum temperature of 21 °C (Fig. 3d).

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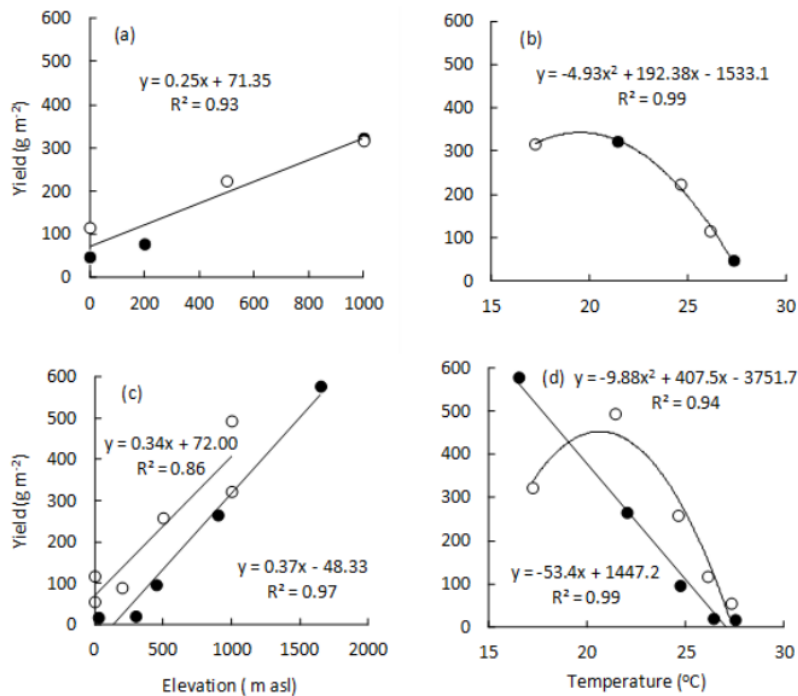


Fig. 3. The relationships between elevation and growing season mean temperature on the grain yield of bread wheat on Lombok Island, Indonesia. The relationships in 2010 (●) and 2011 (○) is between site mean yield and (a) altitude and (b) temperature. The results of Handoko (2007) on Java Island (●) are compared with the results from Lombok Island (○) for the variety Dewata between yield and (c) elevation and (d) growing season temperature

The effect of elevation on yield was generally consistent with previous studies in Indonesia (Handoko, 2007) and elsewhere (Hatfield & Prueger, 2015; Ihsan, El-Nakhlawy, Ismail, Fahad, & Daur, 2016; Rezaei, Siebert, & Ewert, 2015) and the main driver of the response was temperature, which influenced the rates of development and the severity of heat stress. However the level of solar radiation in different parts of the Indonesian archipelago may also influence yield. The mean temperatures experienced during the growing season on Lombok are generally higher than those experienced in many other wheat growing areas. Eventhough growth of wheat during all development phases can be influenced by temperature, the period leading up to flowering is still the most sensitive to heat because it coincides with an important yield forming period (Fahad et al., 2017). Although the range in temperatures on Lombok is small, the cooler conditions around flowering appear to have an

important influence on yield. The importance of the pre-anthesis phase to the yield of wheat on Lombok was shown by the strong relationship between grain per m² and yield, which was consistent across both years and sites.

Effect of Sowing Time

As well, the yield responses to sowing time were mirrored in the responses to anthesis date, which emphasized the importance of flowering time to yield on Lombok. Consequently, managing the crop to minimize the impact of heat stress at this time may be an important aspect of growing wheat on Lombok. The data across the different experiments suggested an optimum temperature for growth on Lombok of about 20 °C.

Like many low-latitude environments, the potential growing season for wheat on Lombok Island is short and characterizing the response to sowing date and elevation is important to develop

the most appropriate management practices. There were significant effects of sowing time on grain yield where, depending on the location, early or late sowing resulted in lower yields. Consequently, the optimum sowing time varied with location, and this was reflected in the relationship between yield and flowering date.

Although yield improved with late sowing at the lowland sites, sowing late into June will cause the crops to flower in August and fill grain during September, which coincides with the start of the rainy season (Fig. 1). Late sown crops would be exposed to rain and high humidity at flowering and during grain filling, which will increase the risk of infection diseases such as FHB. The low yields produced at early planting at the lowland sites could be due to several reasons. There were greater problems with establishment at early sowings in 2010 because of the heavy rainfall and this may be exacerbated by growing wheat after rice. The acceleration of plant growth and developmental phases under early sowing also reduced the number of tillers, spikelets per head, and kernels per spikelet, and consequently reduced plant yield. Shorter duration of floral initiation and spikelet development associated with high temperatures may also limit the grain number (Barlow, Christy, O'Leary, Riffkin, & Nuttall, 2015) as well number of spikelets and florets formed (Talukder, McDonald, & Gill, 2014). After August, maximum temperatures increase rapidly above 30 °C, and flowering at such temperatures may also cause lost of flag leaf chlorophyll contents (Talukder, McDonald, & Gill, 2014) and male sterility (Choudhary, Sharma, Kumar, & Kumar, 2015; Hatfield & Prueger, 2015). The narrow flowering window at the lowland sites and the pervasive high temperatures which limits growth and yield suggest that reliable wheat production in these environments may not be feasible.

Lombok's current farming system consists of two rice crops grown during the rainy season and a non-rice crop or fallow during the dry season. The planting of the first rice crop starts in September/October when the rainy season begins, followed by a second rice planting season in January/February. The third planting, which occurs during the dry season, starts in May/June, at the end of the rainy season or at the beginning of the dry season.

Wheat is suitable as a crop after the second rice crop, both at medium and high elevation where the timing of the start of the dry season matches

with the best sowing time for wheat. However, the response to sowing time at low elevations such as Gunung Sari and Lekok suggests wheat will not easily fit into the cropping sequence as a third crop at all sites. There are three benefits of using wheat as the third crop on Lombok: (a) wheat will not replace rice which is much preferred by Lombok farmers (Gusmayanti, Pertiwi, Handoko, Risdiyanto, & Machida, 2006), (b) it fits in with the current cropping sequence since the best sowing time coincides with the beginning of the dry season and it allows it to be grown during the coolest part of the year, and (c) maturity coincides with the dry season avoiding high occurrence of pest and diseases, and avoiding risk of sprouting of grain before harvest. Wheat production on Lombok is feasible at elevations above about 500 m but it is unlikely to be sustainable at lowland sites because of low yields and high incidence of disease. The growing season for wheat in the proposed rice wheat system on Lombok will coincide with the time when ambient temperatures and rainfall are the lowest (Fig. 1). The results of this study show that crops sown at the start of the dry season (May-June) reached flowering during the coolest period (July-August) of the year. This proposed sowing time gives the greatest possibility of achieving high wheat yields on Lombok.

Effect of Different Varieties

The late flowering varieties in 2010 consistently produced the lowest yields at all sites which was associated with poor grain set and grain growth. This may have been associated with the greater exposure to higher temperatures at flowering and during grain filling. Early and midseason varieties showed differences in their adaptation to different sites on Lombok, and the two Indonesian varieties were generally higher yielding than the two Australian varieties. The Indonesian midseason variety Dewata in particular was highly responsive to improved growing conditions. This analysis is consistent with the apparent difference in the importance of pre-flowering and post-flowering growth at the lowland and upland sites. The negative influence of late flowering and a long stem elongation phase on grain yield suggests that early flowering varieties perform relatively better in these lowland environments, while at the upland sites the later flowering midseason varieties produced higher yields. This difference in the adaptation between

the early and midseason varieties may influence the types of varieties developed in the future. The early maturing varieties, Axe and Nias, performed relatively better at the low yielding, lowland sites, although Nias was consistently 45 g m⁻² higher yielding across all environments. Axe is a very early maturing variety (Table 3) and under the warm growing conditions of Lombok, it develops rapidly and may produce insufficient biomass to develop a high yield potential. The midseason varieties showed a greater responsiveness to higher yielding conditions. The results suggest that if the medium to high elevation sites are to be the target for future wheat production, midseason varieties should be developed.

The Indonesian varieties, Nias and Dewata, were better adapted to the Lombok environment in both years. They were capable of producing high number of grains per m² which was associated with their high spikelets per head and they can form a foundation for future genetic improvement. These two lines were originally developed from Indian lines and they have traits that are suited to tropical environments. More detailed studies of the characteristics of these lines is warranted as they may be useful sources of heat tolerance.

CONCLUSION AND SUGGESTION

Wheat reliably produced grain yields above 3 t ha⁻¹ when it was grown at elevation above 500 m asl. In these areas the wheat production cycle can fit into the current cropping systems in these areas. Sowing wheat at the optimum time (May-early June) on the medium to high elevation of Lombok Island could be an important part of the wheat production system on Lombok. Sowing between May to early June is important to allow crop maturity and harvest in late August or early September before the onset of rain season and ensure timely planting of the next crop. At lowland sites, grain yields are be much lower and it is likely that crop maturity and harvest would overlap with the rainy period which will reduce grain quality as well as delay the planting of the next paddy rice crop.

Crop management practices such as optimal time for planting, plant density, irrigation and fertilization would be critical in sustaining wheat yields in warm environments. It is suggested further investigation on the cropping practises to be adjusted for broader areas with different altitude and yield potential.

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