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The influence of temperature on germination and seedling growth of sorghum

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Abstract. The extensification of agricultural activities to suboptimal areas, including dryland, is being considered. Sorghum as a drought-tolerant crop is usually cultivated in dryland areas in Indonesia. However local farmers are having difficulty in choosing quality seeds suitable for the specific area temperature condition. This study evaluated the physical quality of commonly used sorghum cultivars in Indonesia and their responses to several germination temperatures. The three sorghum cultivars used were Strong Brown (SB) Sorghum known as the local cultivar, Pale yellow (PY), and Light Brown (LB). The result revealed that each sorghum cultivar has specific seed characteristics, especially in the color, shape, and size of the seeds. The seeds of the Light Brown sorghum had the highest quality, followed by Strong Brown sorghum and PaleYellow sorghum cultivars based on both the tetrazolium test and the direct germination test. The optimum temperature for sorghum seed germination ranged from 25 to 35ºC. Each sorghum cultivar has its specific temperature requirement for germination. Low temperature (20°C) potentially reduces the percentage of germination and delays the seed germination time of these three cultivars. LB cultivar has the highest relative growth rate (RGR) from the first week to the second week (R1), while the RGR from the first week to the third week (R2), LB sorghum cultivar is in the second position after the PY cultivar. Cultivar LB is suggested for cultivating in elevations 300-500 m asl, moreover cultivar SB elevations 50-250 m asl.

Keywords: germination, RGR, sorghum, seed characteristics, temperature.

HIGHLIGHT

- Sorghum cultivar can be differentiate based on their color, size, and shape.
- Specific sorghum cultivars require specific temperature for their germination.
- The suitable cultivation area for each sorghum cultivar affected by environmental condition, including temperature.

INTRODUCTION

Drylands in Indonesia cover about 13.3 million hectares. Most of the dry lands in Indonesia have been underutilized or utilized for agriculture using poor cultivation practices. Drylands are the area where average rainfall is lower than the potential moisture loss through evapotranspiration (FAO, 2004). Drylands are characterized by high surface temperature and light intensity, low humidity, and low soil nutrients. Drylands are extremely sensitive to global climate change (Huang *et al*., 2017). Climate change has increased the annual mean temperature in Indonesia by 0.36-0.46°C since 1990 (Mariah, 2010). Drylands are defined as suboptimal land but have the potential for agricultural development. Stewart (2016) suggested that a successful dryland farming system requires 3 components, i.e retaining the precipitation, reducing evapotranspiration, and utilizing drought tolerance crops.

Drought tolerance is a combination of molecular, physiological, and morphological traits in plants (Chaniago, Syarif and Riviona, 2017). Akinseye *et al.* (2020) suggested selecting a suitable cultivar for raising crop production in a certain area. Sorghum (*Sorghum bicolor* [L] Moench) has been reported for a high tolerance of many unfavorable environmental conditions, including drought, salinity, heat, chilling and flooding (Maiti and Satya, 2014). Compared to other cereal crops, sorghum has a higher ability to adapt well under limited water conditions (Bibi *et al*., 2012; Badigannavar *et al*., 2018; Widiyono *et al*., 2020). Schlegel *et al*., 2018 reported that the cultivation of sorghum in dryland resulted in a higher yield than corn. Aerial part biomass of sorghum in the flowering phase has the potential to reach 28.34 t ha^{-1} by 504 mm of water consumption (Garofalo *et al*., 2020). The development of sorghum cultivation in the drylands of Indonesia is potential as an alternative food resource. Queiroz *et al.* (2015) reported that sorghum contains 55.2-75.2% carbohydrates, 8.6-18.9% proteins, 1.7-4.9%lipids, 9.3-25.2% fibers and 1.1-2.4% ash. Sorghum contains many amino acids which are valuable to be consumed as a functional food (Abah *et al*., 2020). Moreover, sorghum biomass is also beneficial as biofuel, sugar, and animal feed industry (Hu *et al*., 2022).

In order to obtain high productivity and produce high-quality seeds, the utilization of superior varieties is one of the important technological components. Seed quality is complex and can be determined by four key quality attributes, including genetic, physiological, physical and health (Bishaw, Makkawi and Niane, 2007). Genetic quality is defined as the potential for resulting higher productivity with better quality and greater tolerance to biotic or abiotic stresses. Physiological quality shows the potential of germination and vigor leading to subsequent seedling emergence and crop establishment in the field. Physical quality can be seen by the free from contamination from other crops and weed seeds, mechanical damage, discoloration, and uniformity of weight and size. Health quality shows the absence of infection of seed-borne pests.

The availability of quality seeds of sorghum in Indonesia is still limited. The farmers usually utilized the seeds harvested from the previous growing season. A higher number of seeds (4-5 seeds per hole) is required in anticipation of failure to grow due to the information unavailability of seed quality. Consequently, sorghum cultivation requires a high number of seeds the wasting of planted seeds was unavoidable. Therefore, this study was conducted to evaluate the physical quality of commonly used cultivars in Indonesia and their responses to several germination temperatures. This result is proposed to motivate the farmers to choose sorghum seeds that are suitable for the daily temperature of field cultivation, especially in drylands.

MATERIALS AND METHOD

Plant materials

Seeds of three sorghum cultivars were used in this study. The cultivars used differed based on the grain color, which were Strong Brown (SB), Pale Yellow (PY), and Light Brown (LB). These cultivars were commonly cultivated during dry seasons in Pajarakan Village, Buleleng, West Bali, Indonesia. SB originated from West Bali, PY from Thailand and LB from China. All seeds were obtained from a farmer in Pajarakan village, Grokgak, West Bali. The seeds were stored in the farmers' storage room for 6 months and carried to Plant Physiology Laboratory, Research Center for Biology, Indonesian Institute of Sciences (LIPI), now BRIN, Cibinong, West Java, Indonesia for experimenting. The experiment site was located at 6°29'52.9"S 106°50'43.4"E, 250 m above sea level with a daily temperature of 30-33°C and air humidity around 70-80%.

Seed characterization

The seeds characterization was performed by the bulk method covering the color, shape, size and weight of 100 seeds. The sample seeds samples were obtained from the top, middle, and bottom of the seed lot. Measurement of seed diameter was conducted using a manual caliper with an accuracy of 0.01 mm. The weight of 100 sorghum seeds was measured using digital analytical scales with an accuracy 0.001 g. Each measurement was replicated 4 times. The seeds' color was observed qualitatively under natural light conditions using RHS Color Chart EditionVI (Royal Horticulture Society, America). Each seed was placed at the bottom of each hole from fully saturated to the less saturated color chart of RHS until matched the most exact color.

Moisture content and conductivity test

Seed moisture content was measured using the oven drying method. A total of 50 fresh seeds were weighed using analytical scales, then dried at a temperature of 105°C for seventeen hours 2 times and reweighted until reaching the constant weight. The moisture content was counted following ISTA (1976) equation. The ion leakage was observed using conductometer CG 855 (Gebrauchsanleitungcompany, German). Seeds were rinsed 3-5 times using the distilled water and soaked in a flask filled with distilled water (50 ml g^{-1} seed) for 24 hours at ambient temperature. The flask filled with distilled water without seed was used as a control (blank). The ion leakage of the blank flask must be < 5 $uS.cm^{-1}$. The measurement was taken at 25°C temperature. The ion leakage was identified as conductivity values through the following equation:

$$CV = \frac{(S-A)x\ B\ x\ K}{W}$$

Notes:
CV = Conductivity values
S = Measurement result for sample
A = Measurement result for blank
B = Bereich scale (20/200/2000 μScm^{-1})
K = Constant (0.91 cm^{-1})
W= Sample weight (gram).

Tetrazolium test

Tetrazolium test refers to Masullo *et al.* (2017). Ten sorghum seeds per replication were soaked in distilled water for 24 hours. The seeds were split into two parts until the embryo was visible, and then they were soaked with 0.5 % tetrazolium solution for 4 hours. A solution of 0.5% tetrazolium in 100 ml of buffer (pH 6.5-7) was carried out by dissolving 0.5 g of powdered 2,3,5-triphenyl tetrazolium chloride (TTC) into 100 ml of buffer (pH 6.5-7). The buffer solution was prepared using 2 solutions. Solution 1 was prepared by dissolving 0.908 g of Na_2HPO_4 thoroughly in some distilled water, then filling up the distilled water to 100 ml. Solution 2 was prepared by weighing 1.1876 g of Na_2HPO_4 powder, putting it in a certain amount of distilled water, and tera up to 100 ml. Both solutions were mixed (40 ml of solution 1 + 60 ml of solution 2) to make 100 ml of a buffer solution with a pH of 6.5-7. The seeds were categorized as viable seeds when the embryo was bright red. If the color of the embryo was pale red or white, the seeds were categorized as dead.

Vigor test and germination value

Seed and seedling vigor was measured using a direct viability test, namely: the germination test and seedling relative growth (Hartmann *et al.*, 2011). During the germination test, seeds were sowed at three germination facilities, i.e seed incubator, nursery (with a waterproof roof and gauze wall) and germination chamber. The temperature in germination facilities were 20 ± 3°C, 25-35°C and 30 ± 3°C, respectively.

This experiment was conducted using the Nested Design (Completely Randomized Group Design) with three replications. The first factor was the germination facilities (the nursery, incubator, and germination chamber). Meanwhile, the second factor was sorghum cultivars, namely PY (Pale Yellow), LB (Light Brown), and SB (Strong Brown). The SB was local cultivar sorghum form Bali, Indonesia; while PY and LB was introduced cultivar from Thailand dan China, respectively. The sorghum seeds were sown in a germination tray with the hilum facing down. Each tray was filled with 5cm height growing media and each tray was planted with 30 seeds. A tray with the seeds of each cultivar was placed in each germination facility. The media was kept in a moist condition by watering twice a day. The number of germinated seeds was recorded daily for ten days. The seed viability evaluation included the percentage of germination (%) and the average number of days to germination. The percentage of germination was calculated based on the percentage of the total number of seeds germinated on day 10 to the total number of seeds planted (Queiroz *et al.*, 2019). The average number of days to germination was counted following Hartmann *et al.* (2011). Germination value (GV) was obtained by multiplying Peak Value (PV) and Mean Daily Germination (MDG). PV is defined as the peak point of increase in percentage germination on the graph of percent germination before sloping down (Hartmann *et al.*, 2011); while the MDG (%) was calculatted by dividing the highest total of percentage of germination by number of days to reach the value.

Seedling growth

The vigor of the seedling phase was observed by measuring the Relative Growth Rate (RGR). The study used a Completely Randomized Design with three replications. The treatments were three sorghum cultivars. Two seeds were sown in each polybag (40×40 cm) containing a mixture of soil and sand (1:1 v/v). After one seed grew, another seed was removed. Thus, there was only one seedling for observation. Each cultivar maintained 30 seedlings for three weeks.

Observation of seedlings' vigor was carried out by destructively observing three seedlings per replication every week starting from the first until the third week after planting (WAP). The seedlings were gently taken out of the media and cleaned with tap water. Shoot height (cm), number and length of leaves, length of root (cm), fresh weight (g), and dry weight (g) were measured. The fresh and dry weight of sorghum seedlings is the accumulation from both the aerial part and the root. The dry weight was measured after the sample was dried in an oven at 105°C until the sample reach the constant weight. RGR of seedling (R) was calculated with the following Whitehead and Myerscough (1962):

$$R = \frac{LogW2 - LogW1}{Tn - T1}$$

Notes:
W1= dry weight of 1 wap
W2 = dry weight of 2 wap
W3 = dry weight of 3 wap
wap = week after planting
Tn = week-n^{th}
T1 = the first week

Microclimate measurement

Environmental parameters consist of temperature (^{o}C), air humidity (%), and light intensity (Lux). The temperature and humidity of the incubator and germination chamber were stable, with temperatures of 20 ± 3°C and 30 ± 3°C, respectively, and RH of 50-53%, in total darkness. While, the environmental parameters at nursey were observed every day at the morning, afternoon, and evening for ten days. The air temperature and humidity were measured with a Thermo-hygro meter (AS ONE Th-321, Corona), while the light intensity was measured with a lux meter (LUXOR). The average microclimate conditions at the nursery are presented in Table 1.

Table 1. Microclimate condition in the nursery.

Observation time	Light intensity (lux)	Temperature (˚C)	Humidity (%)
Morning	5069	28.51	69.4
Afternoon	10318.0	32.31	63.0
Evening	2964. 3	29.65	61.8

Data analysis

All data on seed germination and seedling growth were displayed in graph, documentation and table. Collected data were analyzed using the statistical analysis software (SAS portable 9.0, SAS Institute Inc., Cary, North Carolina, US) and microsoft excel 2013 (Microsoft Office Home and Student 2019, Redmond, Washington, USA).

RESULT AND DISCUSSION

Seed characters

The current study emphasizes the main characteristics of the seeds. The three sorghum cultivars used in this study have different characteristics, such as shape, color, and size (Figure 1). PY cultivar characterized by flat round shape, pale yellow color, with a diameter of 4.06 mm and the weight of 100 seeds of 3.36 g. SB cultivar has an ovate shape, strong brown color, 3.05 mm in diameter and the weight of 100 seeds of 1.84 g. While LB cultivar has an ellipse shape, brownish orange color, 3.51 mm in diameter and a weight of 100 seeds of 2.65 g.

Seeds characters are commonly used to distinguish genera, species, and even varieties since the characters are categorized as high heritability and are readily used in sorghum plant breeding programs (Slamet *et al.*, 2020). According to UPOV (2014) on sorghum identification, there are variations in the shape, size, and color of seeds. Sorghum has color variations ranging from white, pale yellow, red, brown, and purplish brown, while the shape were varies from flat, ovate, and ellipse. The size of the seed varies between 4-8 mm in diameter with 10-60 mg in weight. Queiroz *et al.*, (2019) describe that the differences in seed size affect the amount of amylum and other nutrients in the seeds. Furthermore, it can affect germination and seedling growth.

Seed viability

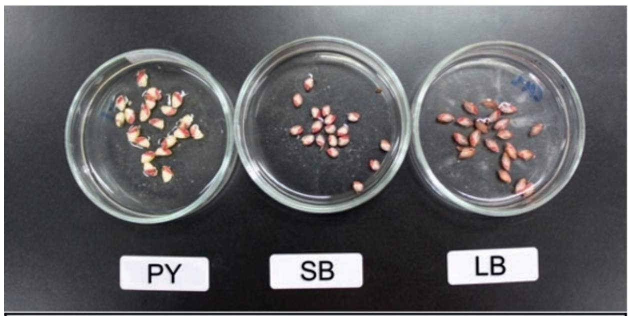
The sorghum seeds' viability was detected through three tests, namely tetrazolium test, ion leakage, and

Seeds Parameter	Sorghum Cultivars		
	Pale Yellow (PY)	Strong Brown (SB)	Light Brown (LB)
Fresh weight	3.36 g	1.84 g	2.65 g
Diameter	4.06 mm	3.05 mm	3.51 mm
Shape	Flat round	Ovate	Ellipse
Color	Pale Yellow 161 D Greyed-Yellow Group	Strong Brown 172 A Greyed-Orange Group	Brownish Orange 165B Greyed-Orange Group

Figure 1. The seed characteristics of PY, SB and LB sorghum cultivars.

moisture test. All three tests are frequently used to estimate seed quality quickly in many species. These tests are very useful for post-harvest handling of large numbers of seeds in a short time in many species. As well as handling the storage and marketing process. Among the three tests, the tetrazolium test is the most popular, due to its simplicity and doesn't require special equipment.

The tetrazolium test was categorized the viable seed is based on the red color that forms in the seed tissue, especially the embryonic part. The intensity of the red color in the tissue indicates the viability of the tissue (Subantoro & Prabowo, 2013). The test result showed that SB and LB cultivars had a 100% bright red color. Meanwhile, the PY cultivar resulted in 90% red color (Figure 2). It indicates that the viability of SB and LB cultivars was 100%, while PY cultivar was 80-90%. Based on the tetrazolium test, it can be concluded that the viability of all three sorghum cultivars qualified based on the ISTA (1976) standard since the result of tetrazolium test was more than 80%. The principle of this test is to distinguish between living and dead seeds based on the rate of respiration in wet conditions (Whitehouse *et al.*, 2020), however, this test is disabled to detect abnormalities of the seed. In order to complete the tetrazolium test data, moisture content measurement and conductivity tests (ion leakage) of sorghum seeds were also performed (Table 2). Both ion leakage and moisture tests are able to detect seed damage due to mechanical damage or pests. The measurement of seed moisture content is important to consider the speed of seed deterioration by the increase of moisture content, meanwhile, ion leakage from the seed to the water indicates a symptom of seed damage due to membrane damage.



Cultivars	Tetrazolium Test (%)
Pale Yellow (PY)	90%
Strong Brown (SB)	100%
Light Brown (LB)	100%

Figure 2. Tetrazolium test result of sorghum seed.

The highest moisture content was obtained by the LB cultivar of 11.32%, followed by PY and SB cultivars of 10.45% and 9.17%, respectively. Seed moisture content is affected by harvest time, drying process, and storage conditions (Surki *et al.*, 2012). However, in the present study, all cultivars were treated equally during the post-harvest handling: drying, packing and storing. Thus, the difference in seed moisture content was affected by each cultivar's characteristics. The ion leakage value of PY, SB and LB cultivars were 0.67 μScm^{-1}, 0.12 μScm^{-1} and 0.06 μScm^{-1}, respectively. A higher ion leakage value indicates lower seed viability in sorghum (Fatonah *et al.*, 2017). Ion leakage occurs because the cell membrane function related to ion exchange between inside and outside the cell is being interrupted. The ions coming out of the cell membrane accumulate in the seed immersion water and are identified as electrical conductivity values (Brunei-Muguet *et al.*, 2015). A higher ion leakage value indicates more ions released from the seeds into immersion water and greater damage to the cell membrane. de Carvalho Miguel & Filho (2002) explains that the electrical conductivity test is one of the best tests for the evaluation of the loss of cell membrane integrity by the concentration of electrolytes released by seeds during imbibition.

Sorghum seeds are grouped as orthodox seeds (Solberg *et al.*, 2020). The recommended moisture content for orthodox seeds is 5% in low humidity conditions storage. However, if the seeds are handled traditionally, the moisture content should be around 13-16% (FAO, 2018). The moisture content of seeds after drying and stored in the storage room fluctuates depending on the humidity of the storage room. If the humidity increases, the moisture content of the seeds will increase, and vice versa (Awosanmi *et al.*, 2020; Mbofung, 2012). In this study, the handling of the three sorghum cultivars was equal. The difference in seed moisture content is affected by the genetic traits, especially the thickness of the seed coat of each cultivar. The difference in ion leakage values was also suspected to be affected by differences in genetic traits. Based on ion leakage, it showed that PY cultivar is more susceptible to environmental fluctuations compared to SB and LB cultivars. In addition to the effect of genetic traits, ion leakage is also affected by temperature in storage room. (Wawo *et al.*, 2019) reported an increase of ion leakage when *Inocarpus fagiferus* seeds with high moisture content are stored at room temperature (25-27°C) for four weeks. We suggest that sorghum seeds at farmer's storage in this study, without temperature and humidity control, are likely to have fluctuated seed moisture levels in accordance with temperature and humidity fluctuations. High-temperature conditions in the room will stimulate the respiration rate in the seeds, which will deplete the food reserves in the seeds and decrease the energy for germination. Sorghum cultivars that are susceptible to high temperatures will experience a rapid decline in viability compared to those that are tolerant of high temperatures. The temperature of Grokgak district (where the seed was stored) during the dry season (September-November) was 40°C, with rainfall of 7.4-91.4 mm (BPS Kabupaten Buleleng, 2018).

Table 2. Moisture content and ion leakage values of three sorghum cultivars

Cultivars	Moisture Content (%)	Ion Leakage (μScm^{-1})
Pale Yellow (PY)	10.45	0.67
Strong Brown (SB)	9.17	0.12
Light Brown (LB)	11.32	0.06

Seed vigor

Each plant requires a certain temperature range (minimum, optimum, and maximum) for each stage of its growth, which is called the cardinal temperature (Salisburry and ross, 1995). Sampayo-Maldonado *et al.* (2019) affirmed that the cardinal temperature is the condition that drives at least 50% germination of the total sample during the test period, while Shaban (2013) stated that the optimum temperature is the temperature that enables to produce of the highest percentage of germination of seeds in one lot in a short time. Shaban (2013) also reported that many types of cereal germinate optimally at 15-30°C with a maximum temperature of 30-40°C.

This study revealed that higher temperature resulted in a higher germination percentage and faster germination time (Table 3). The temperature requirement for sorghum germination was occurred range at 25-30°C. This range of temperature value was tighly related to sorghum temperature requirement for growth stage, ranged from 25-32°C (Garofalo *et al.*, 2020). Each sorghum cultivar had its specific temperature for germination. The highest germination percentage for LB cultivar (93.33%) occurred at 30°C, while for SB (98.89%) and PY (67.78%) cultivars occurred at 25-35°C. It indicated the optimum temperature of SB and PY cultivars is in the range of 25-35°C, while the LB cultivar sorghum is around 30°C.

Germination at 20°C tended to take a longer time (6-9 DAS) and resulted in a lower final germination percentage value than at 25-35°C temperatures (4-5 DAS; >80% germination percentage) (Table 4). The SB cultivar requires a longer time to reach the highest germination percentage compared to LB and PY cultivars. The difference in germination time was influenced by base-moisture content in the seed of each sorghum cultivar. In general, the seed water content of cereal crops must reach

Table 3. Interaction between cultivars and temperature of germination facilities on final germination percentage.

Sorghum cultivars	Temperature (°C)			Means cultivars
	20	30	25-35	
PY	28.89 e ± 1.95	60.00 d ± 2.49	67.78 cd ± 1.53	52.21 b
SB	73.33 cd ± 5.74	74.44 cd ± 3.33	98.89 a ± 0.98	82.22 a
LB	87.78 bc ± 1.26	93.33 ab ± 1.79	86.67 bc ± 0.81	89.26 a
Means Temperature	63.70 b	75.56 a	84.44 a	

Note: Numbers that are followed by the same letter in one column mean that they are not significantly different based on the Duncan test with 5% levels. The number after ± means standard deviation.

Table 4. Interaction between cultivars and temperature of germination facilities on germination mean per day.

Sorghum cultivars	Temperature (°C)			Means cultivars
	20	30	25-35	
PY	8.00 ab ± 2.00	4.33 c ± 1.15	4.33 c ± 0.58	5.55 b
SB	9.00 a ± 2.08	7.67 ab ± 1.73	5.00 c ± 1.00	7.22 a
LB	6.00 bc ± 0.00	5.00 c ± 1.73	4.00 c ± 1.00	5.00 b
Means Temperature	7.22 a	6.11 a	4.44 b	

Note: Numbers that are followed by the same letter in one column mean that they are not significantly different based on the Duncan test with 5% levels. DAS = days after sowing. The number after ± means standard deviation.

at least 35 to 45% of seed dry mass to occur during the germination process (Queiroz *et al.*, 2019). The fact that the handling of the three sorghum cultivars was similar led the author to suggest that the difference in seed moisture content is affected by the character of each cultivar, such as the thickness of the seed coats. Thicker the seed coat need the more time to absorb water from the seed surrounding environment. The present study did not observe chemical changes during the germination process, but Benincasa *et al.* (2019) stated that the chemical and biophysical composition of seeds control the germination process, and the process was driven by environmental conditions, including temperature. At constant high temperatures, the growth enzyme activity will be stimulated and triggers germination (Gardner *et al.* 1991).

A previous study proved that at low temperatures, sorghum seeds consistently reduce the germination percentage (Solberg *et al.*, 2020). Furthermore, each cultivar had a different tolerance to low-temperature germination. LB cultivar was more tolerant to low temperature, while SB and PY cultivars were susceptible (Table 4). Solberg *et al.* (2020) explained that the germination response was influenced by several factors, including species, variety, the mother tree's condition, and both duration and condition of seed storage. The cultivars used in this study originated from different countries. The genetic basis of each cultivar might strongly influence the optimum germination temperature requirement. Thus, SB and PY cultivars which are originated from the equator are more susceptible to low temperatures. In contrast, the LB cultivar has a wider temperature adaptation because it has adapted to a temperate climate, characterized by higher monthly temperature fluctuations.

In accordance with FAO (2018) standard that quality seeds must have a germination percentage of at least 80%. In this study, SB cultivar (82.22%) and LB cultivar (89.26%) can be categorized as the quality seed. While the highest germination in PY cultivar was less than 80%. The low percentage of germination is closely related to the high value of ion leakage (Marcos-Filho, 2015).

One of the important characteristics of seed quality observation is the uniformity of seed germination. The information on the germination process is generally shown by the peak value, mean daily germination, and germination value. The peak value is the time when an increase in germination percentage happened in a short time that can be signed with a sharper increase in the curve simultaneously with an increase in germination percentage which is signed with the slighter increase in the curve and horizontal (Hartmann *et al.*, 2011). The Peak Value (PV) of all three cultivars is strongly affected by germination temperature (Figure 3). The peak value (PV) at 20°C (3-6 DAS) was slower than at 30°C and 25-35°C (2-3 DAS). This value is related to the final germination, when the germination percentage is high, the

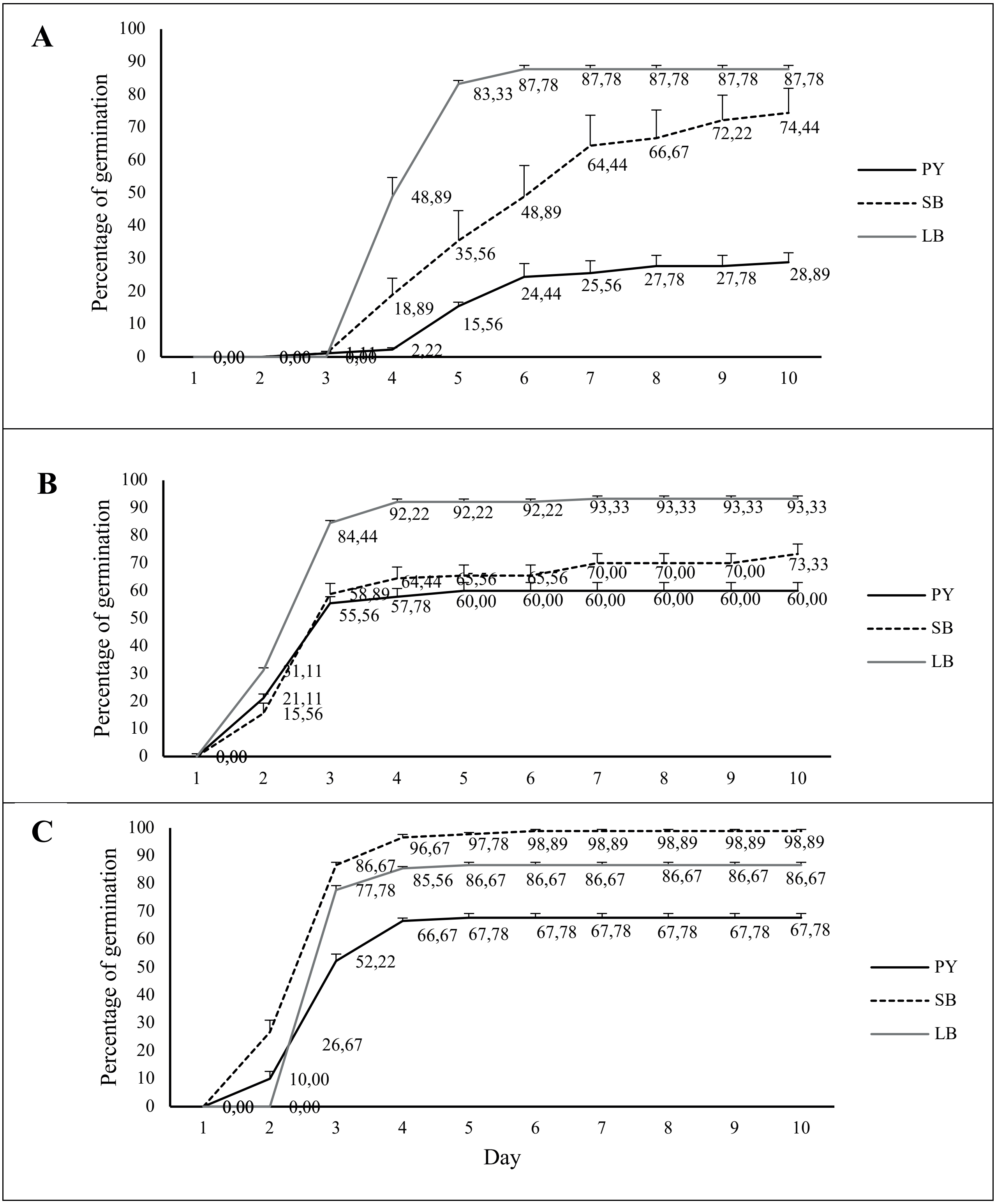


Figure 3. Daily germination percentage of PY, SB and LB sorghum cultivars at 20ºC (A), 30ºC (B) and 25-35ºC (C). vertical bars indicated standard deviation.

Table 5. Peak Value (PV), Mean Germination Day (MDG), and Germination Value (GV) of PY, SB and LB sorghum cultivars at 20°C, 30°C and 25-35°C.

Sorghum cultivars	Temperature (°C)		
	20	30	25-35
	Peak Value (PV)		
PY	4.07	18.52	17.41
SB	8.15	19.63	28.89
LB	16.67	28.89	25.93
	Mean of Germination Day (MDG)		
PY	2.50	12.00	13.56
SB	7.44	7.33	16.48
LB	14.63	23.06	17.33
	Germination Value (GV)		
PY	11.80	222.24	236.08
SB	60.64	143.89	467.11
LB	243.88	649.14	449.37

PV value also showed the same trend. LB and PY cultivars showed a similar trend of PV (Table 5). The PV of both cultivars was lowest at 20°C and highest at 30°C, while SB cultivar had a linear trend related to the raising of germination temperature.

Mean Daily Germination (MDG) values of the three cultivars are varied depending on the germination temperature (Table 5). The MDG of LB cultivar was constantly higher than other cultivars at any germination temperature. The MDG values were found lowest when seeds germinated at 20°C and then increase at 30°C and 25-35°C. The PV and MDG will strongly affect germination value. The highest germination value indicates strong seed vigor to germinate under certain conditions, especially at a specific temperature. The result of this study showed that the LB seeds required 30°C to obtain the highest germination value while the SB and PY seeds required 25-35°C to reach the highest germination value. The specific temperature that is required by each cultivar to reach the highest germination value is called optimum temperature. Shaban (2013) explained the optimum temperature is the temperature that enables to the production of the highest percentage of germination in a short period of time.

Seedling growth

The quality of seeds is also determined by seedling growth. Seedling is defined as a complete germination process after the release of radicle and plumules through the seed coat and grows into young plants with roots and leaves. This process was driven by soil nutrition and light. Dubey et al (2018) confirmed that each phase of plant growth requires different environmental conditions to achieve maximum growth. Plant performance during its life is an interaction between plant genetic potential and the environment. Therefore, the growth of seedlings in the nursery was observed without any control of environmental temperature and light.

The plant characteristics that were observed at the seedling phase included plant height, number of leaves, root length and plant biomass. The sorghum seedling height showed a sigmoid pattern. The curve experiences a rapid increase from the first week to the second week of observation, then sloping in the third week. Overall, the LB cultivar showed the tallest and highest growth rate, followed by PY and SB cultivars (Figure 4a). The highest number of leaves during the 1st and 2nd weeks were found in LB cultivar, followed by SB and PY cultivars. However, in the 3rd week, all cultivars had the same number of leaves (Figure 4b).

The root length was observed for three weeks and experienced a different increase. LB cultivars have the longest roots at 1 WAP (17.2 cm), followed by SB cultivars (12.3 cm) and PY cultivars (10.2 cm). The root length increased along with the age of the plant. The successive increase of the length of the root was 12.7 cm for LB cultivar, 4.1 cm for SB cultivar, and 22.8 cm for PY cultivar. In the third week, the length of the root of PY cultivar decreased by 6.5 cm. It is suspected that a part of the root was broken off during root sampling. The length of the root of SB and LB cultivars increased by 4.9 cm and 0.2 cm from the previous week (Figure 4c).

By all the plant growth parameters, the biomass measurement showed that SB cultivar had lower fresh weight compared to PY and LB cultivars at each seedling age (Figure 4d). The seedling growth rate of LB cultivar was higher compared to the other two cultivars, which started from the beginning of their growth until the third week. The growth rate was drawn from a higher number of leaves and taller ones since the first week of observation. which results in higher fresh weight and dry weight of the seedlings compared to PY and SB cultivars Timotiwu et al (2017) state that seedlings that have high vigor will have longer seedling roots and greater dry weight.

Thai cultivars seemed higher in early growth, but the growth rate gets slow in the second week. The production of leaves is also lower than that of SB cultivars. The seedling growth rate has a significant impact on the fresh weight and dry weight of seedlings. Queiroz *et al.* (2019) state that the seeds of each plant have a different amount of starch and other nutrients. This difference in

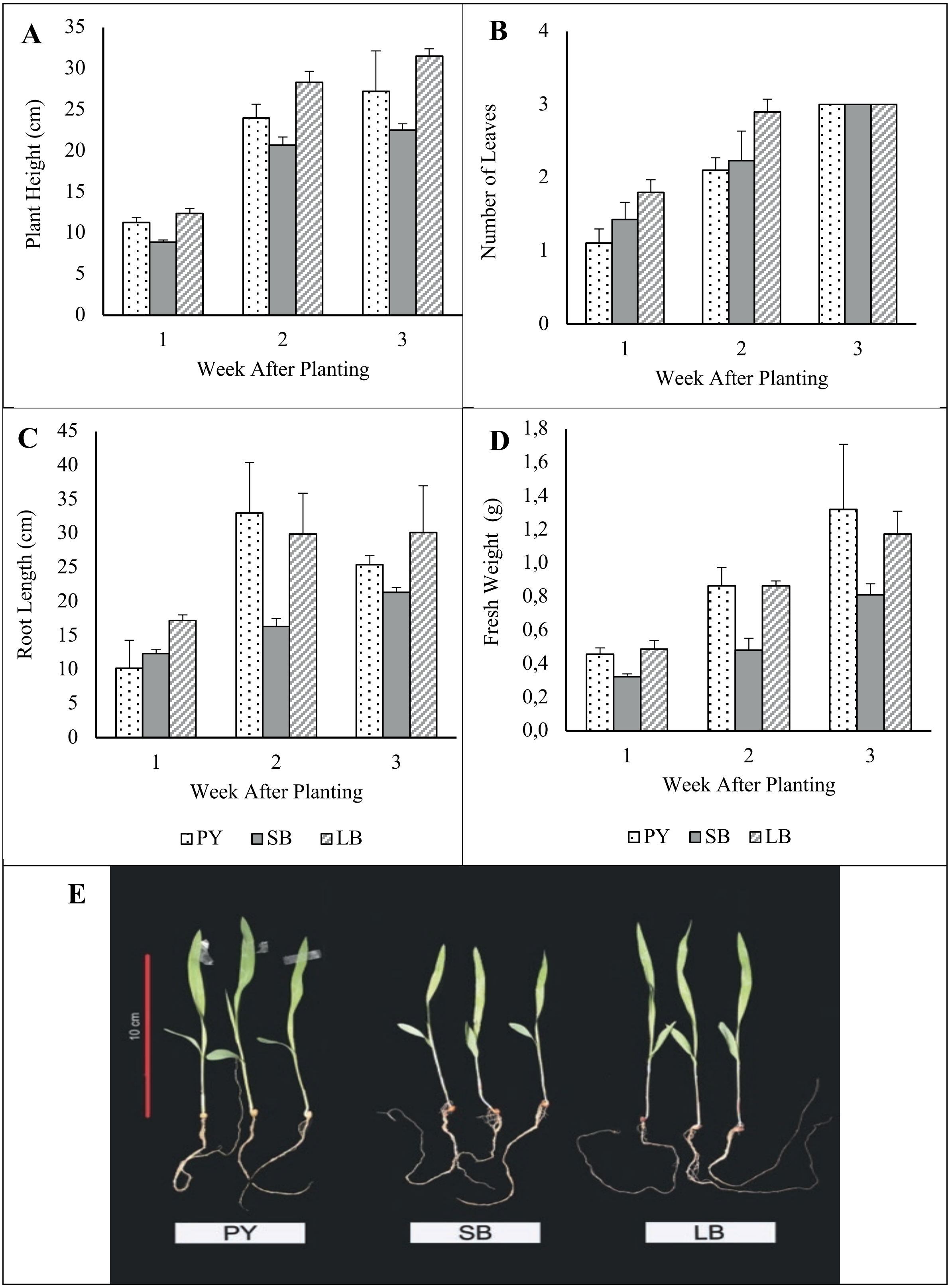


Figure 4. The seedling growth of 3 sorghum cultivars: plant height (A), number of leaves (B), root length (C), fresh weight (D), and Pictures of sorghum seedlings at the third week (E).

the amount of starch and nutrients is one of the major factors affecting seedling growth. Sorghum seeds of SB cultivars have smaller sizes compared to LB and PY cultivars, possibly because of genetic factors of the cultivar and the size of the seeds that affect the seedling growth.

Relative Growth Rate (RGR)

The relative growth rate of seedlings in each cultivar was different (Table 6). It showed that each cultivar has a different growth ability. The relative growth rate in the second week reached 0.321 g week^{-1} for LB cultivar, 0.289 g week^{-1} for PY cultivar, and 0.239 g week^{-1} for SB cultivar. The growth rates of LB and SB cultivars in the third week decreased to 0.261 g week^{-1} and 0.224 g week^{-1}, respectively. Meanwhile, PY cultivar increased to 0.304 g week^{-1} from the previous week. The distribution of biomass to aerial parts of plants appears to be more influenced by genetic factors (plant cultivars) because environmental conditions were homogeneous.

The relative growth rate of each cultivar tends to be higher at R1 (first-second week) than R2 (first-third week). The higher R value indicates faster growth, while lower R values indicate slower plant growth. LB cultivar was thought to be early maturing sorghum, which is characterized by rapid vegetative growth and starts the generative phase quickly. On the other hand, the slower-growing SB and PY cultivars showed both were deep-aged sorghum.

Based on the results and discussion of the research, it can be concluded that the quality of sorghum seeds can be varied, depending on the germination temperature. Therefore, it is important to choose a sorghum cultivar that is suitable for the daily temperature range. Generally, the distribution of temperature and light intensity depends on the altitude above sea level. Considering the cardinal temperature range of sorghum germination, this commodity is suitably cultivated in areas with temperatures below 40°C with full light intensity for optimal growth. Regarding the three sorghum cultivars tested in this experiment, the LB cultivar was recommended to be cultivated at an altitude of 300 – 500 m above sea level. This area is identical with less fluctuation in daily temperature, around 30°C, corresponding to the optimum temperature for LB cultivar germination, but the light intensity is quite high, and the humidity is low. SB cultivar, which has higher germination temperatures, seems to be more suitable for cultivation in lower areas, between 50 – 250 m above sea level. Such areas have more fluctuating daily temperatures due to sea breezes, with low humidity and high light intensity. Sopandie (2013) explained that temperatures above the optimum temperature will reduce plant physiological activities, especially the inactivity of several enzymes, and disrupt the balance between photosynthetic activity and respiration. Conductivity test values in this study had a similar trend to the tetrazolium test, also in line with the direct germination test and moisture test. We consider that the conductivity test can be used by local farmers in assessing the quality of the seeds. This test is simple and requires an inexpensive tool. Conductivity tests can also solve the problem of subjectivity in the color-based assessment of the tetrazolium test. At the seedling level, the relative growth rate measurement based on the growth rate of the plumule can be utilized to assess seed vigor.

Table 5. Relative growth rate (R) of sorghum seedlings.

Cultivars	Dry Weight (g)			Relative Growth Rate (g week^{-1})	
	1 WAP	2 WAP	3 WAP	R1(g)	R2(g)
PY	0.019	0.037	0.077	0.289	0.304
SB	0.015	0.026	0.042	0.239	0.224
LB	0.021	0.044	0.070	0.321	0.261

Notes: WAP= Weeks after planting, R1= first-second week, R2= second-third week.

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