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Effect of harvest age and storage duration on viability and vigor of shallot (*Allium cepa* L.) tubers

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ABSTRACT

Shallot is one of the tuber crops used in human life worldwide. Lembah Palu variety of shallot (LPVS) is the best raw material for the fried shallot industry. The main problem is that tubers have no standard harvest age and storage duration to support these plants' germination and early growth. Therefore, shallots' growth and productivity are influenced by tubers' viability and vigor. This study aimed to investigate the harvest age and storage duration to give the best viability and vigor of shallot tubers. This research was arranged in a randomized complete block design (RCBD) factorial and three replications. The first factor was the harvest age of shallots, which consisted of four levels: 60, 65, 70, and 75 days after planting (DAP). The second factor was the storage duration of tubers, which consisted of four levels: 30, 40, 50, and 60 days after harvest (DAH). The harvesting age of 60-65 DAP significantly affected the parameter of germination power, tuber weight loss, and seedling dry weight. Likewise, the storage duration significantly affected the parameter of germination time, germination rate, tuber weight loss, and seedling dry weight. These research findings show that the harvest age of 60-65 DAP and the storage duration of 30 DAH give the best viability and vigor of shallot tuber. Therefore, we suggest that it is necessary to pay attention to tubers' harvest age and storage duration to find their maximal growth and yield of shallots.

Key words : Germination, shallot, tuber, viability, vigor

INTRODUCTION

Shallot (*Allium cepa* L.) is generally one of the oldest tuber crops used in human life worldwide. The Lembah Palu variety of shallots (LPVS) only exists in the Central Sulawesi Province of Indonesia and has been developed by farming communities for 30 years ago. LPVS tubers are well-known as the main raw material of the highest quality for the fried shallot industry.

LPVS generally can only be developed in lowlands < 400 m above sea level (ASL). In the Palu Valley area of Central Sulawesi Province, Indonesia. LPVS can grow up to 800 m ASL; if the microenvironment was modified, using a plastic hood and mulch to increase the growth and yields were not significantly different at 100 and 400 m ASL (Pasigai *et al*., 2016).

Fried shallots produced from LPVS raw materials are one of the leading horticultural products that have the opportunity to become an export commodity. Market demand for fried shallot products is quite high but has not yet been fulfilled due to limited raw materials for LPVS (Bahrudin *et al*., 2019). The productivity of LPVS is still very low, only 3.5-4.5 tons/ha, while its productivity can reach 9.7 tons/ha (Anonymous, 2011).

One of the problems in increasing LPVS production is using tubers for seedlings that do not yet have a standard harvest age and storage duration for tubers before planting to obtain high tuber viability and vigor. Seed vigor is important because several factors can influence it: genetic composition, environmental conditions during production, parent plant nutrition, ripening and harvesting stages, seed size and mass, seed age, mechanical integrity, and environmental conditions during storage (Ignácio *et al*., 2015).

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Tubers play an important role as an early determinant of plant growth and development and an important factor in increasing crop yields. Saving tubers is an important crop production process to avoid unfavorable environmental conditions and accelerated damage, which starts after harvesting. Storage conditions play an important role in maintaining high seed quality, which is directly related to environmental conditions (especially temperature and relative humidity) (Suriyong *et al.*, 2015).

Seed size is an important physical indicator of seed quality that influences vegetative growth and is often linked to yields, market quality factors, and crop efficiency (Ambika *et al.*, 2014). Seed damage was associated with genotype, seed history, and physiological and chemical composition (Copeland and McDonald, 1999). The shelf life of shallot bulbs is a genetic trait that can be improved by efficient harvesting, post-harvest management, and good tuber storage conditions. The storage quality of shallot bulbs can be influenced by several factors, such as thiosulfonic acid, pyruvic acid, dissolved solids, sugars, and many other biological compounds (Sekara *et al.*, 2017). The power of seeds plays a role in producing agronomic and horticultural crops (Khan *et al.*, 2017). The use of high-quality seeds is one of the essential elements for increasing agricultural production in any agricultural system (Elias, 2018).

Seed viability and viability can predict seed performance under various environmental conditions and strategies to increase seed viability to allow normal growth. However, the sensitivity of seeds to high temperatures depends on the moisture content; the high of water content, the lower the viability (Suriyong *et al.*, 2015). The high physiological potential of seeds with rapid and uniform germination is a fundamental requirement for forming a good plant, especially in adverse environmental conditions. Windauer *et al.* (2012) showed that germination was influenced by temperature and high sensitivity to water deficiency.

Shallots are slow-growing, shallow-rooted plants with no shade habitus. Therefore, their productivity highly depends on water availability in the soil, proper fertilization, and weed control. Storage of shallot nutrient requirements is highest during vegetative growth (Sekara *et al.*, 2017). During the transition from endo-dormancy to ecto dormancy and subsequent growth, shallot bulbs transition from storage to source organs to maintain cell division in meristematic tissue. The biochemical and physiological components were analyzed by identifying the ratio of monosaccharides (fructose and glucose) to disaccharides (sucrose) and the concentration of zeatin riboside to differentiate between germinated and non-germinated tubers. However, this has not been widely used (Chope *et al.*, 2012).

The growth and productivity of shallots are influenced by the viability and strength of the tubers. These characteristic changes are most likely related to the respiration and remobilization of carbohydrates to provide energy for growth. As a result, the tuber receives all the nutrients needed for sprout growth (Chope *et al.*, 2012). Harvest age and storage time determine tuber viability and strength before planting. However, the exact age of harvest and storage of tubers is unknown before planting to obtain higher growth and productivity of shallots. The germination of shallot tubers is strongly influenced by the age of harvest, storage time, and storage area of shallot bulbs. The speed of germination of shallots is determined by the size of the tubers, the content of carbohydrate reserves, and natural growth hormones (Priya *et al.*, 2014).

Handling tubers is different from handling them for consumption. Handling tubers starts from production, harvesting, processing, drying, cleaning, packaging, and storage. One postharvest action of shallots is drying to remove excess moisture from the harvested shallot bulb tissue's outer skin, roots, and neck. It aimed to improve and maintain the quality and reduce the possibility of infection by organisms that cause tuber disease in the warehouse. Tubers production were an agronomic study considering genetic, environmental, and technological aspects of land agroecosystem conditions. Therefore, it is important to focus on vigor and viability to produce shallot tubers.

Vigor is the ability of tubers to grow and develop into ordinary in optimal growth conditions or powerful that produce above-normal products if planted in optimal health conditions. It was further argued that two pieces of information about viability reflect tubers vigors, such as growth strength and storage capacity. tubers viability are determined by pre-harvest conditions, including soil fertility, method and age of harvest, and post-harvest, including drying, seed care, packaging and storage. Ideally all seeds should have high growth strength so that if planted in various field conditions they will still grow healthy and strong and produce high quality with good quality. This study aimed to investigate the harvest age and storage duration to give the best viability and vigor of shallot tubers.

MATERIALS AND METHODS

Study Site

The research was conducted in April-September 2017. Observation of the harvest age of LPVS tubers was carried out on farmers' land in Bulupontou Jaya Village, Sigi-Biromaru District, Sigi Regency, Central Sulawesi Province, Indonesia. Central Sulawesi located between 2°22 North Latitude and 3°48 South Latitude and between 119°22' and 124°22 East Longitude. The study was conducted on dry land at 120 m above sea level (ASL). The average daily temperature is 29-30 °C and the humidity was 60-65%. The storage place for tubers was at the Central Sulawesi Horticultural Seed Center (CSSCH) in Sidera Village, Sigi-Biromaru District, Sigi Regency. The storage time for tubers was carried out in the storage room of shallots at 100 m ASL; the average temperature of the daily storage room was between 28 - 29 °C, and humidity ranged from 60-70%.

Experimental Design

This research was arranged in RCBD factorial and three replications. The first factor was the harvest age of shallots, which consisted of four levels: 60, 65, 70, and 75 DAP. The second factor was the storage duration of the tubers, which consisted of four levels: 30, 40, 50, and 60 DAH. The effect of harvesting age was carried out by harvesting LPVS tubers from the experimental field in stages according to the predetermined harvest age treatment and followed by the treatment of the storage duration of tubers in a special room for storing shallot bulbs at the CSSCH location. The length of time to store the tubers is adjusted to each predetermined treatment.

Research Procedures

Each experimental plot was given organic fertilizer (bokashi from goat manure) at a dose of 15 tons/ha. The organic fertilizer was evenly mixed on the top of the bed. The experimental plot was 1.05 m (width) × 2.55 m (length) × 0.25 m (height). The distance between treatment beds was 50 cm, while between replicates was 75 cm. Plant spacing was 15 cm × 15 cm. Each hole was planted with one shallot bulb sterilized with a fungicide solution (Dithane M-45), a concentration of 0.02%.

Plant maintenance included providing irrigation water every three days and using a pinwheel (sprinkles) for 1-1.5 hours or until it reaches field capacity. Inorganic fertilizers were given after planting. The first fertilizer was applied at the age of 7 DAP, 100 kg/ha N, 100 kg/ha ZA, 150 kg/ha P, and 100 kg/ha K. At 30 DAP, additional fertilizer was given, 100 kg N/ha. Fertilizer application through a hole of about 5-7 cm on the side of the plant with a depth of 7-10 cm. Pest and disease control used insecticides and fungicides to spray on plants if there were symptoms of the attack. In addition, physical pest control was also carried out by killing pests, especially leaf worms that attack shallots.

Parameters

The observation parameters of this experiment were germination power (GP), germination time (GT), germination rate (GR), tuber weight loss (TW), and seedling dry weight can be seen in Eq. 1, 2, 3 and 4.

$$GP\,(\%) = \frac{\text{the number of seeds germinated}}{\text{the number of seeds germinated}} \times 100\% \quad (1)$$

$$GT = \frac{N_1T_1 + N_2T_2 + \ldots + NnTn}{\text{the number of seeds germinated}} \times 100\% \quad (2)$$

$$GR = \frac{\%\ NS_1}{etmal_1} + \frac{\%\ NS_2}{etmal_2} + \ldots + \frac{\%\ NSn}{etmal_n} \quad (3)$$

$$TW (\%) = \frac{\text{Weights before storage}}{\text{Weight after storage}} \times 100\% \quad (4)$$

The seedling dry weight (g) biomass was dried in an oven at a temperature of 70-80 °C for 24 hours or until its weight was constant. N = Number of seeds germinated; T = Time (days); NS = Normal Sprouts.

Statistical Analysis

The observed data were analyzed using analysis of variance (ANOVA) (Gomez and Gomez, 1984). The treatment with a significantly different response was followed by Duncan's new multiple range tests (DMRT) at 5% significant level.

RESULTS AND DISCUSSION

The treatment of harvest age significantly affected germination power, tuber weight loss, and seedlings dry weight of LPVS, but not significantly on germination time and rate. The DMRT at 5% significant level on germination power, tuber weight loss, and seedlings dry weight can be seen in Table 1.

Germination Power

The results showed that the harvest age significantly affected the germination of LPVS tubers. Harvest age 60-65 DAP resulted in higher germination and significantly differed from the harvest age of 75 DAp (Table 1). This was because the tubers that were slow to harvest had passed physiological maturity. High-quality seeds were inseparable from high viability and vigor. Therefore, one seed viability and vigor determinant was the right harvest time to reach physiological maturity (Surtinng *et al.*, 2015). This condition allowed for rapid and uniform seed germination and better seed formation and development (Cardoso *et al.*, 2015). Differently treated seeds become an effective technique to improve seedling growth and survival percentage compared to conventional seed germination (Kamlesh *et al.*, 2022).

Table 1. The effect of harvest age on germination power, tuber weight loss, and seedlings dry weight.

Harvest age (DAP)	Germination power (%)	Tuber weight loss (%)	Seedling dry weight
60	100.00a	14.00a	3.02a
65	99.17a	13.70a	2.82ab
70	97.50ab	7.85b	2.15ab
75	94.17b	5.60c	2.02b

Note : The average number followed by the same letter in the same column shows no significant difference based on the DMRT at 5% significance level.

Tuber Weight Loss

The analysis results showed that the tubers' harvest age and storage time had a major impact on the reduction in tuber weight during storage. Tuber harvesting age of 60-65 DAP resulted in higher tuber weight loss values, namely 14.00% and 13.70%, respectively, significantly different from the 70 and 75 DAP harvest ages. Furthermore, the smallest tuber weight reduction was obtained at the harvest age of 75 DAP (5.60%) (Table 1).

Seedlings Dry Weight

The analysis showed that the harvesting age and tuber storage time significantly differed from the dry weight of LPVS seedlings. Harvest age 60 DAP produced higher seedling dry weight (3.02 g/plant), significantly different from the harvest age of 75 DAP. Still, it was not significantly different from the harvest age of 65 and 70 DAP (Table 1). It shows that the longer the tuber harvest age will reduce the initial growth of shallot seeds. The dry matter content increased during the period of tuber development. Tubers harvested at 70 DAP will lose most of their leaves because they have withered and died. Harvesting more than 80-90% wilted leaves reduced tuber dry matter content and storage capacity.

The results of the quadratic regression analysis showed that the effect of harvesting age on germination was obtained through the equation: y = -0.0195 x2 + 2.0115 x - 36.03 and the reduction in tuber weight with the equation: y = -0.0066 x2 + 0.8834 x - 23.462. Therefore, based on quadratic regression can be represented in Fig. 1.

Fig. 1 shows that tuber harvesting age affected germination time and weight loss value. After 65 DAS, the harvest age caused the tuber shrinkage value to decrease, and the lowest occurred at the harvest age of 75 DAS. On the other hand, the longer the harvesting age tended to increase the germination time of shallot bulbs, but the increase was relatively small or not significantly different. The reduction in tuber weight at harvest age after 65 DAS from (13.7%) to the lowest at 75 DAS (5.6%) was caused by the enlargement and filling of the tubers with maximum photosynthetic carbohydrates so that the tubers were denser and had a slight decrease in tuber weight. There were many changes in physiological and biochemical characteristics during the storage of shallot bulbs, including moisture content and concentrations of flavoring compounds, carbohydrates, minerals, and growth regulators (Chope *et al.*, 2012).

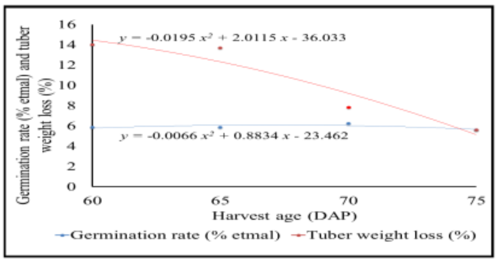

Fig. 1. Effect of harvest age on germination time and the tuber weight loss.

The treatment of storage duration significantly affected germination time, germination rate, tuber weight loss, and seedlings dry weight of LPVS, but not significantly on germination power. The DMRT at 5% significant level on germination time, germination rate, tuber weight loss, and seedlings dry weight can be seen in Table 2.

Germination Time

The results showed that the treatment of tuber storage time significantly affected the germination time of LPVS tubers. The 60 DAH storage time resulted in a faster germination time (3.97 days), significantly different from the storage time of 30, 40, and 50 DAH. Tubers stored for 30-40 days required longer germination time, namely 7.10 and 7.85 days, respectively (Table 2).

Germination Rate

The analysis showed that the storage duration for LPVS tubers significantly affected the germination rate. For example, the storage duration for tubers of 60 DAH resulted in the highest germination rate (26.57%/etmal) and significantly differed from the storage duration for 30, 40, and 50 DAH tubers. On the other hand, storage duration of 30-40 DAH resulted in the lowest germination rates of 15.73 and 13.88%/etmal, respectively (Table 2). These results were supported by Grohs *et al.* (2017), stating that environmental conditions greatly determine the storage capacity of seeds during the production process to store seeds.

The storability of seeds was a quantitative trait influenced by environmental factors during seed formation, harvesting, and storage. Sekara *et al.* (2017) stated that the process of seed maturity included morphological and physiological changes that occur from the beginning of planting until the seeds mature into seeds ready for harvest. During the seed ripening process, certain changes occur in the characteristics of the seeds and ovules, including changes in seed size, moisture content, dry weight, and seed vigor. Chemical energy is synthesized during photosynthesis when carbohydrates, lipids, and proteins accumulate in the seeds, providing carbohydrate reserves for germination. The strength of shallot seeds was

Table 2. The effect of storage duration on germination time, germination rate, tuber weight loss, and seedling dry weight.

Bulb storage duration (DAH)	Germination time (days)	Germination rate (%/etmal)	Tuber weight loss (%)	Seedling dry weight (g/plant)
30	7.10a	15.73c	6.60d	3.14a
40	7.85a	13.88c	9.60c	2.77ab
50	5.19b	20.23b	11.40b	2.21ab
60	3.97c	26.57a	13.55a	1.89b

Note : The average number followed by the same letter in the same column shows no significant difference based on the DMRT at 5% significance level.

also greatly influenced by the dormancy period and the tuber storage length. Kapoor *et al.* (2011) stated that there was an increase in gibberellin, auxins, cytokinins, and abscisic acid at the end of tuber dormancy.

Tuber Weight Loss

Water loss leads to an increase in tuber weight during the storage process. In addition, the length of storage for tubers significantly affected the reduction in tuber weight during storage. The storage time for tubers was up to 60 DAP, resulting in the highest reduction in tuber weight (13.55%) and was significantly different from the storage time for tubers of 30, 40, and 50 DAP (Table 2).

Seedlings Dry Weight

Furthermore, the storage duration of 30 DAH tubers resulted in higher seedling dry weight (3.14 g/plant) and significantly differed from the storage duration of 60 DAH 1.89 g/plant. However, it was not significantly different from the storage duration for tubers of 40 and 50 DAH (Table 2). These results also indicated that the longer the storage duration would reduce the initial growth of shallot seeds. Germination and initial growth of plants were influenced by environmental factors as well as carbohydrate content, dry weight, and growth hormones in the tubers. Tuber moisture and carbohydrate content were in ideal conditions to support faster germination with higher dry weight growth. The high dry weight of the seeds indicated that the vigor and viability of the seeds were increasing.

Shallot tubers with high dry weight were more suitable for long-term storage and tended to contain higher fructan concentrations (Chope *et al.*, 2012). However, low seed vigor causes low seed emergence, especially in less-than-ideal soil conditions. Therefore, seeds should be stored in a conducive environment (optimal temperature) so that seed quality remains high until the end of storage. Germination can be increased by adjusting the substrate for higher surface contact and the presence of light and temperature between 25-35 °C (Cardoso *et al.*, 2015).

The result of the quadratic regression analysis showed that the effect of storage duration on germination time was obtained equation: $y = -0.0085x^2 + 1.6005x - 58.752$ and on tuber weight loss with equation: $y = -0.0197x^2 + 2.4185x - 66.848$. Based on quadratic regression can be represented in Fig. 2.

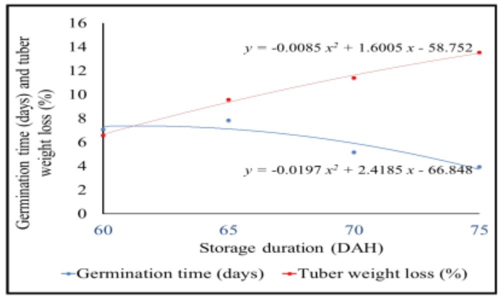

Fig. 2. The effect of storage duration on germination time and tuber weight loss.

Fig. 2 shows that the storage time for tubers will affect the germination time and the reduction in tuber weight. The length of time it takes for shallot bulbs to germinate was shorter (3.97 days) at 60 DAH. On the other hand, the reduction in tuber weight increased with a longer tuber storage duration (13.55%) at 60 DAH. The increase in tuber weight loss during the longer storage time of the tubers was caused by the ongoing process of tuber respiration, which caused changes in the carbohydrate reserves found in shallot tubers. The results were consistent with the statement of Eshel *et al.* (2014) that the tubers storage for a long time, the tubers began to sprout, the roots began to form, and the weight of the tubers decreased. The results of the analysis showed that there was no significant interaction between harvesting age and storage duration on the vigor and viability of LPVS tubers. Harvesting the tubers at the right level of maturity (physiological maturity) was very important to get a high level of tuber quality. The right time to store the tubers will also result in high vigor and viability. Seeds that have high viability and vigor are shown to have the ability to grow above 80%. The germination percentage increased linearly with the seed age (Ruiz and Parera, 2017).

CONCLUSION

Based on the analysis and discussion of the result, it can be concluded that the harvesting age of 60-65 DAP significantly affected the parameter of germination power, tuber weight loss, and seedling dry weight. Likewise, the storage duration significantly affected the parameter of germination time, germination rate, tuber weight loss, and seedling dry weight. These research findings that the harvest age of 60-65 DAP and the storage duration of 30 DAH give the best viability and vigor of shallot tuber. Therefore, we suggest that it is necessary to pay attention to tubers' harvest age and storage duration to find their maximal growth and yield of shallots.

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