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Adaptation of broccoli (*Brassica oleracea* var. *italica* L.) to high and low altitudes in Bali, Indonesia

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Abstract. *Astarini IA, Defiani MR, Suriani NL, Griffiths PD, Stefanova K, Siddique KHM. 2020. Adaptation of broccoli* (*Brassica oleracea var. italica L.) to high and low altitudes in Bali, Indonesia. Biodiversitas 21: 5263-5269.* Broccoli is an important vegetable worldwide, with expanding markets and opportunities in Asia. In Indonesia, there is demand from high-end hotels, restaurants, and export markets, but the local supply is low quality and low yielding. Crown cuts are typically small and misshapen as the varieties are grown are not adapted to local environments. This study targeted new broccoli varieties to identify those best adapted to environmental stresses in Bali, Indonesia, using two-site replicated field experiments. Experiments were undertaken in two regions in Bali (Bedugul and Tabanan) using 13 commercial varieties that included heat-sensitive varieties and others identified as heat-tolerant in trials on the East Coast of the USA. The trials evaluated the varieties for crown initiation, days to maturity, crown size at harvest, crown diameter, and overall performance. The study demonstrated that all 13 varieties could be used for broccoli production in the Bedugul region (1200 m a.s.l. altitude), with Castle Dome being the best performer due to its earlier maturity and large high-quality crown. The varieties Bay Meadows, Belstar, Imperial, and Sarasota could be used in the Tabanan region.

Keywords: Adaptation, breeding, heat tolerant, tropical region

INTRODUCTION

Broccoli (*Brassica oleracea* var. *italica* L.) is an important vegetable crop in Indonesia and around the world. There is increasing demand for broccoli in Indonesia, mainly from high-end restaurants, hotels, and supermarkets. Demand for broccoli in Indonesia and overseas market increase 20-30% per year (Widaryanto and Roviyanti 2017). Indonesia produced 150 tons of cauliflower and broccoli from 12 provinces in 2018, with the main production areas in North Sumatra and Central Java (BPS 2019). Local production varies in quality and yield due to the use of varieties not well adapted to the region. Due to the increasing demand, Indonesia currently imports broccoli from overseas, with combined imports of broccoli and cauliflower of around 1200 tons in 2016 (Statistik Pertanian 2017). Overall, Indonesia imported 904,789 tons of vegetables in 2018, valued at US $738,282 (BPS 2019).

Broccoli is a cool-season crop that usually performs poorly in warm weather. Broccoli production is better suited to temperate climate, as it requires low night temperatures to enable normal bud and crown development (Farnham and Bjorkman 2011a). Broccoli crown initiation occurred at 32 days when the average temperature is 21°C. Lower temperatures result in longer initiation times (Wurr et al. 1995).

Temperature is the main factor for transitioning broccoli from the vegetative to the generative phase. Vernalization model in broccoli was developed (Wurr et al. 1995) that at temperatures above 23.6°C, plants would remain vegetative. Without suitable vernalization, crown production in many genotypes fails, and plant continues to grow vegetatively. At higher temperatures, arrested crown development occurs (Bjorkman and Pearson 1998) resulting in poor-quality crowns, uneven bead size, leafy head, and yellowish color (Farnham and Bjorkman 2011a). Temperatures above 27°C significantly reduce, or even abort crown-forming capacity. The optimum temperature for broccoli is 20°C for the entire growing cycle (Tan et al. 2000). Vernalization and temperature stress are limiting factors for broccoli production in tropical countries such as Indonesia. With the increasing demand for broccoli, new markets are developing in Indonesia and South East Asia—the identification of better-adapted varieties or genotypes for production in these regions would contribute to the development of these markets.

Research is undertaken on the East Coast of the USA investigating commercial varieties and public sector hybrids and genotypes to identify broccoli varieties and genotypes better adapted to stressful growing conditions that could be used to expand production. Suitable variety adaptation and appropriate cultural practices are critical for developing profitable broccoli markets (Branham et al. 2017).

Cornell University, New York, and USDA, South Carolina, have developed broccoli breeding lines with increased tolerance to high temperatures (data not shown) that could be used to develop varieties that are better adapted to more stressful growing conditions. Field trials with 32 broccoli hybrids evaluated at multi-site locations in the USA (Maine, North Carolina, New York, South Carolina, Virginia) identified variable responses of hybrids in these growing regions (Farnham and Bjorkman 2011a). Twelve varieties that varied in quality and yield when grown under high-temperature stress were identified for evaluation in Bali, Indonesia to understand their adaptation in tropical conditions. The hypothesis was that broccoli varieties adapted to tropical regions are high yielding with good quality crowns.

Breeding a vegetable crop for adaptation to a temperature regime that is higher than the recognized optimum for the species is an example of breeding for abiotic stress tolerance. Some abiotic stresses directly reduce crop growth, yield, and quality. Breeding for tolerance to this stress has excellent potential for meeting the increased demand in a broader production region (Farnham and Bjorkman 2011). The aim of this study was to identify broccoli varieties adapted to different altitudes in Bali, Indonesia.

MATERIALS AND METHODS

Plant materials

Thirteen broccoli varieties were included in the field trials, 12 of which were imported from Geneva, New York, along with a locally grown Bali variety Star Green. All imported varieties are F_1 hybrids: each bred from two selected pure lines to obtain heterosis (hybrid vigor) of the two-parent lines. The 12 varieties evaluated were Alborada, Bay Meadows, Belstar, Castle Dome, Fiesta, Green Gold, Green Magic, Imperial, Ironman, Lieutenant, Marathon, and Sarasota (Table 1).

Weather and soil condition

Varieties were grown over two years (2014 and 2015) at two altitudes in Bali, Indonesia: 1200 m a.s.l. (Kembang Merta Village, Bedugul, 8° 15’ 29.247” S, 115° 9’ 44.7608” E) and 600 m a.s.l. (Senganan Village, Tabanan, 8° 22’ 21.5004” S, 115° 9’ 29.4264” E). The two trial locations varied in rainfall amount and temperature. The Bedugul site is located 1200 m above sea level, with an average rainfall of 2261 mm per year and an average of 114 rainy days each year. September has the lowest rainfall, with an average of 20 mm, and January has the highest rainfall, with an average of 491 mm. The Tabanan site is located at 600 m above sea level, with an average rainfall of 2533 mm per year and an average of 180 rainy days each year, August is the driest month, while February is the wettest (climate-data.org 2020).

Bedugul has an average annual temperature of 18.5°C; October is the hottest month with average temperatures reaching 24.2°C, and July is the coolest month with an average temperature of 17.6°C (climate-data.org 2020). Tabanan has an average temperature of 22.7°C; November is the hottest month with an average temperature of 24.6°C, and July is the coolest month, with an average temperature of 22°C. The Bedugul site has a Regosol/Andosol soil type with pH 5.8, and the Tabanan site has a Latosol sandy loam with pH 6.2.

Table 1. Broccoli varieties used in this study and their characteristics

Variety	Producer/ seed company	Days to maturity	Characteristics
Alborada	Bejo	72-90	Compact crown.
Bay Meadows	Syngenta	65-85	Summer broccoli, open plant habit, produces good crops even under stressful conditions. Blue-green well-domed heads.
Belstar	Bejo	75-85	Medium frame producing uniform heavy crowns. Best suited for cooler periods.
Castle Dome	Seminis	75	Heat-loving, early-maturing.
Fiesta	Bejo	80	Cold and heat tolerant, bright green crown, good disease resistance.
Green Gold	Sakata	100	Tight, smooth, heavy, domed, and finely beaded with medium-green color, excellent uniformity.
Green Magic	Sakata	80	Summer, also good for fall harvest, blue/green with uniform, tightly packed heads, excellent flavor, and strong resistance to foliar powdery mildew.
Imperial	Sakata	68-102	Tight dome-shaped heads with small dark green beads. Performs best during long-day growing conditions with moderate heat.
Ironman	Seminis	70-80	Spring to fall, high-quality crowns.
Lieutenant	Seminis	75	Good heat tolerance, uniform dome shape, smooth crowns with minimal bract leaves when grown in warm conditions. Medium-dark green color with good weight.
Marathon	Sakata	90-100	Good cold tolerance and highly recommended for cool-season harvest. High domed with small beads of dark blue-green color. Bead quality is affected negatively by warm weather.
Sarasota	Syngenta	100-110	Summer, dome-shaped head with fine bead size. Excellent stem and head weight. Vigorous open plant habit.
Star Green	-	60-80	Summer to fall crop. Vigorous and resistant to disease. Dome-shaped crown with fine beads in dark green color. Thick, crispy, and solid stem.

Field experiment and design

Seeds of each variety were sown in July in seedling trays using a commercial potting mix and kept in a shade house with temperatures ranging from 20-25°C and irrigated as needed. Seedlings were transplanted to the field four weeks after sowing.

All field trials were conducted using a randomized complete block design with three blocks, each with three replicates, totaling nine replicates for each site and year. Each plot was planted with 20 plants of a given variety. Plants were spaced 50 cm apart within rows 40 cm apart. Plants were irrigated daily in the morning using an overhead irrigation system. Plots were fertilized with 1 kg×m^{-2} cow manure, two weeks prior to transplanting. Cow manure was spread and mixed with soil along the rows on each planting bed/plot. All varieties received 30 g.m^{-2} fertilizer (Phonska (NPK)) on the transplantation date. Pesticides were applied to prevent damage to seeds by *Agrotis* species. Weeds were removed manually prior to transplanting and every two weeks until harvest.

Data collection

The crown initiation time (in days) and days to maturity were recorded, along with crown diameter (cm) and crown fresh weight (g) at harvest. Overall performance was based on field assessments that included plot uniformity, crop color, dome firmness, and bead uniformity (Farnham and Bjorkman 2011a).

Statistical method

A linear mixed model was used to analyze the data. For all four response variables (crown diameter, crown weight, curd initiation, and days to maturity at harvest) the fitted model accounted for blocking and treatment structures. The block structure was a *Block/replicate* fitted as random for all *Year* and *Site* combinations. The treatment structure comprised the fixed main and interaction effects of *Year*, *Site*, and *Variety*. Pairwise comparisons of means were performed using the least significant differences (LSD) test. Statistical analyses were conducted using statistical software GenStat, 20th Edition (VSN International, Hemel Hempstead, UK).

RESULTS AND DISCUSSION

Statistical analysis

The results from the analyses (Table 2) revealed a highly significant *Variety* main effect for all response variables, while *Site* was only highly significant for Crown Initiation and Maturity days. *Year* and, as expected, the interaction of *Site* and *Year* were not significant for any response variable. The climatic conditions at both sites in 2014 and 2015 did not differ much. All other interaction effects, including *Variety*, were highly significant.

Based on the comparison of means, the significance of the third-order interaction term *Site* × *Year* × *Variety* was mainly driven by *Variety* and, to a lesser extent, *Site* for all responses. Further detailed comparisons of the means for the interaction effects of each response variable revealed slightly different patterns.

Crown initiation

Crown initiation varied between varieties, sites, and years. Table 3 presents the estimated means of crown initiation for all 13 varieties, along with LSD values. Overall, the Bedugul site had a shorter crown initiation period than the Tabanan site, which was consistent across years and varieties.

At the Bedugul site in 2014, Castle Dome had the fastest crown initiation at 44 DAT (days after transplanting), followed by Lieutenant, Marathon, and Green Gold which had similar crown initiation times as the control variety Star Green (47 DAT). Crown initiation of the remaining varieties was ≥50 DAT, with Alborada the latest at 53 DAT. Crown initiation at the Bedugul site in 2015 followed a similar pattern to 2014. Each variety had a slightly later crown initiation time, except for Castle Dome and Green Gold. The latest crown initiation time occurred in Alborada and Sarasota at around 54 DAT.

At the Tabanan site in 2014, 'Sarasota' had the fastest crown initiation at 55 DAT, followed by Castle Dome at 59 DAT. The remaining varieties had crown initiation times ≥60 DAT, indicating that the higher temperatures at this site delayed crown formation (Table 3). Crown initiation at the Tabanan site in 2015 also followed a similar pattern to 2014. Green Magic and the control variety Star Green entered the crown initiation stage at 58 DAT, while the other varieties started to initiate their crowns ≥60 DAT (Table 3).

Days to maturity

The time to maturity for all varieties differed between sites within a year (Table 3). With few exceptions, the time to maturity in all varieties did not differ between years within a site. The rankings of *Variety* within each *Year* by *Site* combination were similar. In Bedugul, the time to maturity ranged from 53 DAT (Castle Dome) to 71 DAT (Alborada, Belstar, and Fiesta) in 2014, and 53 DAT (Castle Dome) to 77 DAT for Fiesta in 2015. Bay Meadows, Belstar, Castle Dome, and Lieutenant had consistent maturity days across years (Table 3). At Tabanan, the time to maturity of each broccoli variety varied between years. Mean days to maturity ranged from 66 DAT (Sarasota) to 89 DAT (Marathon) in 2014 and 69 DAT (Green Magic) to 88 DAT (Fiesta) in 2015.

Table 2. The significance (p-values) of the main and interaction effects for all response variables

Term	Crown initiation	Maturity days	Crown diameter	Crown weight
Site	<0.001	<0.001	NS	NS
Year	NS	NS	NS	NS
Variety	<0.001	<0.001	<0.001	<0.001
Site × Year	NS	NS	NS	NS
Site × Variety	<0.001	<0.001	<0.001	0.007
Year × Variety	<0.001	<0.001	<0.001	<0.001
Site × Year × Variety	<0.001	<0.001	<0.001	<0.001

Table 3. Estimated means of crown initiation (days after transplanting) for *Year* × *Site* × *Variety* with LSD value of 2.2 at 0.05 level of significance, and estimated means of maturity days (days after transplanting) for *Year* × *Site* × *Variety* with LSD value of 2.5 at 0.05 level of significance

Variety	Crown initiation				Maturity days			
	2014		2015		2014		2015	
	Bedugul	Tabanan	Bedugul	Tabanan	Bedugul	Tabanan	Bedugul	Tabanan
Alborada	53.3	68.3	54.4	63.7	71.3	84.2	72.7	80.7
Bay Meadows	50.3	68.0	51.4	63.4	67.3	84.6	66.3	80.6
Belstar	49.8	70.0	51.2	70.2	71.9	85.0	71.4	85.4
Castle Dome	44.0	59.0	43.7	62.1	53.3	71.0	53.0	73.1
Fiesta	52.6	71.1	53.6	73.8	71.9	87.2	77.7	88.0
Green Gold	48.3	75.2	46.8	69.6	66.2	86.5	61.1	81.0
Green Magic	48.7	64.9	50.8	58.2	65.8	75.7	63.3	68.9
Imperial	50.1	74.9	51.4	72.0	71.0	86.7	72.4	85.3
Ironman	50.8	74.0	53.0	72.9	66.9	88.2	69.6	85.9
Lieutenant	47.0	66.0	49.6	67.1	65.7	78.6	65.0	80.0
Marathon	48.3	75.1	52.7	67.9	70.1	89.2	72.7	79.6
Sarasota	52.3	55.0	54.1	63.1	70.3	66.0	72.7	75.1
Star Green	47.0	64.0	49.0	58.9	65.0	75.0	62.8	70.7

Table 4. Estimated means of crown weight (g) for *Year* × *Site* × *Variety* with LSD value of 63.8 at 0.05 level of significance

Variety	2014		2015	
	Bedugul	Tabanan	Bedugul	Tabanan
Alborada	336.7	274.1	470.0	366.7
Bay Meadows	291.7	166.7	560.6	476.1
Belstar	341.6	189.8	480.0	319.4
Castle Dome	697.8	209.3	520.0	650.6
Fiesta	326.0	265.0	459.8	300.6
Green Gold	362.2	180.8	449.4	461.7
Green Magic	363.3	201.7	480.0	307.4
Imperial	419.0	343.3	450.6	366.1
Ironman	261.3	244.5	331.1	245.6
Lieutenant	422.0	150.4	370.0	384.4
Marathon	445.6	260.0	271.1	298.3
Sarasota	359.9	227.4	530.0	394.4
Star Green	460.0	275.6	350.6	292.4

Table 5. Estimated means of crown diameter (cm) for *Year* × *Site* × *Variety* with LSD value of 1.4 at 0.05 level of significance

Variety	2014		2015	
	Bedugul	Tabanan	Bedugul	Tabanan
Alborada	12.6	13.7	14.8	12,3
Bay Meadows	13.3	13.3	13.7	13,7
Belstar	13.6	12.5	18.6	15.1
Castle Dome	18.9	13.6	15.8	16.7
Fiesta	13.7	13.0	13.2	12.2
Green Gold	12.8	11.6	13.1	14.2
Green Magic	13.8	12.3	16.8	12.4
Imperial	14.4	12.3	13.7	13.6
Ironman	13.0	13.3	15.1	17.8
Lieutenant	15.2	12.2	12.0	14.9
Marathon	14.4	14.7	12.2	15.8
Sarasota	14.7	13.0	12.4	13.2
Star Green	15.4	13.9	15.1	14.9

Crown weight

Crown weight varied between varieties within and across sites and between years (Table 4). At the Bedugul site, Castle Dome produced the heaviest crown weights—698 g in 2014 and 520 g in 2015—exceeding the control variety Star Green (460 g in 2014 and 350 g in 2015). Imperial, Lieutenant, and Marathon had mean crown weights >400 g in 2014, as did Star Green, while Bay Meadows, Castle Dome, and Sarasota produced crown weights >500 g in 2015.

At the Tabanan site, all varieties produced crowns <400 g in 2014, from 148 g in Lieutenant to 343 g in Imperial. In 2015, Castle Dome produced the heaviest crown weight (650 g), while Bay Meadows and Green Gold produced crown weights >400 g. The control variety Star Green produced crowns weighing <300 g in both years at the Tabanan site (Table 4).

Crown diameter

Crown diameter showed no significant patterns between varieties of sites or years (Table 5). All varieties at both sites produced broccoli crowns of acceptable marketable size, i.e., more than 10 cm in diameter. The largest crown diameter at the Bedugul site was almost 19 cm in Castle Dome in 2014, and 18.6 cm in Belstar in 2015. The control variety Star Green had a crown diameter of 15 cm in both years.

The largest crown diameter at the Tabanan site was 14.7 cm in Marathon in 2014, and 17.8 cm in Ironman in 2015, followed by 16.7 cm in Castle Dome and 15.8 cm in Marathon. The control variety Star Green produced crown diameters of 14 cm and 15 cm in 2014 and 2015, respectively (Table 5). Local Bali markets accept broccoli with diameters from 10-20 cm, while the export markets prefer 15-18 cm.

Overall performance

Overall performance was based on scoring criteria (Figure 1). Almost all varieties performed well in Bedugul, with ratings >4 on the scale. Castle Dome, Ironman, and Imperial performed particularly well in both years. Fiesta and Star Green had the lowest scores, with ratings of 4. Bay Meadows was the most promising variety at the Tabanan site, rating >4 in both years. Belstar and Imperial also had consistent performance, with ratings around 4. The other varieties had ratings <4 (Figure 1).

Heat stress, dome, and hollow stem

Several heat stress symptoms were observed in the field, mainly at the Tabanan site, including uneven bead, yellow crown with many leaves, brown spot crown, small curd with many leaves growing on the crown, cat-eye (small undeveloped bead surrounded by bigger bead) and non-uniform head/unsmooth (Figure 2).

There were three types of dome observed in the field: pyramid, round, and almost flat (Figure 3). Pyramid and round shapes are preferred by farmers because the flat shape crown easily rots as water stays on the crown in the rainy season. Hollow stems, defined as the presence of stem cavities in broccoli crown were observed for some varieties at both sites, which may be the result of the plant spacing/cultural practices used (Figure 3). Hollow stems are undesirable for export markets (Bjorkman and Pearson 1998) as they are lower quality and easily infected by pests and diseases.

Discussion

The performance over two years revealed a consistent response of broccoli varieties at each site. Broccoli grown at the Bedugul site performed better than at the Tabanan site. This is mainly due to cool temperatures at the high elevation site (1200 m a.s.l. altitude). Temperatures at the Bedugul site ranged from 12°C in the morning (minimum) to 24°C (maximum) at noon, which is suitable for broccoli production. As revealed by Farnham and Bjorkman (2011b), broccoli is better adapted to cooler areas to produce high-quality crowns. The optimal growing temperature is 18°C or below to induce bolting and allow for normal flower and head development (Wurr et al. 1995). Broccoli at Bedugul produced high quality, good weight, and compact crowns.

Temperatures at the Tabanan site, being 600 m a.s.l. lower in altitude, were higher with a broader diurnal range (18-30°C) that affect crown formation and quality. This was seen in the longer crown initiation, crown maturity time, low crown weight, and abnormal crown. Significant reduction in fresh weight of cabbage and cauliflower due to heat was also revealed by Rodríguez et al. (2015). Higher temperatures (30°C) cause uneven-sized flower buds on broccoli inflorescences (Bjorkman and Pearson 1998). High temperatures during harvest periods were reported causing decrease in firmness of the broccoli crown (Sahamishirazi et al. 2018).

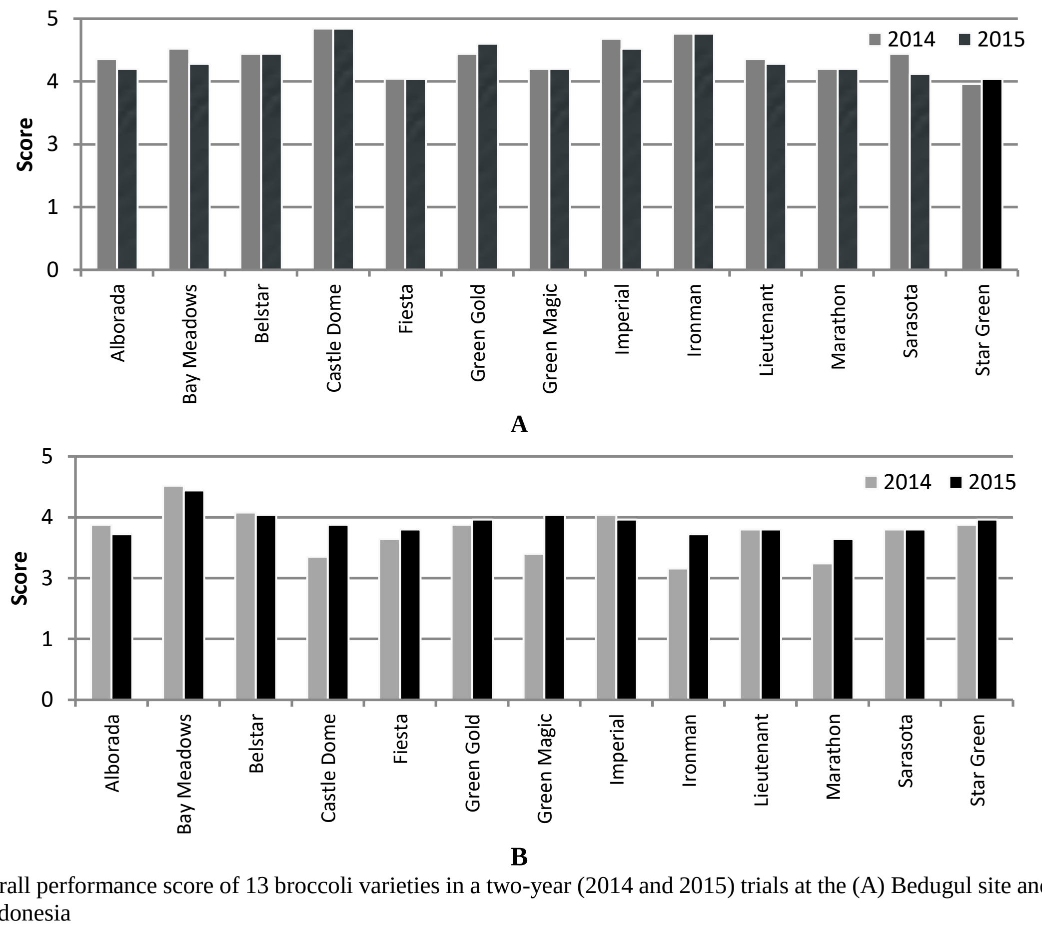

Figure 1. Overall performance score of 13 broccoli varieties in a two-year (2014 and 2015) trials at the (A) Bedugul site and (B) Tabanan site in Bali, Indonesia

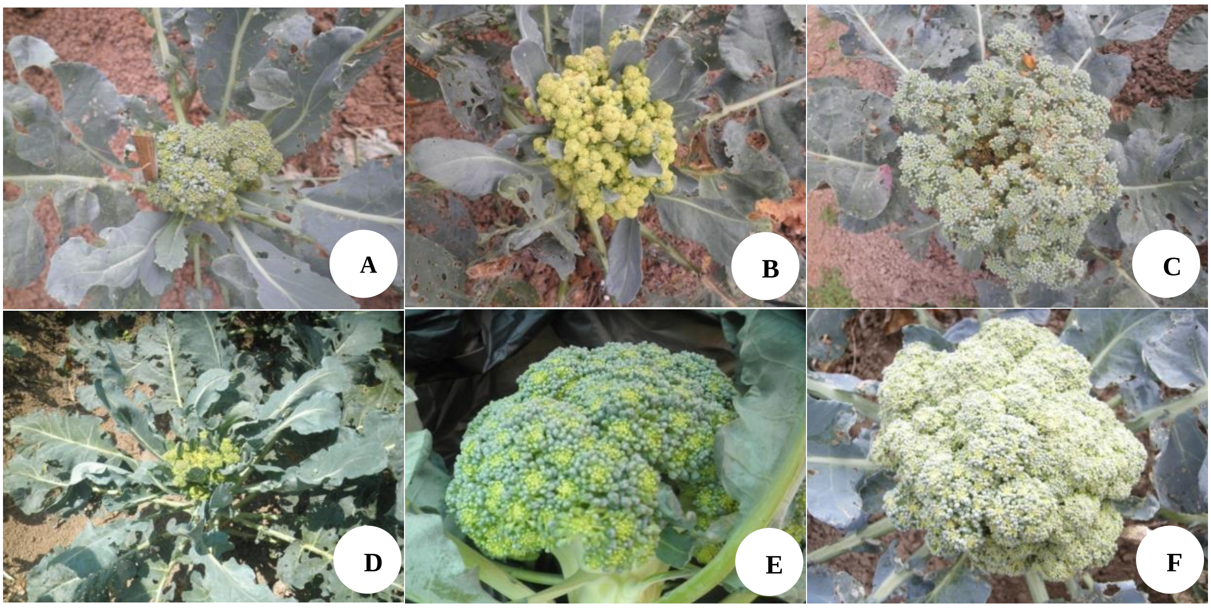

Figure 2. Symptoms of heat stress observed at a trial site in Bali, Indonesia. A. Unevenbeads, B. Leafy and yellow, C. Precocious flowering and separated beads, D. Leafy, E. Cat-eye, and F. Clump

Figure 3. A. Dome types (pyramid, round and flat), B. Hollow stem, and C. Normal stem observed during the trials

Bjorkman and Pearson (1998) also found that the critical period for heat sensitivity in broccoli lasts for ten days. This 'window' of sensitivity corresponds to the time when the growing tip shifts from vegetative growth to flower bud initiation. This is a period of about 10 days prior to when a tiny crown is visible in the center of the plant. Temperatures above 35ºC for more than four days during that period cause uneven bud development at the bud initiation stage, resulting in heads that were uneven and poorly shaped, as shown on broccoli grown in Senganan village at 600 m a.s.l.. The occurrence of hollow stem, however, is probably due to boron deficiency or excessively use of nitrogen fertilizer (increases likelihood of hollow stem, which is often not noticeable until harvest. However, hollow stem can also be exacerbated by excessive nitrogen fertilizer (Bjorkman and Pearson 1998). It can be also due to too much water during growing period, causing rapid growth after head initiation. Local farmer explained that occurrence of hollow stem can be avoided by reducing plant spacing (Wardana W 2015, pers.com).

Heat stress limits plant growth, leaf development, photosynthesis activity, and yield on Brassica (Rodríguez et al. 2015; Soengas et al. 2018). Moreover, Rurek et al. (2018) found that cauliflower closed stomata during heat stress, resulted in moderate photosynthetic with only minor respiratory damage. High temperature has also been reported to causing stress on the reproductive development of other Brassica species, i.e. *Brassica juncea*, *B. napus*, and *B. rapa*, which were exposed to 35/15°C for 7 days. High temperatures at flowering affected yield formation more than high temperature at pod development on those three species (Angadi et al. 2000). Research by Koscielny et al. (2018) revealed that exposure to heat 31°C/14°C (day/night) for 14 days during flowering causing reduction in canola (*B. napus*) yield by 55%. Besides yield loss, high temperatures also causing alterations to seed composition during seed filling in canola (Yu et al. 2014). Wilson et al. (2014) described that when the environmental temperature exceeded the physiological threshold of a plant, it will increase the concentration of reactive oxygen species (ROS) in cells, in which disrupt normal metabolism of plants through the oxidation of membrane lipids, proteins, and nucleic acids, thus affecting plants metabolism and limiting growth and yield. In this experiment, heat stress reduced head weight as well as diameter for broccoli grown at lower altitude with warmer temperature at Senganan village (600 m a.s.l.).

The variation in performance and production of each cultivar studied has provided evidence that variation exists within broccoli variety for heat tolerance. Molecular markers need to be developed for faster and more accurate identification between heat-tolerant and susceptible genotypes. Branham et al. (2017) has reported that breeding for heat-tolerant broccoli is constrained by limited genetic information. A doubled haploid broccoli population segregating for heat tolerance was evaluated for crown quality using multiple quantitative trait loci (QTL) mapping to identify markers for heat tolerance. Five QTL were identified and can be used to develop markers for marker-assisted selection (Branham et al. 2017). Further studies using multiple QTL analyses are needed to select broccoli varieties adapted to the Indonesian region.

Our study suggests that varieties heat sensitivity of the varieties varied, and they have slightly different responses toward high-temperature. All varieties trialed are suitable for growing in higher altitudes, with Castle Dome and Ironman being the best. Sarasota is tolerant of higher temperatures and can form crowns in more stressful environmental situations. Bay Meadows and Imperial had a longer maturity time in lower temperatures but produced marketable crowns. This study presents the groundwork for expanding broccoli production in Indonesia by identifying varieties that are better adapted to different growing regions.

In conclusion, all varieties were suitable for growing in higher altitude areas, such as the Bedugul region in Bali, Indonesia (1200 m a.s.l. altitude), but varied in marketable quality, yield, and maturity. Castle Dome was the best performing variety at this site, with its shorter maturity time and high-quality crown. Other varieties performed well, relative to Star Green the common variety grown in this region. Broccoli can be grown in the Tabanan area (600 m a.s.l. altitude), but the varieties need to be better adapted to higher temperature stress—Bay Meadows, Belstar, Imperial, and Sarasota could be considered for this region. Future research should focus on wet season trials to identify better performing and better-adapted varieties during that growing season and develop markers to assist in the selection of heat-tolerance traits.

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