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EFFECT OF SEED COATING AND PACKAGING MATERIAL ON VIABILITY AND VIGOR OF SOYBEAN SEED IN ROOM TEMPERATURE STORAGE

Olaf Ingmar[1], Setiyono*[,2], Dyah Ayu Savitri[2], Noer Novijanto[3]

[1]Department of Agrotechnology, University of Jember, Jember, Indonesia
[2]Department of Agricultural Science, University of Jember, Jember, Indonesia
[3]Department of Agroindustrial Technology, University of Jember, Jember, Indonesia

*Corresponding author
Email: setiyono.faperta@unej.ac.id

***Abstract**. Soybean seed procurement was challenging due to the quality degradation during the seed storage period. Seed coating is necessary in order to overcome the leakage of seed metabolites. Seed coating has to be supported by a storage package that can protect the seed from temperature and humidity fluctuations in storage. This study aimed to determine the effect of seed coating using antioxidants and storage packaging to maintain the viability and vigor of soybean seeds. The experiment was carried out factorially with the basic pattern of Completely Randomized Design (CRD) and was repetitively replications by three times. The first factor was seed coating, which consisted of 4 levels such as M1=no coating, M2= 3% of Arabic gum + ascorbic acid, M3= 3% of Arabic gum + tocopherol, and M4= 3% of Arabic gum + mangosteen peel extract. The second factor was that the storage package consisted of 3 levels, which were N1= aluminum foil, N2= polyethylene plastic, and N3= plastic sack. The interaction between the seed coating material and storage package on seed moisture content with the best treatment was seed coating using ascorbic acid and aluminum foil package, seed coating treatment carried out the best effect without implementing the seed coating, and the storage package treatment that presented the best effect was aluminum foil package.*
Keywords: soybean seed; packaging; seed coat; viability; vigor

1. Introduction

The availability of soybean seeds in Indonesia is currently constrained because the seeds easily experience quality deterioration so meeting the demand for quality soybean seeds according to standards is difficult (Purwanti, 2015). The need for soybean seeds as planting material nationally from 2017 to 2018 has increased to 91.22% in line with the increase in planting area (Ministry of Agriculture of the Republic of Indonesia, 2018). It is essential to make efforts to meet the availability of quality soybean seeds according to standards on an ongoing basis. Seed coating has received a lot of attention because it can inhibit the increase in seed moisture content so it suppresses the increase in respiration rate more effectively (Manzoor *et al*., 2021).

Seed coating is a process of treating seeds by coating them using certain materials to protect them so they can grow optimally. Seed coating can protect the seeds from the influence of environmental conditions and maintain the moisture content of the seeds during storage (Ikrarwati *et al*., 2015; Zhang *et al*., 2022). There are still problems with seed coating, namely seed deterioration caused by metabolite leakage. The leakage of metabolites is caused by protein

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denaturation due to the fat oxidation process, which breaks the double bonds of unsaturated fatty acids, which produce free radicals resulting in damage to the cell membrane of seed (Justice & Louis, 2019). Damage to the seed cell membrane can reduce the ability of the seed to grow normally under non-optimal conditions (Bewley *et al*., 2013).

Antioxidants have the potential to be developed as carriers in seed coatings. Antioxidant compounds can slow down and prevent the process of lipid oxidation, thereby reducing the activity of free radicals that can damage DNA (Kumalaningsih & Suprayogi, 2006). Antioxidant compounds work to provide electrons to free radical molecules, thereby breaking free radical chain reactions (Sayuti & Yenrina, 2015). Antioxidant compounds in nanoemulsion coatings can increase shelf life because they carry active ingredients that reduce the growth of pathogens. However, antioxidants are easily degraded at high temperatures, so it is necessary to store packaging that is able to protect from the effects of storage space (Ling *et al*., 2022; Mastromatteo *et al*., 2011).

Storage packaging is related to the ability to protect seeds and coating materials from high humidity and temperature fluctuations. Seed storage packaging helps avoid the influence of external storage containers conditions such as temperature and humidity fluctuations in the storage room which cause a decrease in potential viability (Baharudin *et al*., 2010). Soybean seeds stored in an open room with high porous packaging can reduce the percentage of germination per month by up to 45% at the end of the storage period (Ramadhani *et al*., 2018). This indicates that the proper provision of boron for cucurbitaceae plants can help increase or improve plant growth and yield. This study aimed to determine the effect of seed coating using antioxidants and storage packaging to maintain the viability and vigor of soybean seeds.

2. Methods

2.1. Experimental Design

This research was carried out at the Quality Assurance Laboratory of PT. East West Seed Indonesia, Gumuksari Village, Tegal Besar, Kaliwates, Jember. The soybean seeds used came from seed producers, namely biosoy varieties which had been stored for two months. The experimental design was carried out based on a factorial Completely Randomized Design (CRD). The first treatment factor used included seed coating (M) which consisted of four levels, namely without seed coating (M_1), 3% arabic gum + ascorbic acid (M_2), 3% arabic gum + tocopherol (M_3), 3% arabic gum + mangosteen peel extract (M_4) and the second treatment factor used included storage packaging (N) which consisted of three levels, namely aluminum foil (N_1), polyethylene plastic (N_2), plastic sack (N_3). Each treatment combination was repeated three times, therefore there were 36 experimental units.

In this research, mangosteen peel extract (M_4) was prepared by mixing distilled water and methanol in 1: 1 ratio to make a maceration solution. Mangosteen rind was separated from the flesh and the mangosteen rind was weighed as much as 100 grams. Mangosteen rind was macerated together with 400 ml of solvent for 24 hours with several times stirring to make it homogeneous. It was given hot water treatment and filtered using a 4-layer filter cloth so that it is able to separate solid and liquid materials. This process was repeated three times to get maximum results. The filtered solution was centrifuged for 15 minutes and the final result for 75 ml of concentrate had to be evaporated again with a rotary evaporator.

The seeds used were 450 seeds for each treatment multiplied by 36, which required 16,200 soybean seeds. The main coating material used was Arabic gum. The coating material was placed in each container as much as 3 grams. Furthermore, each ingredient was dissolved using 100 ml of water and stirred until evenly all of each ingredient. Preparation of ascorbic acid solution by adding 300 mg to 1 liter of water and tocopherol by adding 400 mg to 1 liter of water. Antioxidant solutions such as ascorbic acid, tocopherol, and mangosteen peel extract were added as much as 15 ml according to the treatment and stirred until evenly distributed. The seeds were put into each container and coated until evenly distributed. The seeds were then removed and dried the seeds under the sun for 4 hours. Soybean seeds with dry coatings were put into three different packages and each package contained 450 seeds. The seed packaging measures 22 cm x 13 cm and were labeled according to the treatment to provide a mark so that there were no errors in later observations. Packaged seeds were stored in their respective containers in an open room where the temperature and humidity were controlled by environmental conditions. The process of storing seeds should not be directly near a window and exposed to direct sunlight. Temperature and humidity were measured using a thermometer every week.

Implementation of research activities consisted of several activities, namely viability and initial vigor testing, seed coating treatment, seed storage, and weekly viability and vigor testing. Testing of seed viability and initial vigor is carried out before the treatment and storage process which aims to determine the physical and physiological quality of the seed before treatment and storage. The variables observed in the viability test included seed moisture content, germination capacity, and maximum growth potential, while the vigor test included vigor index, seed growth synchrony, and seed growth speed. The tested seeds were given treatment and air-dried for 30 hours and then packed into three packages, namely aluminum foil, polyethylene plastic, and plastic sacks.

Packaged seeds were stored in a seed storage warehouse with an average temperature of 29.3°C and an average humidity of 72% for 3 months. Seed testing was carried out every two weeks to determine the physical and physiological quality of the seeds during storage. Variables observed in the viability test included seed moisture content, germination rate, and maximum growth potential while vigor testing included vigor index, seed growth simultaneity, and seed growth rate.

2.2. Data Analysis

The data obtained were analysis of variance (F test) to determine whether there was an effect of the seed coating treatment and storage packaging on the observed variables. The results of the F test which showed a significant effect were further tested with the Duncan Multiple Range Test (DRMT) at the 5% level. Data processing was done using Ms. Excel.

3. Results and Discussion

Table 1 showed the recapitulation of the results of analysis of variance (F-Count) on all observation variables. Based on the results of data analysis, it can be seen that the interaction of seed coating and packaging had no significant effect on all observed variables except for the observation variable seed moisture content. Meanwhile, the main effect of the seed coating factor showed a significantly different effect on the observed variable growth simultaneity, germination and seed growth speed. The main effect of the storage packaging factor shows a significantly different effect on the variable moisture content observation, and the maximum growth potential of seeds.

Table 1. Recapitulation of the results of analysis of variance (F-Calc) on all observation variables

No	Observation Variables	Value of F-Count		
		M	N	M x N
1.	Moisture Content	2.124 ns	4.118 *	3.330 *
2.	Germination Power	5.655 *	2.932 ns	0.788 ns
3.	Maximum Growth Potential	3.211 ns	4.923 *	0.221 ns
4.	Vigor Index	3.113 ns	1.039 ns	0.505 ns
5.	Simultaneous Growth	6.107 **	3.107 ns	0.912 ns
6.	Seed Growth Rate	4.482 *	2.157 ns	0.315 ns

Description: **=Very Significantly Different, *=Significantly Different, ns= not significant

3.1. Effect of Interaction of Seed Coating and Storage Packaging on Soybean Seed Viability and Vigor

Table 2 showed by effect of seed coating and storage packaging on seed moisture content. Based on Table 2, interactions were not significantly different for all variables except for the moisture content of soybean seeds. The interaction on seed moisture content was in line with research conducted by Alamsyah *et al*., (2017) that there was an interaction between the seed coating treatment and the storage packaging for the seed moisture content to remain low. This was thought to be due to the seed coating and storage packaging minimizing the respiration rate of the seeds and the absorption of moisture from the storage environment. A low increase in respiration rate can reduce the stimulation of enzyme activity in the embryo and keep food reserves in the seed intact (El-Maarouf-Bouteau, 2022). Seeds that absorb moisture will have a high moisture content therefore it supports the development of fungi which will damage the purity of the seeds and damage the seed embryos (Fachruri *et al*., 2019; Rahmawati *et al*., 2019).

Table 2. Effect of seed coating and storage packaging on seed moisture content

Seed Coating	Storage Packaging		
	N_1	N_2	N_3
M_1	8.60 ab A	8.53 b B	8.97 a A
M_2	8.30 b A	8.97 a A	8.40 b B
M_3	8.40 a A	8.67 a AB	8.50 a B
M_4	8.37 a A	8.43 a B	8.57 a B

Description: Numbers followed by the same letters are not significantly different in Duncan's DMRT test at the 5% level. Numbers followed by capital letters (vertical) indicate the simple effect of the seed coating factor on the same level of packaging. Lowercase letters (horizontal) indicate the modest effect of the storage packaging factor at the same level of seed coating.

The best combination of interactions between seed coatings on storage packages is coatings using ascorbic acid and aluminum foil (M_2N_1) storage containers with low seed moisture content. These results concluded that the treatment using aluminum foil storage packaging with seed coating using ascorbic acid was an appropriate application for seed moisture content. Based on these observation parameters, it can be said that the application of seed coatings with proper storage packaging is a promising thing to be able to produce low moisture content of soybean seeds.

This was presumably because the seed coating using arabic gum and the antioxidant ascorbic acid has the ability to reduce environmental influences during the storage process which is needed to keep the seed moisture content low. The seed coating using arabic gum has a very high density level therefore there are no pores that will be penetrated by moisture. Arabic gum has high viscosity properties and is a polymer that is insoluble in organic solvents (Dauqan, 2013; Jones *et al*., 2022). Aluminum foil storage packaging which has low permeability is shown to help maximize the role of seed coating. According to (Marsvia *et al*. (2020) aluminum foil packaging has the ability to be water vapor and gas impermeable so it protects the influence from outside the package. In addition, aluminum foil packaging has the ability to withstand moisture therefore it can protect the physical and physiological quality of seeds (Baributsa & Baoua, 2022; Silva *et al*., 2018).

3.2. Effect of Coating Materials on Soybean Seed Viability and Vigor

Table 3 showed the recapitulation of the effect of seed coating materials on the viability and vigor of soybean seeds. Germination capacity, soybean seeds in the treatment without seed coating (M_1) in the third month showed the highest seed germination compared to other seed coating treatments of 26.2% which was not significantly different from the seed coating treatment using mangosteen peel extract (M_4) of 23.8%, but significantly different from the seed coating treatment using ascorbic acid (M_2) and tocopherol (M_3). This was thought to be due to the coating of the seeds using liquid ingredients that damages the biochemistry of the soybean seeds. According to (Nile *et al*. (2022), when water/moisture absorbed by the seed causes the protein in the mitochondrial membrane to break down and decrease. Damage to mitochondrial membrane proteins will inhibit and disrupt the process of energy conversion (Ratajczak *et al*., 2019). In another study, it was reported that soaking corn seeds in water increased exudate content such as amino acids, fats and sugars. The exudate formed causes a reduction in metabolic energy activity and the ability to maintain cellular integrity (Tatipata, 2008).

This was consistent with the low yield of maximum growth potential. Soybean seeds in the treatment without seed coating (M_1) in the third month showed the highest maximum growth potential compared to other seed coating treatments of 40.44%. Deterioration occurs when giving liquid seed coating treatment therefore the ability of the seeds to grow is reduced. The high fat content formed can accelerate seed deterioration (Tatipata, 2008). Research by Raghavendra *et al* (2002) informed that lipase activity in rice seeds would cause the release of free fatty acids from triglycerides. Free radicals that are produced in seeds cause a lot of damage to seed cell membranes (Utami, 2013).

Table 3. Recapitulation of the effect of seed coating materials on the viability and vigor of soybean seeds

Treatment	Germination Power (%)	Maximum Growth Potential (%)	Vigor Index (%)	Simultaneous Growth (%)	Growth Rate (KN/Etmal)
M_1	26.2^{a}	40.44	18.3	24.1^{a}	6.8^{a}
M_2	17.6^{c}	31.44	13	16^{c}	4.4^{b}
M_3	21.33^{bc}	31.44	17	19^{bc}	5.9^{ab}
M_4	23.89^{ab}	36	19.2	20.8^{ab}	6.6a

Description: Numbers followed by the same letters are not significantly different in DNMRT test at the 5% level

A decrease in seed viability will lead to a decrease in soybean seed vigor which can be seen in the vigor index, the simultaneity of growth and the growth speed of soybean seeds. Leakage of cell membranes due to seed deterioration causes a rapid decline in vigor (Umar, 2012). This is due to damage to the cell membrane which disrupts the activity of membrane constituents such as phospholipids and proteins (Tatipata, 2008). Phospholipid activity causes a decrease in membrane integrity which causes inhibition of the enzyme system and respiratory enzymes. Decreased respiration causes the energy produced by the synthesis of new compounds and germination to decrease (Tatipata, 2010).

In the simultaneous growth treatment without using seed coating (M_1) in the third month showed the highest growth simultaneity of 24.1% which was not significantly different from the seed coating treatment using mangosteen peel extract (M_4) of 20.8% but different significantly with seed coating treatment using ascorbic acid (M_2) and tocopherol (M_3). And at growth rate, soybean seeds treated without seed coating (M_1) in the third month showed the highest growth synchrony of 6.8 KN/Etmal which was not significantly different from seed coating treatment using mangosteen peel extract (M_4) and tocopherol (M_3). Seed growth vigor continues to decrease due to decreased seed viability (Ramadhani *et al*., 2018).

3.3. Effect of Storage Packaging on Soybean Seed Viability and Vigor

Table 4 showed the recapitulation of the effect of storage packaging on the viability and vigor of soybean seeds. Germination capacity, soybean seeds in the aluminum foil storage packaging (N_1) treatment in the third month showed the highest seed germination rate of 24.9% compared to other storage packaging treatments. This was thought to be due to all the packaging not being able to suppress enzyme activity and respiration rate during the storage process. Research conducted by Purwanti (2004) showed that soybean seeds stored in plastic bags with a moisture content of 9% for 2 months at 27-29°C had a germination percentage of 41% compared to the previous 80%. Meanwhile, in this study, soybean seeds were stored with an average daily temperature range of 28.7°C which caused a decrease in the average percentage of germination in the third month reaching 45.2%. The higher the temperature of the storage room, the faster the rate of seed decline so the seeds have low germination (Nurisma *et al*., 2017).

Table 4. Recapitulation of the effect of storage packaging on the viability and vigor of soybean seeds

Treatment	Germination Power (%)	Maximum Growth Potential (%)	Vigor Index (%)	Simultaneous Growth (%)	Growth Rate (KN/Etmal)
N_1	24.9	39.4^{a}	18.2	22.4	6.7
N_2	21	30.1^{b}	16.9	18.8	5.6
N_3	20.9	34.9^{ab}	15.5	18.7	5.5

Description: Numbers followed by the same letters are not significantly different in DNMRT test at the 5% level

At the maximum growth potential, soybean seeds in the aluminum foil storage packaging (N_1) treatment in the third month showed the highest maximum seed growth potential of 39.4% which was not significantly different from the plastic sack packaging (N_3) treatment but significantly different treated with polyethylene (N_2) plastic packaging. An increase in seed moisture content will lead to an increase in respiration rate and stimulate enzyme activity in the embryo resulting in a rapid overhaul of food reserves in the seed resulting in local starvation of the embryo (Sucahyono, 2013). Soybean seeds experience a loss of food reserves which causes a lack of energy for the germination process making it difficult to germinate.

The use of different storage containers had no significant effect on the seed vigor index (VI) variable. Soybean seed vigor index in the aluminum foil storage packaging (N_1) treatment in the third month showed the highest seed vigor index compared to other storage packaging treatments of 18.2%. Packaging that has high permeability will cause seed respiration to be more active because oxygen in the package is always available (Justice & Louis, 2019). In addition, the longer the seeds are stored, the lower the vigor, which can also be seen in the simultaneity of growth and the speed at which the seeds grow. In the third month, the simultaneous growth of soybean seeds in aluminum foil (N_1) storage containers showed the highest value compared to treatments stored in other types of packaging, namely 22.4%. Seeds that have high vigor because they have high food reserves therefore they can simultaneously assist the germination process in optimum and suboptimal environments (Febriyanti & Surahman, 2015). Food reserves in seeds have been reduced due to increased water content which increases the rate of respiration and enzyme stimulation. Study conducted by (Ramadhani *et al*. (2018) showed no significant different results on the simultaneity variable of growing soybean seeds which were stored in different packages every month until the sixth month. In terms of growth rate, soybean seeds in the aluminum foil storage packaging (N_1) treatment showed the highest seed growth synchrony compared to other storage packaging treatments of 6.7 KN/Etmal. The decrease in the vigor and strength of growth has decreased in a positive correlation with a decrease in seed viability (Ramadhani *et al*., 2018). In addition, the suboptimal conditions during the germination process in the field added to the weakness of the seeds (Waterworth *et al*., 2019).

4. Conclusions

There was an interaction between seed coating and storage packaging on seed moisture content and the best treatment was seed coating using ascorbic acid and aluminum foil (M_2N_1) storage packaging. The seed coating treatment had a significant effect on germination, growth simultaneity, and growth speed therefore the best treatment was without using seed coating (M_1). The storage packaging treatment had a significant effect on the variable moisture content of the seeds and the maximum growth potential so the best treatment was aluminum foil (N_1) storage packaging.

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References

Alamsyah, A. N., Slamet, W., & Kusmiyati, F. (2017). Efektivitas pelapisan benih kelengkeng (Dimocarpus longan Lour.) menggunakan kombinasi jenis bahan pelapis dengan ekstrak biji selasih dan wadah simpan berbeda. *Journal of Agro Complex*, 1(3), 85. https://doi.org/10.14710/joac.1.3.85-93

Baharudin, Ilyas, S., Suhartanto, M. R., & Purwantara, A. (2010). Pengaruh Lama Penyimpanan dan Perlakuan Benih Terhadap Peningkatan Vigor Benih Kakao Hibrida. *Jurnal Pengkajian Dan Pengembangan Teknologi Pertanian*, 13(1), 73–84. https://doi.org/http://dx.doi.org/10.21082/jpptp.v13n1.2010.p%25p

Baributsa, D., & Baoua, I. B. (2022). Hermetic bags maintain soybean seed quality under high relative humidity environments. *Journal of Stored Products Research*, 96, 101952. https://doi.org/10.1016/j.jspr.2022.101952

Bewley, J. D., Bradford, K. J., Hilhorst, H. W. M., & Nonogaki, H. (2013). *Seed: Physiology of Development, Germination and Dormancy, 3rd Edition* (3rd ed.). Springer.

Dauqan. (2013). Utilization of Gum Arabic For Industries and Human Health. *American Journal of Applied Sciences*, 10(10), 1270–1279. https://doi.org/10.3844/ajassp.2013.1270.1279

El-Maarouf-Bouteau, H. (2022). The Seed and the Metabolism Regulation. *Biology*, 11(2), 168. https://doi.org/10.3390/biology11020168

Fachruri, M., Muhidong, J., & Sapsal, M. T. (2019). Analisis Pengaruh Suhu dan Kelembaban Ruang terhadap Kadar Air Benih Padi di Gudang Penyimpanan PT. Sang Hyang Seri. *Jurnal Agritechno*, 131–137. https://doi.org/10.20956/at.v0i0.221

Febriyanti, F., & Surahman, M. (2015). Viabilitas Benih Koro (Canavalia ensiformis (L.) DC.) yang Disimpan pada Beberapa Jenis Kemasan dan Periode Simpan. *Buletin Agrohorti*, 3(1), 119–126. https://doi.org/10.29244/agrob.v3i1.15437

Ikrarwati, I., Ilyas, S., & Yukti, A. M. (2015). Keefektifan Pelapisan Benih terhadap Peningkatan Mutu Benih Padi Selama Penyimpanan. *Jurnal Penelitian Pertanian Tanaman Pangan*, 34(2), 145. https://doi.org/10.21082/jpptp.v34n2.2015.p145-152

Jones, K. L., Hu, B., Li, W., Fang, Y., & Yang, J. (2022). Investigation of rheological behaviors of aqueous gum Arabic in the presence of crystalline nanocellulose. *Carbohydrate Polymer Technologies and Applications*, 4, 100243. https://doi.org/10.1016/j.carpta.2022.100243

Justice, O. L., & Louis, N. B. (2019). *Principles and Practices of Seed Storage*. Scientific Publishers.

Kumalaningsih, S., & Suprayogi. (2006). *Tamarillo (Terung Belanda) Tanaman Berkhasiat Penyedia Antioksidan Alami*. Trubus Angrisarana.

Ling, J. K. U., Sam, J. H., Jeevanandam, J., Chan, Y. S., & Nandong, J. (2022). Thermal Degradation of Antioxidant Compounds: Effects of Parameters, Thermal Degradation Kinetics, and Formulation Strategies. In *Food and Bioprocess Technology*, 15(9), 1919–1935. Springer. https://doi.org/10.1007/s11947-022-02797-1

Manzoor, S., Gull, A., Wani, S. M., Ganaie, T. A., Masoodi, F. A., Bashir, K., Malik, A. R., & Dar, B. N. (2021). Improving the shelf life of fresh cut kiwi using nanoemulsion coatings with antioxidant and antimicrobial agents. *Food Bioscience*, 41, 101015. https://doi.org/10.1016/j.fbio.2021.101015

Marsvia, S. A., Liviawaty, E., Rochima, E., & Afrianto, E. (2020). Shelf Life of Nori from Eucheuma cottonii with Aluminum Foil Packaging Based on the Accelerated Shelf Life Test Method. *Asian Journal of Fisheries and Aquatic Research*, 10(3), 7–15. https://doi.org/10.9734/ajfar/2020/v10i330182

Mastromatteo, M., Mastromatteo, M., Conte, A., & Del Nobile, M. A. (2011). Combined effect of active coating and MAP to prolong the shelf life of minimally processed kiwifruit (Actinidia deliciosa cv. Hayward). *Food Research International*, 44(5), 1224–1230. https://doi.org/10.1016/j.foodres.2010.11.002

Ministry of Agriculture of the Republic of Indonesia. (2018). *National Soybean Production 2014-*

2018. https://www.pertanian.go.id/home/?show=page&act=view&id=61.

Nile, S. H., Thiruvengadam, M., Wang, Y., Samynathan, R., Shariati, M. A., Rebezov, M., Nile, A., Sun, M., Venkidasamy, B., Xiao, J., & Kai, G. (2022). Nano-priming as emerging seed priming technology for sustainable agriculture—recent developments and future perspectives. *Journal of Nanobiotechnology*, 20(1), 254. https://doi.org/10.1186/s12951-022-01423-8

Nurisma, I., Agustiansyah, A., & Kamal, M. (2017). Pengaruh Jenis Kemasan dan Suhu Ruang Simpan terhadap Viabilitas Benih Sorgum (*Sorghum bicolor* [L.] Moench). *Jurnal Penelitian Pertanian Terapan*, 15(3), 183–190. https://doi.org/10.25181/jppt.v15i3.128

Purwanti, M. D. (2015). Efektifitas Kemasan dan Suhu Ruang Simpan terhadap Daya Simpan Benih Kedelai (Glycine max (L.) Meirril). *Planta Tropika: Journal of Agro Science*, *3*(1), 1–7. https://doi.org/10.18196/pt.2015.033.1-7

Purwanti, S. (2004). Kajian suhu ruang simpan terhadap kualitas benih kedelai hitam dan kedelai kuning. *Ilmu Pertanian*, 11(1), 22–31. https://doi.org/10.22146/ipas.58601.

Rahmawati, Suwarti, & Aqil, M. (2019). Maize seed quality evaluation at the temperature room storage. *Agrivita*, 41(3), 482–490. https://agrivita.ub.ac.id/index.php/agrivita/article/view/1269.

Ramadhani, F., Surahman, M., & Ernawati, A. (2018). Pengaruh Jenis Kemasan terhadap Daya Simpan Benih Kedelai (*Glycine max* (L.) Merrill) Varietas Anjasmoro. *Buletin Agrohorti*, 6(1), 21. https://doi.org/10.29244/agrob.6.1.21-31

Ratajczak, E., Małecka, A., Ciereszko, I., & Staszak, A. M. (2019). Mitochondria Are Important Determinants of the Aging of Seeds. *International Journal of Molecular Sciences*, 20(7), 1568. https://doi.org/10.3390/ijms20071568

Sayuti, K., & Yenrina, R. (2015). *Antioksidan Alami dan Sintetik*. Andalas University Press.

Silva, R. D. S., Alves, E. U., da Silva, C. F. R., Araújo, L. R., & Rodrigues, C. M. (2018). Physiological quality of seeds of enterolobium contortisiliquum (Vell.) morong. stored. *Bioscience Journal*, 34(6), 1603–1610. https://doi.org/10.14393/bj-v34n6a2018-39609

Sucahyono, D. (2013). Teknologi penyimpanan dan invigorasi benih kedelai. *Balai Penelitian Tanaman Aneka Kacang Dan Umbi*, 185–194. http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2018/03/bunga_rampai_2017_12_sucahyono.pdf.

Tatipata, A. (2008). Pengaruh Kadar Air Awal, Kemasan dan Lama Simpan terhadap Protein Membran Dalam Mitokondria Benih Kedelai. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy)*, *36*(1), 8–16. https://journal.ipb.ac.id/index.php/jurnalagronomi/article/view/1339.

Tatipata, A. (2010). Perubahan Asam Lemak Selama Penyimpanan Benih Kedelai (*Glycine max* L. Merr) dan Hubungannya dengan Viabilitas Benih. *J. Agron. Indonesia*, 38(1), 30–35. https://journal.ipb.ac.id/index.php/jurnalagronomi/article/view/18229

Umar, S. (2012). Effect of Organic Matter Application on Storage Period of Soybean {*Glycine max* (L .) Merr.} Seed. *Berita Biologi*, 11(3), 401–410. https://e-journal.biologi.lipi.go.id/index.php/berita_biologi/article/view/510.

Utami, S. (2013). Uji Viabilitas dan Vigoritas Benih Padi Lokal Ramos Adaptif Deli Serdang dengan Berbagai Tingkat Dosis Irradiasi Sinar Gamma di Persemaian. *AGRIUM: Jurnal Ilmu Pertanian*, 18(2), 158–161. http://jurnal.umsu.ac.id/index.php/agrium/article/view/358

Waterworth, W. M., Bray, C. M., & West, C. E. (2019). Seeds and the Art of Genome Maintenance. *Frontiers in Plant Science*, 10. https://doi.org/10.3389/fpls.2019.00706

Zhang, K., Khan, Z., Yu, Q., Qu, Z., Liu, J., Luo, T., Zhu, K., Bi, J., Hu, L., & Luo, L. (2022). Biochar Coating Is a Sustainable and Economical Approach to Promote Seed Coating Technology, Seed Germination, Plant Performance, and Soil Health. *Plants*, 11(21), 2864. https://doi.org/10.3390/plants11212864