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Packaging types as influencing seed quality in some soybean [*Glycine max* (L.) Merr.] varieties during storage period

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Abstract: The post-harvest process at the storage stage is one of the most critical processes for maintaining soybean seed quality. The type of packaging and the type of material stored will affect its shelf life. One type of packaging has specific properties that are different from other types of packaging. Therefore, this study used several types of packaging materials and soybean varieties to determine changes in its quality during storage. The treatments were arranged in a 5 × 4 × 7 factorial experiment in a randomised block design (RBD) with three replications, consisting of totally 140 treatment combinations involving five different types of packaging materials. Water content, the weight of 100 grains, seedling dry weight, electrical conductivity (EC), and germination percentage were assessed monthly. The factorial analysis of variance (ANOVA) was used to compare water content, the weight of 100 grains, EC, germination, and seedling dry weight. A qualitative descriptive analysis method was employed for the temperature and relative humidity of the storage room. The results showed that Grobogan had the lowest germination percentage of 84.85% compared to the other varieties (86.97–90.82%). Plastic sack resulted in the most inferior seed quality (82.00% for plastic sack *vs.* 88.23–90.17% for the other containers). A more extended storage period of soybean seeds caused a decrease in soybean quality for all varieties and packaging materials. Up to 6 months of storage at room temperature, the quality of soybean seeds remained high, with the lowest germination of 80%.

Keywords: electrical conductivity; post-harvest; critical process; germination percentage

In Indonesia, besides rice and maize, soybean is one of the three primary commodities targeted to be self-sufficient in 2020. Farmers' inappropriate implementation of technologies also caused low productivity and selling prices so that it could not compete with imported soybeans (Miruts 2016). The local soybean varieties, such as Grobogan, Anjasmoro, Argomulyo, and the Burangrang, are widely used in Indonesia as raw materials for making tempeh and tofu (Ginting et al. 2009; Elisabeth et al. 2018), and the demand for these products is so high that soybeans must be available at all times.

The post-harvest process at the storage stage is one of the most critical processes for maintaining soybean seed quality, especially in tropical climates where variations in temperature and relative humidity negatively affect seed quality (Wang et al. 2013; Wijewardana et al.

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2019; Coradi et al. 2020b). Indonesia is a country with a tropical climate. A tropical climate has unfavourable conditions for the storage of soybean seeds due to its hygroscopic property (Han et al. 2014; Coradi et al. 2019; Taher et al. 2019). The proper packaging technology should manipulate air temperature and humidity to slow down metabolism in soybean seeds, when this process may accelerate damage and decrease soybean seed quality (Sarath et al. 2016; Bakhtavar et al. 2019; Ebone et al. 2020).

Seed storage generally aims to maintain seed viability and protect it from factors that cause a decline in viability, so that high-quality seeds remain available for the next planting season (Desheva et al. 2017). After harvesting, soybean seeds will experience a reduction in quality and quantity caused by several external factors. These factors include physical factors, such as temperature and humidity, chemical factors like the availability of oxygen, and biological factors such as bacteria, fungi, insects, and mice (Abbasi 2012; Destiana et al. 2016). The purchase of seeds is often carried out before the planting season so that the seeds must be stored properly to maintain high seed germination when planted. Deteriorated seed during storage is one of the primary reasons for low soybean productivity (Kandil et al. 2013a).

Storage packaging type affects the exchange of energy and mass between the stored seeds and the storage medium (de Jong et al. 2005; Coradi et al. 2020a). Seeds stored in permeable packaging materials experience a greater humidity exchange with the environment, increasing or decreasing their mass until they reach a hygroscopic balance. This phenomenon deteriorates the seeds and reduces their quality (de Oliveira et al. 2016; Keneni et al. 2019; Coradi et al. 2020b).

Seed longevity is measured by the level of damage in a given time. Seed longevity and seed damage rates are influenced by the initial moisture content when stored, and the temperature and humidity of the environment (Monira et al. 2018). Moreover, seed longevity is also determined by the seed condition when stored, the method and material used for storage, seed variety, and the shape/size of the seeds (Befikadu 2014). Proper room temperature, water content, and packaging techniques with airtight plastic should be used to maintain the quality of soybean seeds (Mbofung et al. 2013). Breeders and traditional farmers in Indonesia store seeds using plastic packaging materials or plastic sacks because it is cheap and easy to get.

Many studies using different packaging materials for soybean storage have been carried out around the globe. However, to the authors' knowledge, packaging materials and soybean varieties tested in this study have never been used before. It was hypothesised that the type of packaging materials and soybean varieties would result in different effects on the shelf-life of the seeds. Therefore, this study aimed to determine the effect of the type of packaging materials and soybean varieties on the decline in water content, the weight of 100 grains, seedling dry weight, percentage of germination, and electrical conductivity (EC) of soybean seeds during storage.

MATERIAL AND METHODS

Site and time research. This research was conducted at the Agricultural Science Park (ASP) Natar Laboratory, Lampung Province, Indonesia, from June to December 2018.

Design research. The treatment was arranged in a 5 × × 4 × 7 factorial experiment in a randomised block design (RBD) with three replications, consisting of totally 140 treatment combinations involving four soybean varieties (Grobogan, Burangrang, Anjasmoro, and Argomulyo), seven storage periods (0, 1, 2, 3, 4, 5, and 6 months), and five packaging types [black jerry can, white jerry can, polyethylene (PE) plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + plastic sack (Figure 1)].

Grobogan and Burangrang varieties are classified as large seeds, with a weight of 18 g (100 grains)$^{-1}$ and

(A) (B) (C) (D) (E)

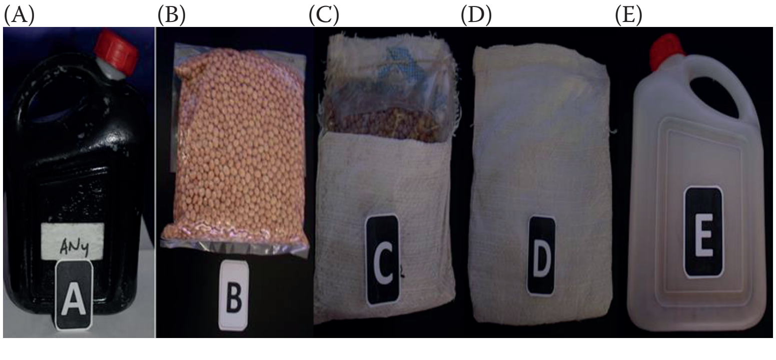

Figure 1. Storage package materials used in the study: (A) black jerry can, (B) polyethylene (PE) plastic 0.7 mm, (C) 0.7 mm PE plastic + plastic sack, (D) plastic sack, and (E) white jerry can

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17 g (100 grains)$^{-1}$, respectively. Anjasmoro variety is classified as a small seed [14.8–15.3 g (100 grains)$^{-1}$], while Argomulyo is categorised as a medium seed [16 g (100 grains)$^{-1}$] (Balitkabi 2016). The selection of packaging materials used was based on their availability in the market. The black jerry can and the white jerry can, used in this study, are made from high-density polyethylene (HDPE) plastic with a capacity of 2 L and a thickness of 1 mm. PE plastic used has a size of 2 kg and a thickness of 0.7 mm. The plastic sack (woven bag) used is a woven plastic thread made from polypropylene (PP), PE, and calcium carbonate with a capacity of 2 kg.

Test parameters. Parameters measured were water content, the weight of 100 grains, seedling dry weight, germination, and EC. Water content was measured using a seed moisture meter (JV001; Amtast, China). Based on the protocol described in the manufacturer's manual, the soybean seeds (100 g) inside the measuring cup were poured to a measuring device with a sensor. The moisture content of the material was read on a digital monitor on the gauge.

One hundred grains of soybean were randomly selected from each variety and weighed with a two-digit digital scale (FS-AR; Fujitsu Limited, Japan). The measurement was replicated three times. Measurements of germination were performed using the germination test paper International Seed Testing Association (ISTA) method by spreading 100 soybean seeds on a tray that had been given wet tissue paper, then covered with damp tissue paper, which was sprinkled with water every day to keep it moist (ISTA 2006). After three days, the number of soybean seeds germinated was counted and then compared with the total number of seeds. The measurement was replicated three times.

EC was measured using a conductivity/total dissolved solids (TDS)/°C meter (CyberScan con 11; Eutech Instruments, Singapore) (ISTA 2006). Twenty-five soybean seeds were weighed using a digital scale and were placed into a 200 mL plastic cup. As much as 75 mL of distilled water was added into the cup and then stirred. The glass containing the soybean seeds was then placed in an incubator (HI-50 L; Biobase, China) at a temperature of 20 °C and left for 24 h. After that, the electrode was sprayed using distilled water and dried with tissue paper. The value of the EC of the sample was recorded and printed on the device. The measurement was replicated three times.

Statistical analysis. Data were analysed statistically using analysis of variance (ANOVA) by Genstat Release 18.1 software and qualitative descriptive analysis. If the F-test for treatment was significant ($P \leq 0.05$), the treatments were compared by Duncan's multiple range test with a significance value of 5%.

RESULTS AND DISCUSSION

Storage room temperature and relative humidity during the experiment are presented in Figure 2. The average temperature of the storage room during the experimental period was 25.5–32.4 °C, while the average relative humidity was 52–84%. Table 1 shows that water content, the weight of 100 grains, and EC were affected by soybean varieties ($P < 0.05$ for all). It shows that the Grobogan variety has the highest weight of 100 grains, the lowest EC, the highest seedling dry weight and the

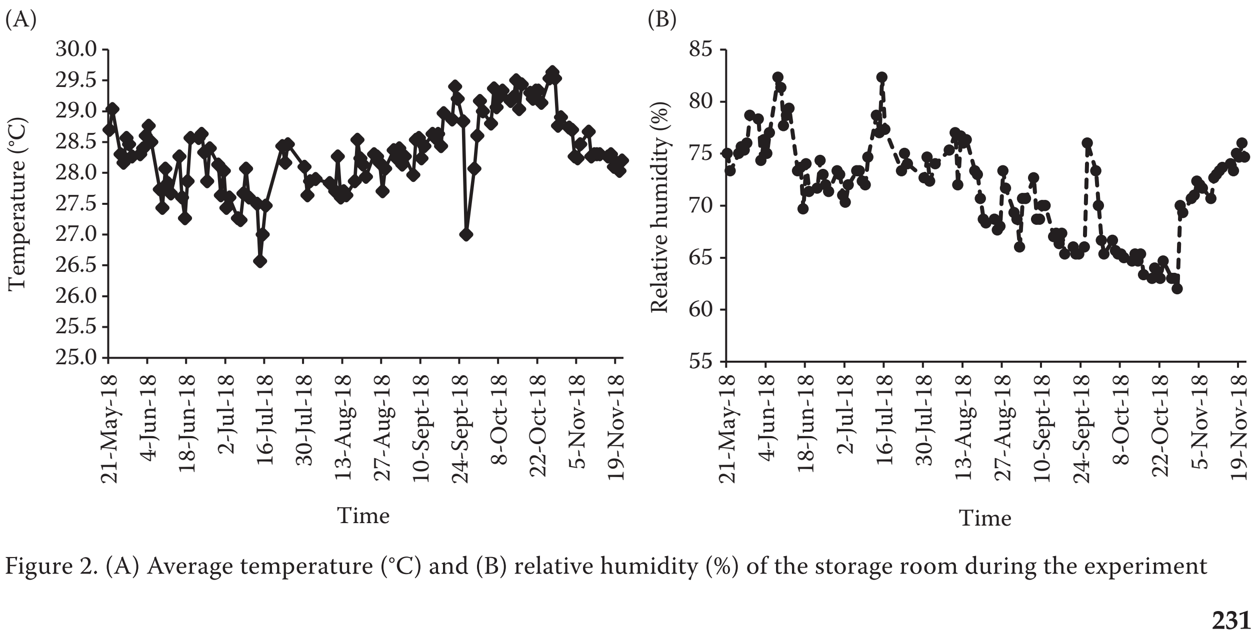

Figure 2. (A) Average temperature (°C) and (B) relative humidity (%) of the storage room during the experiment

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Table 1. Average water content, weight of 100 grains, electrical conductivity (EC), germination, and seedling dry weight, as affected by soybean varieties, packaging materials, and storage period (mean ± SD; n = 120)

Treatment	Parameter				
	water content (%)	weight of 100 grains (g)	EC [μS (cm g)$^{-1}$]	germination (%)	seedlings dry weight (g)
Soybean variety (V)					
Grobogan	9.74 ± 0.82^{d}	20.36 ± 1.01^{a}	36.47 ± 6.25^{d}	84.85 ± 13.20^{c}	20.81 ± 2.95^{a}
Burangrang	10.46 ± 0.69^{b}	12.89 ± 0.62^{d}	50.98 ± 10.16^{a}	87.92 ± 8.55^{b}	12.96 ± 1.62^{c}
Anjasmoro	11.09 ± 1.00^{a}	14.72 ± 0.47^{b}	46.16 ± 9.28^{c}	86.97 ± 10.16^{bc}	14.93 ± 2.54^{b}
Argomulyo	10.05 ± 1.10^{c}	14.14 ± 0.50^{c}	49.23 ± 9.25^{b}	90.82 ± 8.81^{a}	14.75 ± 2.16^{b}
Packaging materials (P)					
Black jerrycan	10.07 ± 0.96^{cd}	15.66 ± 3.05^{ab}	45.16 ± 10.47^{bc}	89.14 ± 10.84^{a}	16.15 ± 4.20^{a}
PE plastic bag	10.15 ± 0.84^{c}	15.46 ± 2.74^{c}	46.66 ± 9.92^{a}	88.67 ± 7.05^{a}	15.65 ± 3.42^{b}
PE plastic bag + plastic sack	10.25 ± 0.76^{b}	15.23 ± 2.89^{d}	46.08 ± 10.00^{ab}	90.17 ± 7.01^{a}	15.80 ± 3.79^{b}
Plastic sack	11.13 ± 1.26^{a}	15.54 ± 3.01^{bc}	46.48 ± 11.64^{a}	82.00 ± 15.47^{b}	15.55 ± 3.64^{b}
White jerrycan	10.06 ± 0.96^{d}	15.75 ± 3.09^{a}	44.18 ± 10.21^{c}	88.23 ± 7.86^{a}	16.16 ± 3.89^{a}
Storage period (T)					
Month 0	10.27 ± 0.59^{b}	16.15 ± 3.05^{a}	34.34 ± 1.24^{f}	94.58 ± 2.03^{ab}	18.87 ± 3.76^{a}
Month 1	10.73 ± 1.41^{a}	15.96 ± 3.01^{a}	46.02 ± 7.21^{c}	95.62 ± 4.18^{a}	18.55 ± 3.37^{a}
Month 2	10.78 ± 1.41^{a}	15.70 ± 3.15^{b}	41.55 ± 6.99^{e}	92.15 ± 5.55^{b}	16.54 ± 3.41^{b}
Month 3	10.26 ± 0.94^{b}	15.45 ± 2.94^{c}	42.29 ± 6.67^{e}	85.15 ± 10.87^{c}	15.12 ± 2.86^{d}
Month 4	10.00 ± 0.78^{c}	15.23 ± 2.93^{d}	44.27 ± 7.94^{d}	85.10 ± 8.47^{c}	15.64 ± 3.41^{c}
Month 5	10.29 ± 0.78^{b}	15.12 ± 2.75^{d}	52.24 ± 9.59^{b}	80.95 ± 14.00^{d}	13.10 ± 2.50^{e}
Month 6	10.00 ± 0.87^{c}	15.09 ± 2.77^{d}	59.26 ± 9.05^{a}	79.93 ± 9.79^{d}	13.20 ± 2.48^{e}
Interaction					
V × P	**	**	**	**	**
V × T	**	**	*	**	**
P × T	**	**	**	**	**
V × P × T	ns	**	ns	**	**

**Significant; ns – not significant; $^{a–f}$different letters in the superscript within the same column and treatment indicate that values are significantly different by Duncan's multiple range test (P < 0.05); PE – polyethylene; SD – standard deviation

lowest germination compared to other soybean varieties (P < 0.05 for all). Nevertheless, the quality of soybean seeds stored at room temperature for up to six months remained high, indicated by the germination percentage of 80%. There were significant interactions between two factors [V × P; V × T; P × T (where: V – soybean variety; P – packaging materials; T – storage period)] for all parameters (P < 0.05 for all). However, the interaction of three factors (V × P × T) was significant for EC, seedling dry weight, and moisture content. However, the weight of 100 grains and germination did not show any significant interactions (P > 0.05).

Water content. The results of water content indicated that the water content of soybean seeds during storage was changed. Changes in the moisture content of four soybean varieties during six months of storage with different packaging materials and their interactions were investigated. Soybean seeds packed in plastic sacks had the highest fluctuations in water content compared to other packaging materials for all soybean varieties stored (Figure 3), indicating that the packaging type strongly influences the seed water content. The present study is in agreement with the results of Tatipata et al. (2004). Tatipata et al. (2004) revealed that the storage of soybean seeds in flour bags caused a faster increase in water content than in those stored in PE plastic bags, due to the more porous material of flour bags compared to PE plastic bags.

Water content was significantly different between soybean varieties (Table 1). The water content of An-

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jasmoro was higher than in Grobogan (Figure 3) and other varieties. It is suspected that this was because Anjasmoro had smaller seeds than Grobogan [14.91 g (100 grains)$^{-1}$ to 15.68 g (100 grains)$^{-1}$ of Anjasmoro compared to 20.01–21.94 g (100 grains)$^{-1}$ of Grobogan]. Small grains cause a wider surface area so that evaporation or absorption of water from soybean seeds is also higher. Pereira et al. (2013) reported that the variation in the water content of soybean was caused by differences in storage temperature and soybean varieties. Postharvest handling methods such as the thickness of the soybean pile and the length of drying significantly affected the quality of soybean seeds produced (Gavhale et al. 2015). Water content is the most influential factor in the decline of seed quality. The seed quality will be reduced with the increase of water content (Palupi et al. 2016; Afzal et al. 2019). Seeds with high initial viability before storage will show a high vigour value (de Vitis et al. 2020). In addition, Situmeang et al. (2014) revealed that soaking soybean seeds at 45 °C for 10 min before storage can maintain the quality of soybean seeds. The thickness and permeability of the epidermis will affect seed germination. The thicker skin of soybean seeds causes lower permeability to develop because the thicker skin will absorb water more quickly than the thinner skin (Nooden et al. 1985).

Weight of 100 soybean grains. The changes in the weight of 100 soybean grains showed that the plastic sack resulted in the most significant change in the weight of 100 grains (15.54 ± 1.70 g), while PE 0.7 mm + plastic sack produced the lowest change in the weight of 100 grains (15.23 ± 1.63 g) for all soybean varieties

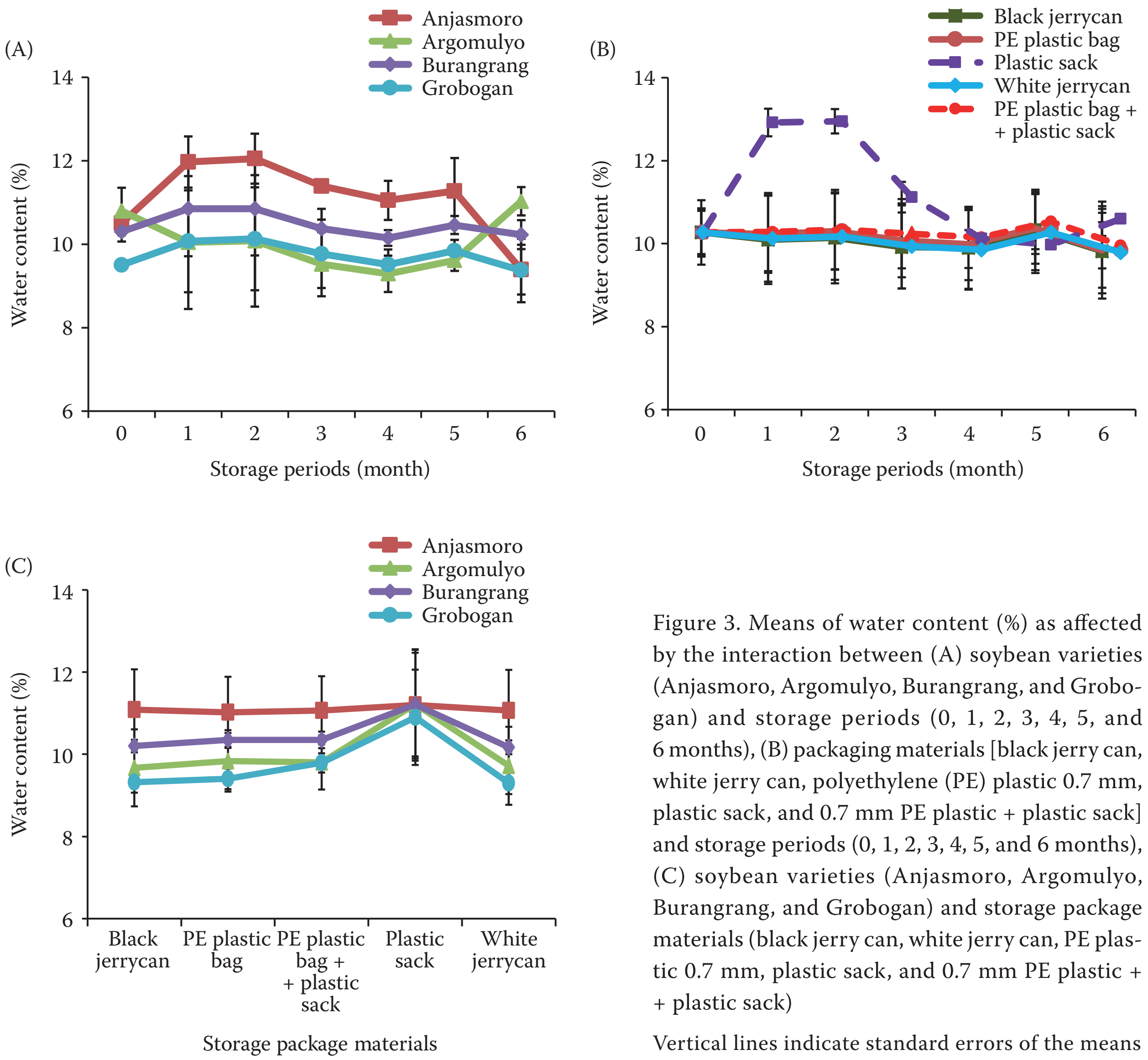

Figure 3. Means of water content (%) as affected by the interaction between (A) soybean varieties (Anjasmoro, Argomulyo, Burangrang, and Grobogan) and storage periods (0, 1, 2, 3, 4, 5, and 6 months), (B) packaging materials [black jerry can, white jerry can, polyethylene (PE) plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + plastic sack] and storage periods (0, 1, 2, 3, 4, 5, and 6 months), (C) soybean varieties (Anjasmoro, Argomulyo, Burangrang, and Grobogan) and storage package materials (black jerry can, white jerry can, PE plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + + plastic sack)

Vertical lines indicate standard errors of the means

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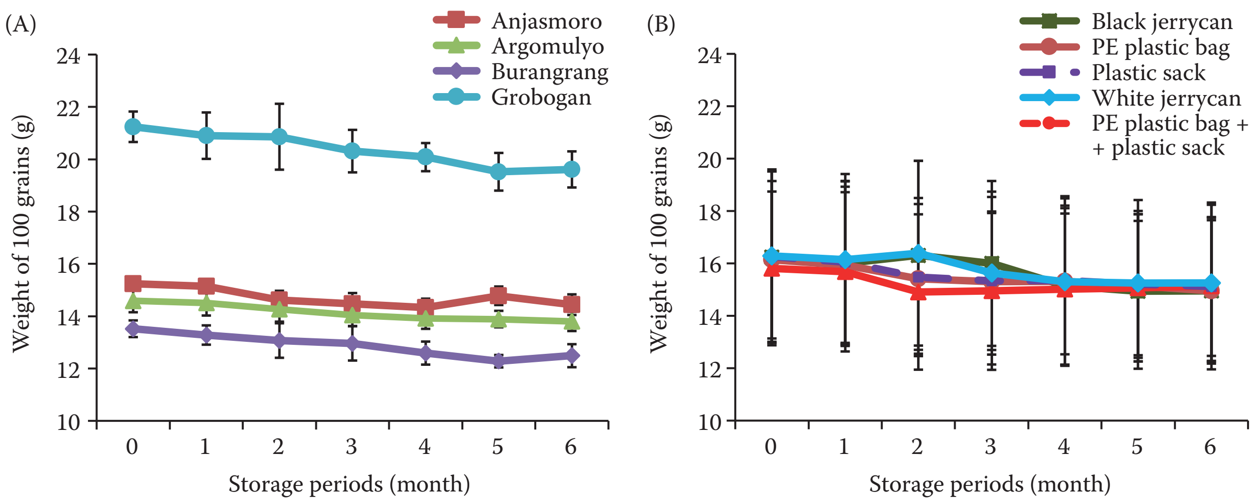
(Figure 4). According to Purwanti et al. (2018), PE plastic has airtight properties. Its protection against water vapour is very high, so that it can maintain the water content stability and the weight of 100 grains during storage. The difference was caused by the size of Grobogan seeds which are bigger than the seeds of other soybean varieties (Balitkabi 2016).

EC test. The EC test is a physical test to measure the cell membrane leakage level. The ANOVA ($P < 0.05$) indicated a significant variation in the EC of the solution that contained the soybean due to the interaction of soybean varieties, packaging materials, and storage period. Means of EC as affected by the interaction between storage packaging materials and storage periods are shown in Figure 5. The observation on EC from the first month until the sixth month showed that the white jerry can produced the lowest EC [44.18 ± 10.21 µS (cm g)$^{-1}$]. Increasing EC during storage is due to the seed permeable cell membranes that make the materials inside and outside the cell come in and out without being controlled by the membrane (Nurmauli and Nurmiaty 2010). High conductivity values indicate low vigour (do Prado et al. 2019). Fessel et al. (2006) stated that the conductivity is related to the number of ions leached into the solution, directly associated with the integrity of the cellular membranes; poorly structured membranes and damaged cells are usually associated with the process of seed deterioration and reduced vigour. The results showed that Grobogan had the lowest EC [36.47 ± 6.25 µS (cm g)$^{-1}$], while Burangrang had the highest EC [50.98 ± 10.16 µS (cm g)$^{-1}$]. The difference was caused by the thickness of the soybean endocarp (Enstone et al. 2015).



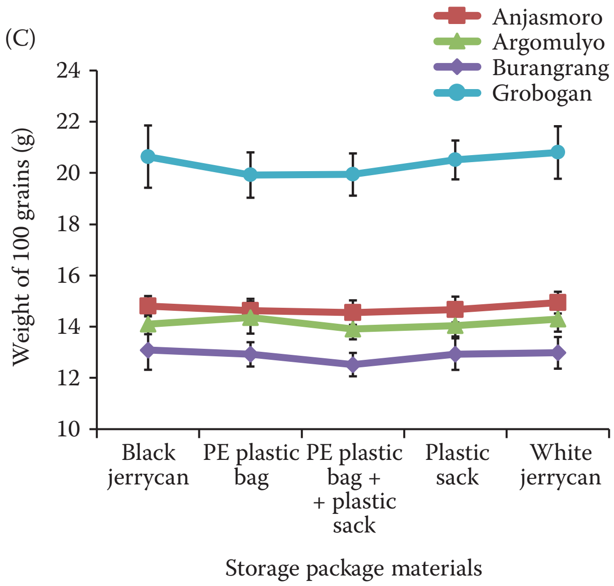


Figure 4. Weight of 100 soybean grains as affected by the interaction between (A) soybean varieties (Anjasmoro, Argomulyo, Burangrang, and Grobogan) and storage periods (0, 1, 2, 3, 4, 5, and 6 months), (B) packaging materials [black jerry can, white jerry can, polyethylene (PE) plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + plastic sack] and storage periods (0, 1, 2, 3, 4, 5, and 6 months), (C) soybean varieties (Anjasmoro, Argomulyo, Burangrang, and Grobogan) and storage package materials (black jerry can, white jerry can, PE plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + + plastic sack)

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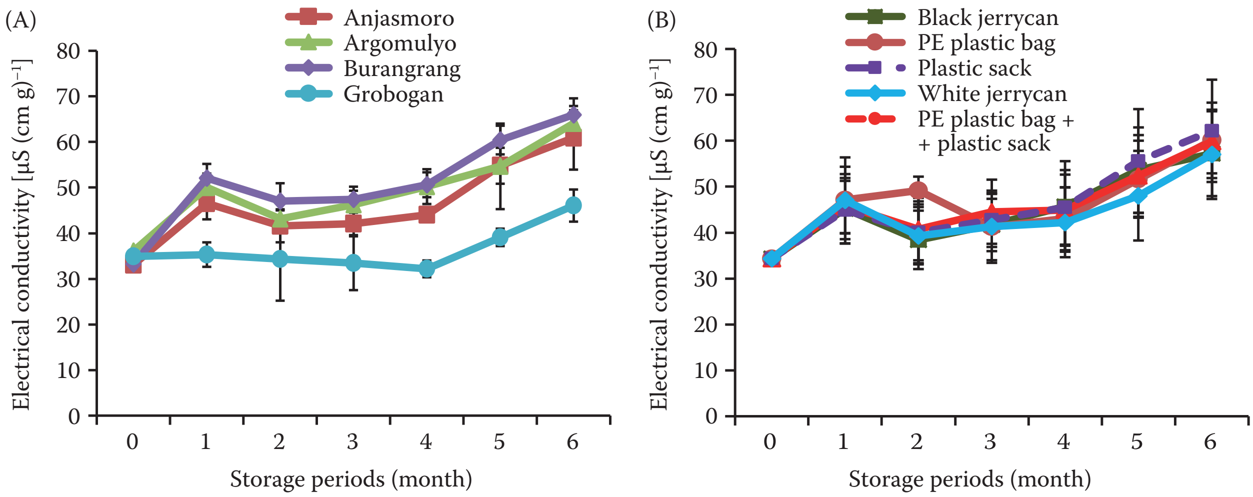
Seed germination. Soybean seed germination before storage ranged from 92% to 95%. The results showed that plastic PE 0.7 mm and plastic PE + plastic sack resulted in the lowest reduction in the germination of soybean seeds, while plastic sack resulted in the highest reduction in germination (Figure 6). These results indicated that plastic PE 0.7 mm could reduce the rate of decline in the germination of soybean seeds better than other packaging types. Compared to plastic PP, plastic PE is more flexible. Arora and Padua (2010) revealed that PP plastic is rigid and light, shows lower water vapour permeability and is resistant to high temperatures. In addition, Purwanti (2015) stated that soybean seeds stored at room temperature (27–29 °C) in PE and PP plastic bags that were vacuumed or unvacuumed could maintain soybean seed quality for four months of storage. In certain situations and conditions, soybean seeds cannot be planted directly after harvest, and they must be stored to break down the dormancy period (Graeber et al. 2012). Tatipata et al. (2004) reported that the damage to the cell membrane due to deterioration would affect the state of the embryo and cotyledons, consisting mostly of carbohydrates, proteins, and fats useful for the initial growth of seeds.

Figure 6 revealed that the Argomulyo variety (90.82 ± 8.81%) significantly exceeded the others (84.85 ± 13.20–86.97 ± 10.16%) in germination during storage. Grobogan seeds had the lowest germination (*P* < 0.05). The difference between varieties might be due to the genetic factors and seed chemical composition that influence the expression of seed deterioration and vigour decline. Kandil et al. (2013b) stated that the storability of different soybean cultivars is regulated by initial seed quality and physical and chemical



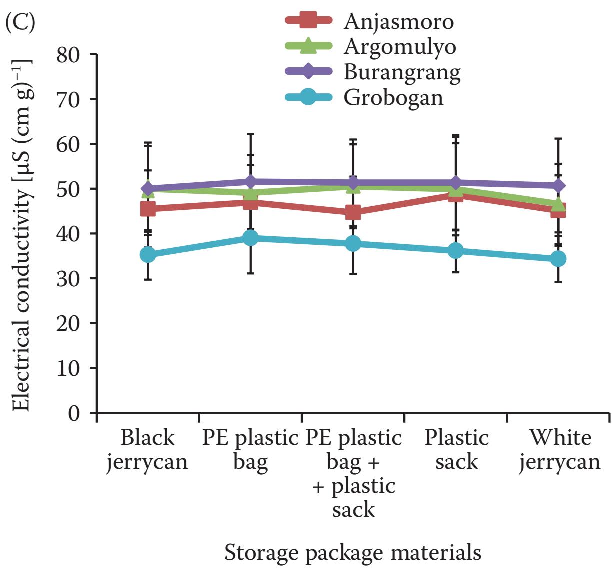


Figure 5. Electrical conductivity (EC) [μS (cm g)–1] as affected by the interaction between (A) soybean varieties (Anjasmoro, Argomulyo, Burangrang, and Grobogan) and storage periods (0, 1, 2, 3, 4, 5, and 6 months), (B) packaging materials [black jerry can, white jerry can, polyethylene (PE) plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + plastic sack] and storage periods (0, 1, 2, 3, 4, 5, and 6 months), (C) soybean varieties (Anjasmoro, Argomulyo, Burangrang, and Grobogan) and storage package materials (black jerry can, white jerry can, PE plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + plastic sack)

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composition of the seed as different cultivars possess different physical structures. In addition, Sugiarti and Ria (2019) revealed that decreasing germination capacity during the storage of soybean seeds is also caused by the attack of warehouse pests *Callosobruchus* sp., with a loss rate of 79–98%. Efforts to control *Callosobruchus* sp. pests during storage can be carried out physically, chemically, biologically, and mechanically (Nenaah et al. 2015). However, in this study, the attack of warehouse pests was not measured.

Seedling dry weight. The observations on seedling dry weight showed that the weight tended to decrease during storage (Figure 7). The seedling dry weight reflects the vigour of plant physiological conditions. Seeds with high physiological quality and vigour will also produce higher seedling dry weight (Enstone et al.

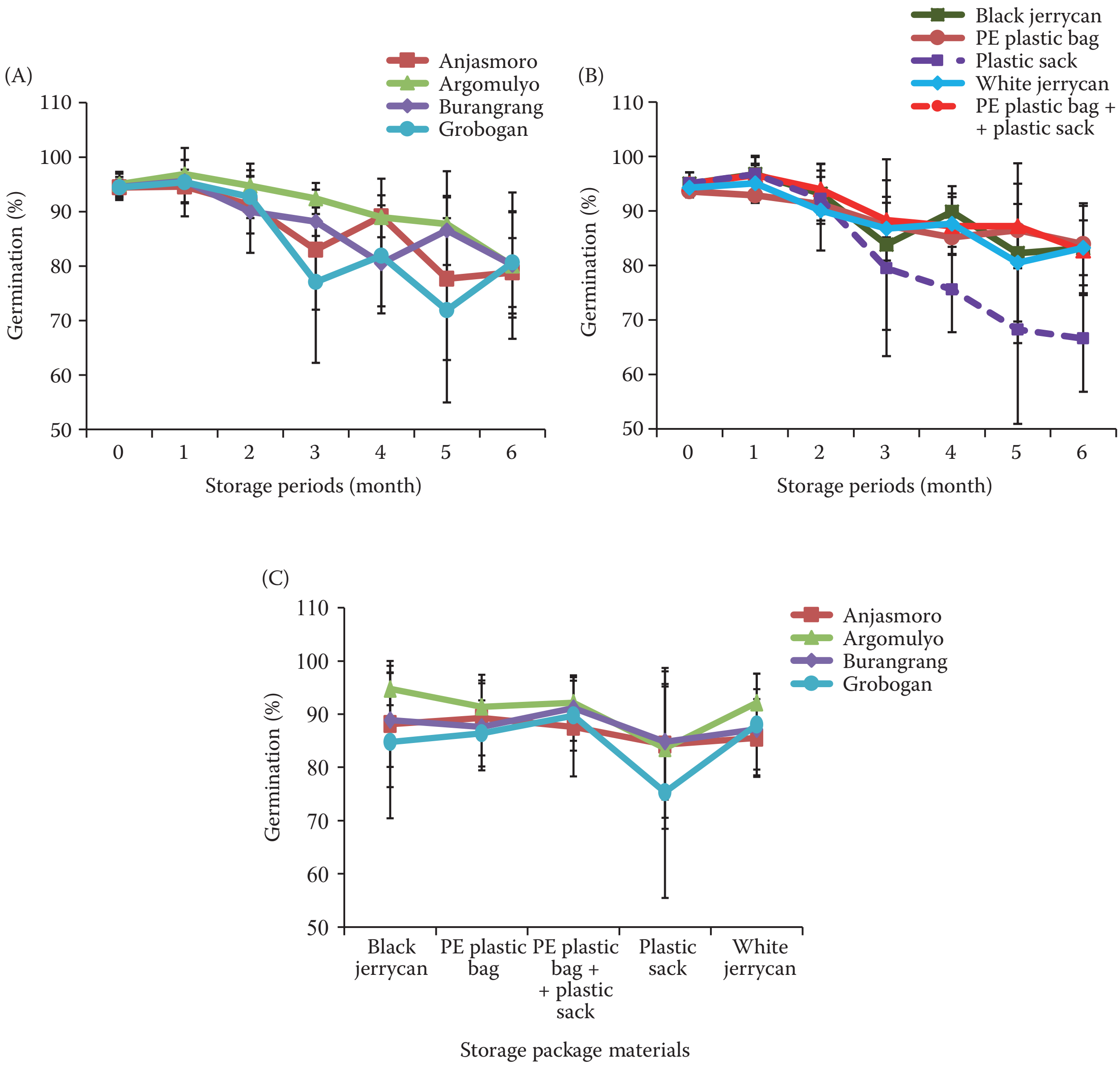

Figure 6. Seed germination (%) as affected by the interaction between (A) soybean varieties (Anjasmoro, Argomulyo, Burangrang, and Grobogan) and storage periods (0, 1, 2, 3, 4, 5, and 6 months), (B) packaging materials [black jerry can, white jerry can, polyethylene (PE) plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + plastic sack] and storage periods (0, 1, 2, 3, 4, 5, and 6 months), (C) soybean varieties (Anjasmoro, Argomulyo, Burangrang, and Grobogan) and storage package materials (black jerry can, white jerry can, PE plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + plastic sack)

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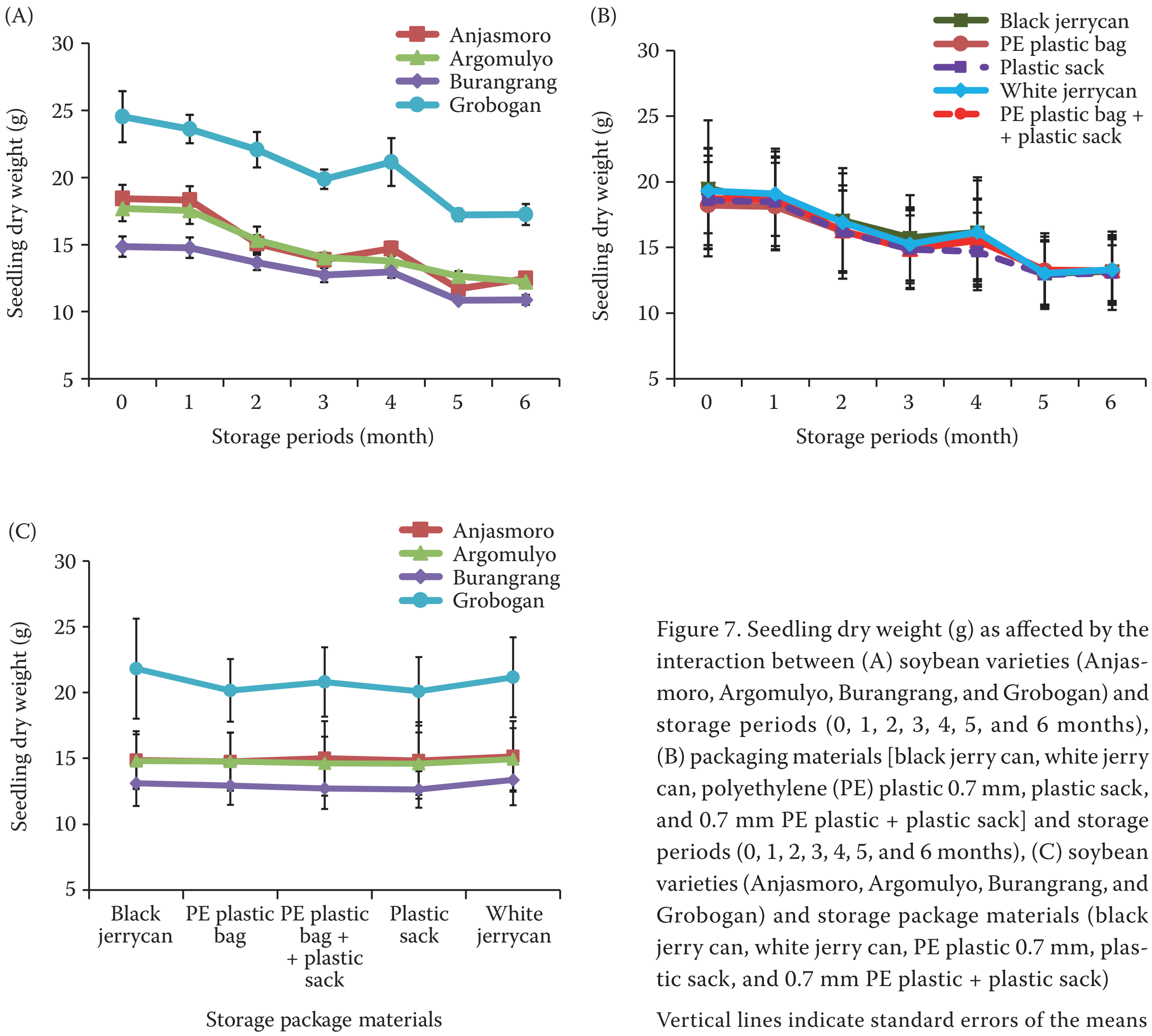

Figure 7. Seedling dry weight (g) as affected by the interaction between (A) soybean varieties (Anjasmoro, Argomulyo, Burangrang, and Grobogan) and storage periods (0, 1, 2, 3, 4, 5, and 6 months), (B) packaging materials [black jerry can, white jerry can, polyethylene (PE) plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + plastic sack] and storage periods (0, 1, 2, 3, 4, 5, and 6 months), (C) soybean varieties (Anjasmoro, Argomulyo, Burangrang, and Grobogan) and storage package materials (black jerry can, white jerry can, PE plastic 0.7 mm, plastic sack, and 0.7 mm PE plastic + plastic sack)

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2015). When the seeds are planted, if the seed vigour decreases, the germination rate becomes low, and the dry weight of the seeds when germinated becomes low, which will produce a low seed yield (Finch-Savage and Bassel 2016).

CONCLUSION

Grobogan is the type of soybean with the fastest decreasing germination during storage compared to Anjasmoro, Argomulyo, and Burangrang. The packaging material of 0.7 mm PE plastic bags covered with plastic sacks provided the best physical and physiological qualities for soybean seeds during storage. The more extended storage period caused decreasing soybean quality in all soybean varieties and packaging types. However, up to 6 months of storage at room temperature, the quality of soybean seeds remained high, with the lowest germination of 80%.

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