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RESEARCH ARTICLE

Growth Performance and Productivity of Several Soybean Genotypes (*Glycine max* L. Merr.) Cultivated at High Altitude Areas in Indonesia.

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Abstract

The low productivity of soybeans (*Glycine max*) and the impacts of climate change have led to the need for adaptive varieties to high altitude to produce high yields. In this study, nine soybean genotypes from different geographic regions, tropical and subtropical, were tested. The aim of the research was to investigate the growth and productivity of different genotypes of soybean when grown in high-altitude environment. Results showed that the tropical genotypes, “Tanggamus” and “SC-1-8” from Indonesia, “Manshuu-masokutou” from China, and “San Sai” from Thailand, had longer growth duration than the subtropical genotypes, “Enrei” and “Fukuyutaka” from Japan, “Stressland” and “Ht-2” from the United States, and “Hakubi” from China. Tropical genotypes have greater growth values than subtropical genotypes as shown by taller plants, greater number of leaves and dry weight. Among the tropical genotypes, “SC-1-8”, which is a soybean line from IPB, showed the best growth rates and competitive crop yield, making it a potentially good candidate for high yielding soybean in Indonesia.

Keywords: genotypes, *Glycine max* (L) Mer., high altitude, pod filling, subtropical

Introduction

Glycine max, commonly known as soybeans, is one of the important commodities in Indonesia, especially for processed food ingredients such as tofu, tempe, soy sauce, etc. Population growth in Indonesia is continuously inducing high demand for soybeans. Local production of soybean in 2015 reached 0.96 million tons while importation to meet the national requirement reached more than 1.67 million tons (Riniarsi, 2016). The inadequate local production and the high import demand for soybeans require for new alternatives that will result in high domestic soybean production.

Soybean in Indonesia are usually cultivated in 1 to 1300 m above sea level in elevation where there is sufficient sunlight for optimal plant growth (Sumarno and Manshuri, 2007). Areas of different elevation have various microclimates brought about by varying air temperature, light intensity, and light humidity. The altitude of an area correlates with the air temperature; the higher the elevation, the lower the temperature. Micro climate greatly affect plant physiology (Fajri and Ngatiman, 2017). The high altitude areas have air temperatures of 18 - 24^{o}C (Rusman et al., 2018). This temperature range is similar to the temperatures of the subtropical region (18-26^{o}C) (Matsuo et al., 2018).

The optimal temperature for soybean growth varies according to the growing phase; 20-23^{o}C is best for seed germination, 23-26^{o}C for vegetative growth, and 21-23^{o}C for the seed formation phase (Holmberg, 2018). In tropical environment, average temperatures are usually higher than the optimum temperatures required for soybean growth. High temperatures will inhibit growth and affect the quality of the seeds due to quality of maturity and the rate of seeds filling (Raper and Kramer, 1987).

Tropical and subtropical regions vary in agro climate, resulting in differences in the rate of soybean growth and production (Sumarno and Manshuri, 2007). The average soybean productivity in Indonesia is relatively lower (1.4 ton.ha^{-1}) compared to the average world soybean productivity of 2.5 ton.ha^{-1} (Riniarsi, 2016). Subtropical countries, like the United States,USA have a average productivity of 2.9 ton.ha^{-1}. Sagala et al. (2018) reported subtropical soybean genotypes that can adapt to the tropical environment and could have high yield in Indonesia. In this study, various genotypes of soybean from both tropical and subtropical regions were grown in high elevation and their growth and productivity were examined.

Material and Methods

Cultivation of various genotypes of soybean was conducted on March-July 2017 in Pasir Sarongge Experimental Station, IPB University, Bogor, Indonesia. The experimental station is located in Pacet Subdistrict, Cianjur Regency, West Java, with an altitude of 1230 meters above the sea level. The type of soil in the study area was andosol. Postharvest studies were conducted on May-August 2017 at the Postharvest Laboratory, Department of Agronomy and Horticulture, IPB University.

Nine soybean genotypes from different geographic regions, i.e. tropical, subtropical, were tested in this study. The tropical genotypes included “Tanggamus” and “SC-1-8” from Indonesia, “Manshuu Masshokutou” from China, and “San Sai” from Thailand. The subtropical genotypes included “Enrei” and “Fukuyutaka” from Japan, “Stressland” and “Ht-2” from the United States, and “Hakubi” from China.

Soybean Cultivation and Harvesting

A total land area of about 400 m^2 was used for this study. Each soybean genotype was planted on plot area of 3 m x 2 m. Soil preparation and tillage were carried out two weeks before planting. Soil tillage was done twice. Prior to the second tillage, 2 ton.ha^{-1} cow manure and 1 ton.ha^{-1} agricultural lime were added into the soil. Drainage with a width of 40 cm and a depth of 30 cm were created in order to avoid waterlogging. Before planting, the soybean seeds were soaked for 15 minutes in Plant Growth Promoting Rhizobacteria containing *Rhizobium* sp. with a concentration of 50 grams per 10 liters of water. The seeds were planted by a hole digger, 2 seeds per hole and carbofuran was placed in each hole. Plant spacing used was 30 cm x 15 cm.

Fertilizers were applied at the time of planting, including 30 kg.ha^{-1} urea, 150 kg.ha^{-1} SP-36 and 100 kg.ha^{-1} KCl. Weeding was conducted three times until the plant enters the flowering phase. Watering was carried out when there was no rain to avoid drought stress during vegetative and generative stages. Pest and disease control using pesticides was conducted if the pest population cannot be controlled manually.

Harvesting was conducted at various times depending on the genotypes. Harvesting was conducted when 90% of the pods had reached the color of the mature pods (brownish yellow), and most of the leaves had turned yellow and had fallen.

Data Collection and Analysis

Weather conditions including air temperature, solar radiation, and humidity were measured using a field router. To measure growth, the age of the plant (number of days) was recorded where the different genotypes reached different plant stages, phase R1: when there was one flower blooming on the main stem, R5: when the pod on the main stem contained seeds with a size of 2 mm x 1 mm, R7: when the pod on the main stem changed in color (brownish), R8: when 90% is ripe (brownish or blackish yellow). In addition, growth measurements were conducted using various instruments, including plant height, number of leaves, number of branches, number of nodes, and photosynthetic rate of the five sample clumps per plot. Fresh and dry weight of pods, seeds, stems + leaves, total biomass, and harvest index were taken from two clumps per plot. Dry weight was measured after drying at 80^o C oven for 48 hours. Plant productivity (ton.ha^{-1}) was obtained from conversion of productivity from 1x1 m^2 plots.

Statistical Analysis

The research was carried out using a factorial in a randomized complete block design. The genotypes of soybean was considered the factor which consists of nine genotypes The treatment was repeated three times so that a total of 27 experimental units were measured. Observational data were statistically analyzed using analysis of variance at α = 5% (95% confidence interval). Significant differences between means were further tested using LSD tests at α = 5% (95% confidence interval). All statistical analysis were carried out using the SAS 9.1 software.

Result and Discussion

Weather conditions at the time of the study (April-June) indicated that the air temperature did not significantly differ in April and May and it was decreased in June. Solar radiation received is quite low in the range of 261-279 W.m^{-2}.s^{-1} of the radiation compared to lowlands (Table 1). Low solar radiation could be attributed to the frequent cloudiness in the location of the experimental station. Solar radiation increased in June. Relative humidity (RH) was quite high at 80% or more during the study period.

Table 1. Monthly mean air temperature, solar radiation, and relative humidity (RH) during the experiment period

Month	Solar radiation ($W.m^{-2}.s^{-1}$)	Air temperature (°C)	RH (%)
April	268.6	21.1	82.5
May	261.9	21.2	81.3
Jun	279.0	20.6	80.0

The number of days to reach flowering vary with genotypes of soybean, i.e. from 35 to 53 days after planting (Table 2). Subtropical soybeans (“Enrei”, “Fukuyutaka”, “Hakubi”, “Ht-2”, and “Stressland”) were the earliest to flower compared to the tropical genotypes (“Tanggamus”, “SC-1-8”, “Manshuu Masshokutou”, and “San Sai”). This is supported by previous studies by Sumarno and Manshuri (2007). The earlier flowering stage of the subtropical genotypes can be due to shorter day length in the tropics. Generally, soybean growing in subtropical regions reach the flowering stage at the age of 20-22 days from planting. On the other hand, tropical genotypes of soybeans reach the flowering stage at a slower rate, likely due to the exposure to more solar radiation (Afidah et al., 2016). Exposure to solar radiation is related to the conversion of phytochrome Pr to Pfr; higher ratio of Pfr to Pr at certain intervals will promote earlier generative phase (Sutoyo, 2011).

Plant growth performance varies with soybean genotypes. The tropical genotypes were taller (27.9-60.7 cm) than the subtropical genotypes (17.1-32.9 cm) (Table 3). Among the tropical genotypes, “SC-1-8” (from Indonesia) was the tallest, namely 60.7 cm when the plant entered the R8 phase. The shorter plant of subtropical genotypes as demonstrated in this study can be due to differences in day length between the origin (e.g. Japan, China, United States) of the subtropical genotypes and where they were planted. As an example, the subtropical genotype “Fukuyutaka” (from Japan) reaches an average of 29 cm in the experiment field but reaches 70 cm when planted in Japan (Matsuo et al., 2018).

In addition to plant height, the number of leaves during flowering and pod filling phases was the greatest in the tropical genotype “SC-1-8”.This shows that the “SC-1-8” genotype source capacity was greatest compared to other genotypes. The subtropical genotypes had higher single leaf photosynthetic rates of 25.2 to 26.4 μmol $CO_2.m^{-2}.s^{-1}$ than the tropical genotypes that had 18.2 to 23.2 μmol $CO_2.m^{-2}.s^{-1}$ (Table 3). Although there are more leaves per plant in the tropical genotypes than the subtropical genotypes, their single leaf photosynthesis was lower. The increasing number of leaves shows that the plants have more leaf area, which results in an increase in sunlight interception (Sopandie, 2014).

Table 2. Number of days to reach reproductive phase of various tropical and subtropical soybean genotypes

Genotype	Number of days required to reach flowering				
	R1	R3	R5	R7	R8
Tropical genotypes					
“Manshuu Masshokutou” (China)	38.0c	43.3c	49.0c	89.0c	95.6c
“San Sai” (Thailand)	53.0a	58.0b	63.0b	91.0b	98.3b
“SC-1-8” (Indonesia)	53.0a	61.7a	66.3a	94.3a	105a
“Tanggamus” (Indonesia)	51.0b	59.0b	63.0b	91.0b	98.6b
Subtropical genotypes					
“Enrei” (Japan)	35.0d	38.0f	41.0e	70.3g	81.7e
“Fukuyutaka” (Japan)	35.0d	40.3ed	45.0d	78.7f	91.0e
“Hakubi” (China)	35.0d	39.7efd	42.7e	77.7f	91.0e
“Ht-2” (USA)	35.0d	41.7cd	47.7c	80.3e	91.0e
“Stressland” (USA)	35.0d	38.3ef	42.0e	85.0d	94.7d

Note: Means followed by the same letter within a column were not significantly different according to LSD test at α=5%.

Table 4. Rate of pod filling and pod dry weight of various tropical and subtropical soybean genotypes

Genotypes	Pod filling (g per day)			Pod dry weight (g per plant)			
	R5-R5+7d	R5+7d - R5+14d	R5+14d-R5+21d	R5	R5+7	R5+14	R5+21
Tropical genotypes							
"Manshuu Masshokutou" (China)	0.22	0.45	0.39	0.06c	1.59bc	4.75abcd	7.45bc
"San Sai" (Thailand)	0.04	0.65	0.73	0.29b	1.24cd	5.78abc	10.9ab
"SC-1-8" (Indonesia)	0.17	0.67	0.69	0.51a	1.67bc	6.48ab	11.33a
"Tanggamus" (Indonesia)	0.25	0.6	0.41	0.41ab	2.83a	7.04a	9.89abc
Subtropical genotypes							
"Enrei" (Japan)	0.1	0.47	0.14	0.08c	0.81de	4.11bcd	5.1c
"Fukuyutaka" (Japan)	0.06	0.41	0.34	0.09c	0.53ef	3.42cd	5.81bc
"Hakubi" (China)	0.04	0.32	0.43	0.03c	0.38f	2.52d	5.55c
"HT-2" (USA)	0.26	0.58	0.27	0.13c	1.92b	6.01abc	7.89bc
"Stressland" (USA)	0.03	0.38	0.31	0.04c	0.22f	2.9d	5.1c

Note: means followed by the same letter within a column were not significantly different according to LSD test at α=5%; R5: stage R5 plant, R5+7 : 7 days after R5, R5+14: 14 days after R5, R5+21: 21 days after R5

Tabel 5. Yield components, shoot fresh weight, total biomass, and harvest index of various tropical and sub-tropical soybean genotypes

Genotype	Seed	Stem+leaves	Pod	Total biomass	Harvest Index
	grams per 5 plants				
Tropical genotypes					
"Manshuu Masshokutou"	67.0abc	16.7c	39.3a	123.0cde	54.5ab
Sansai	69.9ab	37.1ab	33.9ab	140.9abc	47.5ab
"SC-1-8" (Indonesia)	100.8a	44.0a	41.7a	186.5a	54.1ab
"Tanggamus" (Indonesia)	94.7a	40.1a	37.6ab	172.4ab	54.9ab
Subtropical genotypes					
"Enrei" (Japan)	35.0de	18.1c	31.8abc	84.8def	41.3b
"Fukuyutaka" (Japan)	66.9abc	25.3bc	38.9a	131.1bcd	51.0ab
"Hakubi" (China)	25.8e	13.1c	18.9cd	57.9f	44.6ab
"Ht-2" (USA)	41.1cde	23.5c	11.7d	76.3ef	53.8ab
"Stressland" (USA)	56.1bcd	14.1c	23.4bcd	93.7cdef	59.9a

Note: Means followed by the same letter within a column were not significantly different according to LSD test at α=5%

The more number of leaves of the tropical soybean genotypes indicates that these crops have more photosynthetic sources. However, Table 3 shows that the more leafy genotypes originating from the tropical regions had lower photosynthetic rates. The differences in photosynthetic rates between the tropical and subtropical genotypes can be due to the fact that at seven weeks after planting when the measurement of photosynthetic rate occurred, the genotypes were in different growth phases. The subtropical genotypes, at this point, had entered the reproductive phase, while the tropical genotypes were still in the vegetative phase.

The greatest number of branches and nodes were observed in the tropical genotypes, particularly "SC-1-8" (Table 3). The number of branches and nodes in soybean are interrelated and indicate the production potential of soybean plants. When the number of nodes and branches is low, then the number of crop pods is also low. One of the factors influencing the number of nodes and branches is the onset of flowering or flowering date in soybean. The faster the flowering date the less the number of branches and the number of nodes (Table 2 and 3). The number of branches and nodes is inversely proportional to the increase in temperature. High temperature

Table 6. Correlation and linear regression analysis of seed dry weight (g per 5 plants) to all agronomic characters in nine soybean genotypes

Inpendent variable (x)	Regression equation	Coefficient of correlation	Coefficient of determination
DP	7.98 + 1.75 x	0.71**	0.52**
DSL	23.83 + 1.48 x	0.66**	0.45**
TB	-7.284 + 0.58 x	0.96**	0.93**
HI	- 35.9 + 190.6 x	0.51**	0.26**
PH	17.78 + 1.22 x	0.67**	0.45**
NB	17.72 + 8.72 x	0.52**	0.28**
NN	13.23 + 1.55 x	0.73**	0.53**
RP	171.2 - 4.65 x	-0.47*	0.23*
NL	15.60 + 2.06 x	0.71**	0.50**
DR1	- 36.71 + 2.39 x	0.67**	0.45**
DR3	- 37.65 + 2.13 x	0.70**	0.49**
DR5	- 46.61 + 2.13 x	0.69**	0.48**
DR7	- 159.8 + 2.63 x	0.69**	0.47**
DR8	- 245.9 + 3.27 x	0.71**	0.50**
PF R5-R5+7	52.52 + 57.58 x	0.30 ns	0.09ns
PF R5+7-R5+14	50.01 + 24.50 x	0.20ns	0.04ns
PF R5+21-R5+14	51.57 + 25.08 x	0.27ns	0.07ns
PF R5+21-R5	27.15 + 97.56 x	0.45*	0.20*

Note: DS= seed dry weight (g); DP= pod dry weight (g); DSl= dry weight of stem + leaves; TB (gtotal biomass (g); HI= harvest index (%); PH= plant height (cm); NB= number of branch; NN: number of nodes; RP= rate of photosyntesis; NL= number of leaves; DR1=days to R1; DR3= days to R3; DR5=days to R5; DR7= days to R7; DR8= days to R8; PF R5-R5+7(g per day)= pod filling R5 to 7 days after R5; PF R5+7-R5+14= pod filling 7 days after R5 to 14 days after R5; PF R5+21-R5+14= pod filling 14 days after R5 to 21 days after R5; PF R5+21-R5= pod filling R5 to 21 days after R5;**: siginificant at P>0.01%, *: siginificant at P>0.05%, ns : non-significant

accelerate flowering, thereby suppressing the growth of branches and nodes (Kumagai and Sameshima, 2014).

In terms of rate of pod filling, the different genotypes studied demonstrated variation depending on the week of observation which corresponds to growth and development phase happening in the plants (Table 4). The tropical genotypes “San Sai” and “SC-1-8” and the subtropical genotype”Hakubi” increased in the rate of pod filling during the first to third weeks after seed filling (R5) phase begins. The rest of the genotypes increased in the rate of pod filling during the first two weeks after the R5 phase began and decreased from third week onwards. Among all genotypes of soybean, the subtropical “Ht-2” and the tropical “Tanggamus” had the highest rate of pod filling during the first week after the seeding phase started. Most of the genotypes did not show any significant difference in the rate of pod filling on the second week after the seeding phase started

When it comes to yield, among the different soybean genotypes, the tropical genotypes ”Tanggamus” and “SC-1-8” showed slow onset of flowering (Table 2). This is seen in weight of seed, stem + leaves, and pod per five plants and in the total biomass (Table 5). In terms of harvest index (HI), the subtropical genotype “Stressland” and “Enrei” had the highest and lowest records at 59.9% and 41.3%, respectively. This is not consistent with the results of a previous study where subtropical genotypes had lower HI than the tropical genotypes (Saryoko et al. 2017). The HI for the rest of the genotypes were not significantly different from one another (Table 5). The HI in plants represents their efficiency in using photosynthates to maximize yield. Higher HI indicates that plants are more efficient in using photosynthates (Hakim, 2012). The high HI in most of the subtropical genotypes in this study can be attributed to cool climate at the high altitude of this experiment and indicates that a part of low adaptation of subtropical to tropical environment is due to high temperature (Taufiq and Sundari, 2012).

Correlation and regression analyses showed that seed yield (g per 5 plants) correlates with almost all agronomic characters observed such as number of days to flowering and harvest, plant height, number of leaves, number of branches, number of nodes, and pod dry weight (Table 6). Dry seed weight is positively correlated significantly with day to flowering and harvest, which is consistent with the study of Enideg et al. (2016). All genotypes in this study exhibited determinate growth whereby the vegetative growth stops after entering the generative phase. Total biomass correlates strongly with dry seed weight, which indicates that high sources will support seed development (Salimi and Moradi, 2015). High biomass usually results in high yields. Seed yields were positively correlated significantly with the number of node, number of branches, and pod dry weight. This indicates that the higher the number of nodes, branches and pod dry weight, the higher the seed yield (Salimi and Moradi, 2015).

Rate of pod filling per week at the first to third week after R5 did not correlate significantly with seed yield. However, the accumulation of pod filling rate for 21 days after R5 correlates significantly with seed yield. High pod growth rates and pod filling 20 days after R5 usually result in high yield (Shiraiwa et al., 2004).

Conclusion

Soybeans from tropical and subtropical regions showed different growth performance and productivity or yield. The tropical genotypes, particularly “SC-1-8” from Indonesia, were the tallest and had the highest number of leaves, nodes and branches with high harvest index. On the other hand, the subtropical genotypes were found to reach their flowering age earlier, and had the lowest (“Enrei” from Japan) and highest (“Stressland” from United States) harvest indices. Vigorous growth as seen in tropical genotypes is an indicator of high yield. This study showed that tropical genotypes, like “SC-1-8” has the potential to be further developed to obtain higher production of soybean in Indonesia. Additionally, “Stressland” genotype from the United States can potentially be used as a genetic source in developing improved soybean crop yield potential in Indonesia.

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References

Afidah, Khurotul, I., Karyawati A.S., and Sitompul, S.M. (2019). Pengaruh lama penyinaran terhadap pertumbuhan dan hasil pada tiga varietas kedelai (*Glycine max* L . Merr). *Jurnal Produksi Tanaman* **7**, 68–73.

Dogra, Kumar, A., Kaur, J. and Srivastava, A. (2015). Relationship between growth and photosynthetic efficiency of soybean (*Glycine max* L. Merr) genotypes under variable photoperiods. *International Journal of Plant Research* **28**, 183–193.

Enideg, B., Alamerew, S., Tesfaye, A., and Barnabas, J. (2016). Character correlation and path analysis for yield and yield related components in soybean (*Glycine max* L.) genotypes. *International Journal of Science and Applied Research* **3**, 97-104..

Fajri, M., and Ngatiman, N. (2017). Studi iklim mikro dan topografi pada habitat *Parashorea malaanonan* Merr. *Jurnal Penelitian Ekosistem Dipterokarpa* **3**, 1–12.

Hakim, L. (2015). Komponen Hasil dan Karakter Morfologi Penentu Hasil Kedelai. *Jurnal Penelitian Pertanian Tanaman Pangan* **31**, 173–179.

Holmberg, S.A. (1973). Soybeans for cool temperature climates. *Agri Hortique Genetica* **31**,1-20.

Kementerian Pertanian. (2016). “Outlook Komoditas Pertanian Sub Sektor Tanaman Pangan”. Pusat Data dan Informasi Pertanian, Kementan, Jakarta, Indonesia.

Kumagai, E., and Sameshima, R. (2014). Genotypic differences in soybean yield responses to increasing temperature in a cool climate are related to maturity group. *Agricultural and Forest Meteorology* **198**, 265–272.

Matsuo, N., Yamada, T., Takada, Y., Fukami, K., and Hajika, M. (2018). Effect of plant density on growth and yield of new soybean genotypes grown under early planting condition in southwestern Japan. *Plant Production Science* **21**, 16–25.

Raper, C.D. Jr, and Kramer, P.J. (1987). Soybeans: improvement, production and stress *In* “Stress Physiology” (J.R. Wilcox, ed.) pp. 589-641. Agronomy Monographs 16.

Riniarsi, D. (2016). "Outlook Komoditas Pertanian Tanaman Pangan: Kedelai". Pusat Data dan Sistem Informasi Pertanian. Kementerian Pertanian. 85 pp.

Rusman, I.W., Suniti N.W., Sumiarta, I.K., Sudiarta, I.P., Wirya, G.N.A.S., and Utama, I.M.S. (2018). Pengaruh penggunaan beberapa paket teknologi terhadap perkembangan penyakit layu Fusarium pada tanaman cabai rawit (*Capsicum frutescens* L.) dan cabai besar (*Capsicum annuum* L.) di dataran tinggi. *Jurnal Agroekoteknologi Tropika* **7**, 354-362.

Sagala, D., Ghulamahdi, M.,Trikoesoemaningtyas, T., Lubis, I., Shiraiwa, T. and Homma, K. (2018). Response of temperate, subtropical and tropical soybean genotypes to type-b overflow tidal swamp of indonesia. *Agrivita, Journal of Agricultural Science* **40**, 461 - 471.

Salimi, S., and Moradi, S. (2012). Effect the correlation, regression and path analysis in soybean genotypes (*Glycine max*) under moisture and normal condition. *International Journal of Agronomy and Plant Production* **3**, 447–454.

Saryoko, A., Homma, K., Lubis, I., and Shiraiwa, T. (2017). Plant development and yield components under a tropical environment in soybean cultivars with temperate and tropical origins. *Plant Production Science* **20**, 375-383.

Shiraiwa, T., Ueno, N., Shimada, S., and Horie, T. (2004). Correlation between yielding ability and dry matter productivity during initial pod filling stage in various soybean genotypes. *Plant Production Science* **7**, 138–142.

Sopandie, D. (2013). "Fisiologi Adaptasi Tanaman Terhadap Cekaman Abiotik pada Agroekosistem" Tropika. IPB Press. Bogor. Indonesia

Sumarno and Manshuri, A.G. (2007). "Persyaratan Tumbuh dan Wilayah Produksi Kedelai di Indonesia". Pusat Penelitian dan Pengembangan Tanaman Pangan, Bogor

Sutoyo. (2011). Fotoperiode dan pembungaan tanaman. *Buana Sains* **11**, 137–144.

Taufiq, A. and Sundari, T. (2014). Respons tanaman kedelai terhadap lingkungan tumbuh. *Buletin Palawija* **23**, 13-26.