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# Mechanism and Dormancy Persistence of Ground Cherry Seeds (*Physalis peruviana* L.) at Different Seed Maturity Stages

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## Abstract

Ground cherry (*Physalis peruviana*) seeds have a period of dormancy after ripening. A study was conducted to understand the mechanism of dormancy, the duration of persistence after ripening, and to determine the effective methods to break dormancy. The study was conducted in an experimental field at Ciwidey, West Java, Indonesia, and the Seed Testing Laboratory, Faculty of Agriculture, Department of Agronomy and Horticulture, IPB University, in February to November 2020. The first study examined the effects of the storage temperatures, i.e. 20 ±2 °C and 25 ± 2°C, and the seed maturity stages, i.e. 49 days after anthesis (DAA), 58 DAA and 62 DAA. Several methods to break seed dormancy were tested, i.e. soaking seeds for 24 hours in distilled water, in 0.5% or 1% $KNO_3$ and, 50 ppm $GA_3$. The results showed that the seed dormancy was broken at 7 weeks after treatment, indicated by seed germination of >80%. The ABA levels of the seeds declined from week 0 to week 11, and the seed ABA and GA reached a balance from week 7 to week 11. Seeds treated with $KNO_3$ or distilled water break dormancy after 8 weeks. The most effective treatment to break seed dormancy is the use of exogenous hormone $GA_3$ at 50 ppm, with seed germination of >80% at week 5.

Keywords: abscisic acid, dormancy release, gibberellin, storage temperature, viability, vigor

## Introduction

Ground cherry (*Physalis peruviana* L.) fruit and leaves contains vitamins, minerals, and antioxidants that act as antibacterial, anti-inflammatories, and antioxidants. According to Osho et al. (2010) the active compounds include lupeol-ursolic acid, triterpenoids, and phytosterol, which present on roots, twigs, leaves, and fruits (Brar, 2017). Breeding of ground cherry *Physalis peruviana* conducted by The Colombian Corporation of Agricultural Research (CORPOICA) has produced ground cherry varieties with good quality marketable fruits for consumption.

Ground cherry is propagated by seeds, and the seeds have low germination due to seed dormancy. The fresh seeds had a dormancy percentage of 85.22%; the dormancy is slowly released and after 12 month storage decreased to 12.5% (Ozaslan, 2017). Another study by Nunes (2018) reported 40-50% seed germination after 6 months, and 80% after 12 months of storage (Nunes, 2018). Low percentage germination from freshly harvested seeds is caused by the after ripening dormancy (Baskin, 2020).

Seed dormancy is defined as a condition in which seeds do not germinate even though there are ideal environmental conditions for germination. Seed dormancy is a common attribute in rice (Ilyas and Diarni, 2007) and it is difficult to predict the germination time of rice seeds. The term seed dormancy persistence is defined as the duration of storage (usually in weeks) required for seeds from the time of harvest until the percentage of germination reached at least 80%. Baskin (2014) describes one of the characteristics of dormancy after ripening, i.e. the dormancy will break by itself during dry storage without any treatment. Saputra et. al. (2020) reported that in two local Cayenne pepper varieties, seed dormancy broke naturally after 6 weeks of storage, whereas in other pepper varieties, e.g."Konsel 1" and "Konsel 2", it was 83.3% and 80%, respectively.

The duration of after ripening is affected by the levels of the endogenous hormones, particularly gibberellic

acid (GA) and abscisic acid (ABA). Kucera (2005) reported that dormancy after ripening occurs when the seed had high ABA content. Over time the ABA content decreases whereas GA content increases; the balance of ABA and GA in the seed determines the end of the after ripening period. A study by Yogeesha (2006) reported the levels of ABA in *Solanum melongena* seeds at 2 months after storage is 6 ppm, and decreased after 12 months of storage to 2.2 ppm.

After ripening is the period of dry storage to release dormancy and to promote germination. Several chemicals have been reported to shorten the period and to release dormancy effectively. $KNO_3$ solution has been reported to be effective in breaking dormancy after ripening of rice seeds. According to Hayati et al. (2005) 0.1% $KNO_3$ is effective in breaking dormancy of *Solanum torvum*, whereas Cutti (2016) reported by an increase in germination from 79% in control seeds to 89% with $KNO_3$ at 0.2%, and to 85% with $GA_3$ at 0.05 ppm.

The seed germination of freshly harvested ground cherry seeds is related to the abscisic acid content, where high ABA content correlates with the longer dormancy persistence (Farooq, 2021). Therefore, methods to break seed dormancy, and information on the duration of the dormancy in relation to the seed ABA and GA levels is very important. This research is aimed to study the persistence and dormancy mechanism of the ground cherry seeds, and to determine the most effective method to break seed dormancy.

## Material and Methods

*Time and Location*

The experiment was conducted from February to November 2020 at the Seed Science and Technology Laboratory, Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University. The ground cherry seeds were sourced from a grower in Rancabali Village, Ciwidey Regency, West Java, Indonesia, with an altitude of 1,100 m above sea level. Analysis of $GA_3$ and ABA content was carried out in the Laboratory of Residues of Agrochemicals, Bogor.

*Materials and Methods*

"Ciwidey" accession seeds were used in this study. The seeds were harvested and classified into three stages, i.e. stage 1 or fruit sheath stage at 49 DAA (days after anthesis), stage 2: 58 DAA, and stage 3: 62 DAA. The seeds were extracted by soaking the seeds in 2% HCl solution for one hour, then washed and dried until the moisture content reached 5%. The germination test was carried out using the top paper test method (ISTA 2018) using filtered paper in a seed germination box with dimensions of 17 cm x 5 cm. The experiment used 400 seeds and consists of 4 replications. Seeds are germinated at 25 °C and 80% RH. Observations and measurements were made on the germination capacity, vigor index, growth speed, dry weight of normal seedling. Testing of seed dormancy persistence was carried out by testing seed germination every week for 0 to 11 weeks. High Performance Liquid Chromatography (HPLC) was conducted to determine GA and ABA levels in the seeds.

*Experiment 1. Determination of Ground Cherry Seed Dormancy Persistence and Dormancy Mechanism*.

The mechanism of seed dormancy was studied by analyzing the GA and ABA content of ground cherry seeds. GA and ABA analysis was conducted every 2 weeks for 12 weeks using the method of Ljung et al. (2010). The experiment was arranged using a nested design with two factors, storage temperature and level of seed maturity. The storage temperature consists of 20 ± 2°C and 25 ± 2°C. The levels of seed maturity tested was 49 DAA, 52 DAA, and 62 DAA. All treatments were repeated four times. The seed dormancy is considered broken if the minimum germination is 80%.

*Experiment 2. Methods to Break Ground Cherry Seed Dormancy*

The experiment was arranged using a completely randomized design and organized in split-plot with two factors, the level of maturity, and dormancy breaking method. The first factor is the level of maturity that is (M) consisted of three levels: 49 DAA, 52 DAA, and 62 DAA. The second factor is dormancy breaking method using water, solution of 0.5% and 1% $KNO_3$, and 50 ppm $GA_3$. Seeds were soaked in this solution for 24 hours.

*Measurement and Data Analysis*

Seed viability was measured based on germination percentage, vigor index, growth rate (%/day), GA and ABA content. Data were analyzed using ANOVA at α = 5% using Statistical Analysis System (SAS) 9.4. Significant differences between means were further analyzed using Duncan Multiple Range Test at α=5%.

## Results and Discussion

*Experiment 1. Determination of Ground Cherry Seed Dormancy Persistence and Dormancy Mechanism*.

At the beginning of storage the ABA content of the seeds from all stages of maturity was higher than the GA3 content (Figure 1). The 62 DAA seeds have higher ABA content than 49 and 52 DAA seeds.

Hormone concentration and seed germination are related to the seed maturity stages and seed dormancy. The increase in seed germination was in line with the decrease in the seed ABA content. Seed dormancy is considered to be broken when germination percentage is at least 80%. Seeds harvested at 49 and 52 DAA broke dormancy at 8 weeks after storage, i.e. earlier than seeds harvested at 62 DAA at 10 weeks. At this time the seed ABA content has decreased to about 2 ppm, and the ABA content has become balanced with the $GA_3$ content.

Cembrowska-Lech (2016) reported the balance between ABA and GA is important for germination of Arabidopsis seeds. Seeds begin to germinate when there is a balance between seed ABA and seed GA content. *P. peruviana* seeds stored at seven weeks had low germination and high ABA concentrations at all maturity levels. The hormone content in ripe seeds is in the right balance, so that the seeds can germinate and achieve high germination. The seeds will remain dormant when the seed ABA content is still high. Xia (2019) describes dormancy release formation was due to a decrease in the content of ABA and an increase in the content of GA.

Yogeesha (2006) reported that *S. melongena* seed have high ABA content of 6 ppm at two months of seed storage. ABA concentration decreased after 12 months of storage to 2.2 ppm. López-Valdez (2020) reported pepper seeds that have reached physiological maturity showed the highest content of tryptophan, gibberellins, and kinetin. Gibberellins play important roles to weaken the endosperm and tryptophan which then results in stimulation of germination. Koprivova (2016) reported that $GA_3$ and IAA can suppress ABA and stimulate cell division, expansion, and cell elongation for initiation of germination. Yamaguchi (2008) states that germination initiation begins when imbibition, activated gibberellins, stimulates synthesis for enzyme production hydrolase as α-amylase or β-amylase. Neto (2017) reported that these enzymes can break down starch molecules in the endosperm into glucose and maltose, and transport them to the embryo to provide energy for germination.

The 49 DAA seeds stored at 25°C had low germination at 7 and 8 weeks, i.e. 70% and 80%, respectively. At the storage temperature treatment of 20°C 49 DAA seeds showed the lowest germination and slower dormancy release. The most effective treatment to release dormancy after ripening was shown at 25°C on 62 DAA seeds, i.e. 83% germination at week 7. At a temperature of 20°C the seed dormancy was broken at week 9 for seeds of all maturity levels (Table 1). At 25°C, the highest vigor index was on 62 DAA, i.e. 40.25%; the growth rate within the same week (week 7) was 5.177 %/day (Table 1).

The difference in the seed storage temperatures likely affects the internal metabolism of the seeds, as the ground cherry seeds stored at 25°C germinated a week earlier (week 7) than those stored at 20°C (week 8, Table 1). Wu (2018) reported that in *Physalis hederifolia* significantly increased germination up to 80% at 30°C. In Lopez-Valdes (2020) study, red chili seeds stored at 24°C germinated earlier, i.e. 54%, compared to seeds stored at 4°C, i.e. 36% after 9 month. In another study by Rodriguez et al. (2018), sunflower seeds stored at 25°C can germinate 30 days earlier than seeds stored at 12°C.

Seeds harvested at 62 DAA showed a higher germination rate of 83% compared to 49 DAA and 52 DAA; these results is in accordance with Diniz et. al (2019) who reported that ground cherry seeds with green maturity stage had the immature embryo, whereas the highest germination rate was shown by brown color seeds, which indicates a maturity stage. The internal and external environmental factors interact and regulate the process of seed development and seed maturity, which then impact dormancy and germination. For example, De Souza (2011) reported that the red chilies showed the highest germination and maximum dry weight when mature seeds were planted. Growth rate of seeds stored at 25°C were the highest in the 7$^{th}$ week, i.e. 5,177 %/day..

In general, dormancy persistence in ground cherry seed takes 8 weeks to release without any treatment. The most suitable maturity stages to be used as seed material is 62 DAA as the dormancy was released 7 days earlier than those from 58 DAA. The results of further germination tests on 58 DAA and 62 DAA seeds had no significant effects and the seeds had a longer shelf life. Therefore, selection of planting material for the seed procurement should select seeds from the yellow fruits.

*Experiment 2. Methods to Break Ground Cherry Seed Dormancy*

Table 2 showed the interaction between dormancy breaking method and seed maturity stages. The

Table 1. Vigor index and growth rate as affected by interaction between storage temperatures and seed maturity levels

| Treatment | After ripening period (weeks) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| | Seed germination (%) | | | | | | | | | | | |
| 25-H | 1$^{a}$ | 0.5$^{a}$ | 14.5$^{ab}$ | 16.2$^{b}$ | 23$^{dc}$ | 45.7$^{bc}$ | 42.5$^{c}$ | 70$^{bc}$ | 80.5$^{c}$ | 92.7$^{ab}$ | 90.7$^{a}$ | 91$^{b}$ |
| 25-K | 1$^{a}$ | 1.2$^{a}$ | 16$^{ab}$ | 23.5$^{a}$ | 32.7$^{bc}$ | 54.7$^{ab}$ | 54.7$^{b}$ | 70.7$^{bc}$ | 96.2$^{a}$ | 90.7$^{ab}$ | 87$^{a}$ | 94$^{ab}$ |
| 25-C | 1.5$^{a}$ | 0.5$^{a}$ | 22.5$^{a}$ | 8.5$^{c}$ | 53$^{a}$ | 58.7$^{a}$ | 63.2$^{a}$ | 83$^{a}$ | 95.2$^{a}$ | 93.7$^{ab}$ | 94.2$^{a}$ | 95.5$^{a}$ |
| 20-H | 0.5$^{a}$ | 0.7$^{a}$ | 10.2$^{b}$ | 7.25$^{c}$ | 17.2$^{d}$ | 47.7$^{abc}$ | 57.7$^{ab}$ | 65.7$^{c}$ | 75$^{c}$ | 95.7$^{a}$ | 86.7$^{a}$ | 93$^{ab}$ |
| 20-K | 0.0$^{a}$ | 0$^{a}$ | 7.7$^{b}$ | 12.5$^{bc}$ | 21$^{dc}$ | 38$^{c}$ | 39.2$^{c}$ | 74.7$^{b}$ | 84.7$^{b}$ | 85.2$^{c}$ | 82.2$^{a}$ | 94.7$^{ab}$ |
| 20-C | 1.5$^{a}$ | 0.2$^{a}$ | 18$^{ab}$ | 12.2$^{bc}$ | 43$^{ab}$ | 44.5$^{bc}$ | 42$^{c}$ | 75$^{b}$ | 88.2$^{b}$ | 90.5$^{b}$ | 84.2$^{a}$ | 94.5$^{ab}$ |
| | Vigour index (%) | | | | | | | | | | | |
| 25-H | 0$^{a}$ | 0$^{a}$ | 2.7$^{abc}$ | 2.7$^{b}$ | 9.2$^{dc}$ | 19.5$^{bc}$ | 19.5$^{b}$ | 31$^{b}$ | 36.5$^{b}$ | 43$^{ab}$ | 38.5$^{bc}$ | 42.5$^{a}$ |
| 25-K | 0.5$^{a}$ | 0.5$^{a}$ | 3.5$^{ab}$ | 5.5$^{a}$ | 12.5$^{bc}$ | 24.5$^{ab}$ | 25.7$^{a}$ | 28.2$^{b}$ | 48.7$^{a}$ | 46$^{a}$ | 42.5$^{ab}$ | 46.7$^{a}$ |
| 25-C | 0.7$^{a}$ | 0$^{a}$ | 5$^{a}$ | 1.7$^{b}$ | 20.7$^{a}$ | 25.5$^{a}$ | 26$^{a}$ | 40.2$^{a}$ | 39.5$^{b}$ | 46.7$^{a}$ | 49.7$^{a}$ | 46.5$^{a}$ |
| 20-H | 0.2$^{a}$ | 0$^{a}$ | 0.2$^{c}$ | 1.7$^{b}$ | 5.2$^{d}$ | 20.2$^{b}$ | 25.7$^{a}$ | 30$^{b}$ | 36.5$^{b}$ | 46.2$^{a}$ | 37$^{bc}$ | 44.7$^{a}$ |
| 20-K | 0$^{a}$ | 0$^{a}$ | 0.2$^{bc}$ | 1.7$^{b}$ | 7.2$^{dc}$ | 14.7$^{c}$ | 15$^{b}$ | 31.2$^{b}$ | 40$^{b}$ | 39.2$^{b}$ | 34.2$^{bc}$ | 46$^{a}$ |
| 20-C | 0.7$^{a}$ | 0$^{a}$ | 2.5$^{abc}$ | 2.5$^{b}$ | 17.7$^{ab}$ | 20$^{b}$ | 16$^{b}$ | 32$^{b}$ | 38.5$^{b}$ | 42.2$^{ab}$ | 33$^{c}$ | 43.75$^{a}$ |
| | Growth rate ( %/day) | | | | | | | | | | | |
| 25-H | 0$^{a}$ | 0.01$^{a}$ | 0.63$^{a}$ | 0.72$^{b}$ | 1.25$^{dc}$ | 2.45$^{bc}$ | 2.33$^{b}$ | 4.07$^{b}$ | 4.88$^{c}$ | 5.74$^{a}$ | 5.37$^{ab}$ | 5.61$^{b}$ |
| 25-K | 0.07$^{a}$ | 0.07$^{a}$ | 0.75$^{ab}$ | 1.11$^{a}$ | 1.71$^{bc}$ | 3$^{ab}$ | 2.07$^{b}$ | 4.18$^{b}$ | 6.01$^{a}$ | 5.54$^{a}$ | 5.35$^{ab}$ | 5.88$^{ab}$ |
| 25-C | 0.11$^{a}$ | 0.02$^{a}$ | 0.99$^{a}$ | 0.37$^{c}$ | 2.86$^{a}$ | 3.17$^{a}$ | 3.47$^{a}$ | 5.17$^{a}$ | 5.77$^{a}$ | 5.85$^{a}$ | 5.96$^{a}$ | 5.945$^{a}$ |
| 20-H | 0.03$^{a}$ | 0.03$^{a}$ | 0.38$^{b}$ | 0.33$^{c}$ | 0.84$^{d}$ | 2.54$^{abc}$ | 3.21$^{a}$ | 3.92$^{b}$ | 4.5$^{d}$ | 5.85$^{a}$ | 5.28$^{ab}$ | 5.79$^{ab}$ |
| 20-K | 0$^{a}$ | 0$^{a}$ | 0.31$^{b}$ | 0.53$^{bc}$ | 1.07$^{dc}$ | 1.97$^{c}$ | 2.07$^{b}$ | 4.27$^{b}$ | 5.07$^{bc}$ | 5.03$^{b}$ | 4.88$^{b}$ | 5.98$^{a}$ |
| 20-C | 0.10$^{a}$ | 0.01$^{a}$ | 0.73$^{ab}$ | 0.56$^{bc}$ | 2.29$^{ab}$ | 2.37$^{bc}$ | 2.31$^{b}$ | 4.33$^{b}$ | 5.25$^{b}$ | 5.49$^{a}$ | 5.03$^{b}$ | 5.82$^{ab}$ |

Table 1. Vigor index and growth rate as affected by interaction between storage temperatures and seed maturity levels (continued)

| Treatment | After ripening period (weeks) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| | Normal seedling weight (gram) | | | | | | | | | | | |
| 25-H | 0$^{a}$ | 0$^{a}$ | 0.24$^{ab}$ | 0.22$^{a}$ | 0.20$^{cd}$ | 0.27$^{b}$ | 0.21$^{b}$ | 0.39$^{bc}$ | 0.40$^{c}$ | 0.40$^{ab}$ | 0.39$^{a}$ | 0.40$^{a}$ |
| 25-K | 0.0077$^{a}$ | 0.0042$^{a}$ | 0.25$^{ab}$ | 0.23$^{a}$ | 0.27$^{bc}$ | 0.32$^{ab}$ | 0.37$^{a}$ | 0.39$^{ab}$ | 0.41$^{b}$ | 0.39$^{c}$ | 0.39$^{a}$ | 0.40$^{a}$ |
| 25-C | 0.0130$^{a}$ | 0.0045$^{a}$ | 0.28$^{a}$ | 0.25$^{a}$ | 0.38$^{a}$ | 0.36$^{a}$ | 0.38$^{a}$ | 0.40$^{a}$ | 0.42$^{a}$ | 0.40$^{a}$ | 0.40$^{a}$ | 0.40$^{a}$ |
| 20-H | 0.0077$^{a}$ | 0.0042$^{a}$ | 0.16$^{b}$ | 0.22$^{a}$ | 0.17$^{d}$ | 0.27$^{b}$ | 0.36$^{a}$ | 0.37$^{c}$ | 0.39$^{d}$ | 0.40$^{a}$ | 0.39$^{a}$ | 0.40$^{a}$ |
| 20-K | 0$^{a}$ | 0$^{a}$ | 0.21$^{ab}$ | 0.20$^{a}$ | 0.17$^{d}$ | 0.27$^{b}$ | 0.26$^{b}$ | 0.39$^{ab}$ | 0.40$^{d}$ | 0.39$^{bc}$ | 0.39$^{a}$ | 0.40$^{a}$ |
| 20-C | 0.0087$^{a}$ | 0.0022$^{a}$ | 0.26$^{a}$ | 0.21$^{a}$ | 0.29$^{b}$ | 0.33$^{ab}$ | 0.27$^{b}$ | 0.39$^{bc}$ | 0.40$^{b}$ | 0.40$^{ab}$ | 0.39$^{a}$ | 0.40$^{a}$ |
| | Dormancy (%) | | | | | | | | | | | |
| 25-H | 100$^{a}$ | 90$^{b}$ | 31$^{a}$ | 48.7$^{c}$ | 22.5$^{a}$ | 3.2$^{ab}$ | 2$^{b}$ | 0.5$^{a}$ | 0.5$^{a}$ | 0.7$^{a}$ | 0.5$^{a}$ | 0$^{a}$ |
| 25-K | 99$^{a}$ | 97.5$^{bc}$ | 10.2$^{c}$ | 52$^{c}$ | 17.2$^{ab}$ | 4$^{ab}$ | 2.2$^{ab}$ | 1$^{a}$ | 0$^{b}$ | 0.5$^{a}$ | 0.7$^{a}$ | 0.2$^{a}$ |
| 25-C | 98.5$^{a}$ | 97.5$^{bc}$ | 25$^{ab}$ | 66.5$^{b}$ | 10$^{b}$ | 3$^{b}$ | 1.2$^{b}$ | 1$^{a}$ | 0$^{b}$ | 0$^{a}$ | 0$^{a}$ | 0.2$^{a}$ |
| 20-H | 99.5$^{a}$ | 97.7$^{b}$ | 27.5$^{a}$ | 79.2$^{a}$ | 21.7$^{a}$ | 6$^{ab}$ | 2$^{b}$ | 1.5$^{a}$ | 1.5$^{a}$ | 0.7$^{a}$ | 0.5$^{a}$ | 0.7$^{a}$ |
| 20-K | 100$^{a}$ | 100$^{a}$ | 15$^{bc}$ | 70$^{b}$ | 13$^{ab}$ | 8.5$^{a}$ | 3.5$^{a}$ | 0.5$^{a}$ | 1.5$^{a}$ | 0.7$^{a}$ | 0.2$^{a}$ | 0.5$^{a}$ |
| 20-C | 98.5$^{a}$ | 95.7$^{c}$ | 35.7$^{a}$ | 65.7$^{b}$ | 11.2$^{b}$ | 4.25$^{ab}$ | 1.5$^{b}$ | 1$^{a}$ | 1.5$^{a}$ | 0.7$^{a}$ | 1$^{a}$ | 0.2$^{a}$ |
| | Maximum growth potential (%) | | | | | | | | | | | |
| 25-H | 0$^{a}$ | 2$^{b}$ | 68$^{c}$ | 68$^{c}$ | 77.5$^{b}$ | 96.2$^{a}$ | 96.5$^{a}$ | 98.2$^{a}$ | 98.5$^{b}$ | 98.2$^{ab}$ | 96$^{a}$ | 98.2$^{a}$ |
| 25-K | 1$^{a}$ | 2.5$^{ab}$ | 88.2$^{a}$ | 88.2$^{a}$ | 80.2$^{ab}$ | 95.5$^{ab}$ | 97$^{a}$ | 98.5$^{a}$ | 99.5$^{a}$ | 97$^{bc}$ | 95$^{a}$ | 98$^{a}$ |
| 25-C | 1.5$^{a}$ | 2.5$^{ab}$ | 73.5$^{bc}$ | 73.2b$^{c}$ | 89.2$^{a}$ | 95.7$^{ab}$ | 96.7$^{a}$ | 98$^{a}$ | 99.5$^{a}$ | 99.5$^{a}$ | 98.2$^{a}$ | 99$^{a}$ |
| 20-H | 0.5$^{a}$ | 2.2$^{b}$ | 69.5$^{c}$ | 69.5$^{c}$ | 78$^{b}$ | 93$^{ab}$ | 96.2$^{a}$ | 97.2$^{a}$ | 95.5$^{c}$ | 99.2$^{a}$ | 98$^{a}$ | 97.7$^{a}$ |
| 20-K | 0$^{a}$ | 0$^{c}$ | 82$^{ab}$ | 82$^{ab}$ | 86.5$^{ab}$ | 89.7$^{b}$ | 94.5$^{a}$ | 98.5$^{a}$ | 96.7$^{b}$ | 96.2$^{bc}$ | 96.5$^{a}$ | 97.7$^{a}$ |
| 20-C | 1.5$^{a}$ | 4.2$^{a}$ | 61.5$^{c}$ | 61.5$^{c}$ | 88.5$^{a}$ | 93.5$^{ab}$ | 97$^{a}$ | 97.$^{a}$ | 96.7$^{b}$ | 95.5$^{c}$ | 97.2$^{a}$ | 97.7$^{a}$ |

Note: The values within the same column followed by the same letter in each treatment are not significantly different according to the DMRT at α=0.05; 20 = 20$^{o}$C, 25 = 25$^{o}$C; H=49 DAA; K=52 DAA; C=62 DAA.

effect of $GA_3$ on germination rate is increased significantly from the 1st week (Table 2). The 62 DAA seeds treated with $GA_3$ at 50 ppm broke dormancy on the 5th week (93.5%), whereas those treated with $KNO_3$ at 1% had the germination rate of 80% – 90% for all maturity stages at week 8. $GA_3$ treatment significantly increased the vigor index, growth speed, and normal seedling dry weight for seeds at maturity level of 62 DAA. All treatments of breaking dormancy significantly decreased the duration of dormancy compared to control. $GA_3$ treatment was significantly most effective in reducing dormancy, i.e. to 0% at week 2, while with $KNO_3$ treatment 100% germination was reached at week 9, and the control water at week 11.

Ground cherry seeds that have reached physiological maturity but still had low germination had a higher proportion of hard seeds, an indication that the seeds are still dormant. After ripening ground cherry seed dormancy was released when there was a balance between the hormones ABA and GA levels at week 8. Santiago (2019) reported the dormancy in *Physalis angulate* is physiological because treatment with $GA_3$ can break the dormancy. The higher concentration of seed ABA than $GA_3$ can delay germination. Xia (2019) study demonstrated that the dormant sunflower seeds stored at 20°C had higher GA concentration than those stored at 10°C

Freshly harvested ground cherry seeds cannot germinate after harvest and require a certain period of time until germination can reach > 80%. Bewley and Black (2020) reported that during the seed filling ABA was produced and accumulated in seeds, resulting in higher ABA concentrations in the seeds. The concentration of ABA decreases during the dry storage and stimulated GA synthesis, so the ABA and GA levels became more balanced. A study by Torres-González (2019) reported that seed dormancy of *Solanum betaceum* and *Solanum quitoense* can be broken by immersing the seeds in 2 ppm GA solution, or by exposing the seeds to alternating temperatures, particularly 25/15°C.

Breaking dormancy using $GA_3$ was effective, indicated by 93% germination at week 5, when seeds were at the brown maturity stage. According to Kucera (2005) $GA_3$ can stimulate the activity of hydrolysis enzymes and promote the metabolism of the food reserve for embryo development, resulting in promoted germination. $KNO_3$ effectively breaks seed dormancy at 7 weeks. Cutti (2016) reported low concentrations of $KNO_3$ (0.1%) can increase germination from 40% to 100%. Seed soaking in $GA_3$ solution at 10 ppm can increase germination up to 100% in seeds *Solanum torvum* (Cutti, 2016). Germination yield pattern from week 0 to week 4 shows seeds does not respond to the fracture method dormancy. It is suspected ground cherry seeds are in the condition of quiescence, i.e. a deep seed resting phase where there is an inactive condition of metabolism and no cell division. Seeds at the quiescence phase are unable to respond to any treatment (Considine and Considine, 2016).

Seeds treated with $KNO_3$ (0.5% or 1%), or water for 24 hours, showed 50% germination at week 8, whereas seeds treated with $GA_3$ demonstrated a higher vigor than those from the other treatments. In the study by Santiago et al. (2019) $GA_3$ treatment promoted radicle emergence by 80% compared to without $GA_3$. Synthesis of gibberellins can suppress ABA and stimulate seeds to germinate (Cembrowska-Lech, 2016). The fastest growth rate of the seedlings in our study was from treatment with $GA_3$ at 50 ppm for 24 hours, whereas treatment with $KNO_3$ and water did not affect the growth rate.

*Physalis divaricata (*Norsatti, 2016) seeds treated with $GA_3$ at 100 ppm had germination of 80%, higher than those treated with $KNO_3$ 50 ppm of <60%. Gibberellins plays important roles in increasing cell activities and enzyme dehydrogenase activation, causing starch reserve in the cotyledon to break down more quickly and promoted seed germination (Bewley and Black, 2020).

Our study demonstrated that the dormancy breaking method using $KNO_3$ at 0.5% , or 1% for 24 hours, were ineffective from week 0 to week 7th, indicated by germination rate that was still below 80%. The low germination occurred in seeds at three maturity stages. However, treatment with $GA_3$ at 50 ppm for 24 hours was effective at week 5, indicated by high seeds germination of 90%, 80%, and 82% for seeds harvested at 49 DAA, 58 DAA, and 62 DAA, respectively. Santiago et al. study (2019) reported that treatment with $GA_3$ at 50 ppm for 24 hours can break seed dormancy of *Physalis angulate*, whereas after ripening dormancy breaks naturally after 9 weeks with water immersion for 24 hours. The results of this study has reported after ripening of ground cherry seeds and its dormancy persistence, which would be useful to produce quality ground cherry seeds sustainably.

Table 2. Viability and vigor of ground cherries seeds as affected by interaction of seed maturity level with dormancy breaking methods

| Treatment | After-ripening period (week) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 2 | | | 4 | | | 6 | | | 8 | | |
| | 49 DAA | 52 DAA | 62 DAA | 49 DAA | 52 DAA | 62 DAA | 49 DAA | 52 DAA | 62 DAA | 49 DAA | 52 DAA | 62 DAA | 49 DAA | 52 DAA | 62 DAA |
| | Germination rate (%) | | | | | | | | | | | | | | |
| Control | 6.5cd | 0.5d | 3d | 9.75d | 7d | 5.5d | 24.5defg | 28.5cd | 22.5efg | 42.5def | 54.75c | 32gh | 76.75fg | 86bcd | 91.5ab |
| KNO3 0,5% | 6.75cd | 16.25c | 10.75cd | 6d | 9.25d | 10.75 | 27cde | 23.25defg | 19.5gf | 38.5gf | 46de | 26.75h | 83.75cd | 76.25fg | 77.5efg |
| KNO3 1% | 12.25cd | 16.75c | 38b | 34c | 13d | 14.25d | 24defg | 25def | 31.5c | 47d | 38.75gf | 39.5ef | 90.75ab | 80.5edf | 82.75cde |
| GA3 50 ppm | 5.25cd | 9.75cd | 51.25a | 50.5b | 64.5a | 61.5ab | 46.25b | 45.25b | 74a | 83.75b | 91a | 84.5b | 88.5bc | 95a | 94.75a |
| Water | 10.25cd | 10.25cd | 11.5dc | 16.75d | 14.5d | 8.75d | 19g | 23.25defg | 23.25defg | 26.25h | 32.25gh | 40.25def | 83.5cd | 64.25h | 75.5g |
| | Vigour index (%) | | | | | | | | | | | | | | |
| Control | 0d | 0d | 0 | 1.5d | 2d | 1.25d | 9.25cde | 10cd | 7.25efg | 19.5c | 25.75b | 13.25efg | 33.5cde | 35.25cde | 37.75bc |
| KNO3 0,5% | 0d | 2.75cd | 0.75d | 1.25d | 2d | 3d | 8.5cdef | 7.5defg | 6.25fg | 14.5def | 19cd | 9.25g | 31.25de | 33.75cde | 32.25cde |
| KNO3 1% | 0d | 6ab | 5.5bc | 9.25c | 12.75b | 12.25bc | 8.25cdefg | 6.5gf | 10.5c | 18.5cd | 14.5def | 17cde | 35.5cd | 36cd | 31.5de |
| GA3 50 ppm | 2.25cd | 3.25bcd | 8.5a | 13.25b | 18a | 18.25a | 19b | 19.25b | 22.5a | 37.75a | 33.5a | 33.5a | 34.25cde | 41.75ab | 45.25a |
| Water | 0d | 1d | 0.25d | 1.75d | 3.75d | 2.25d | 5.75g | 8.25cdefg | 7.25efg | 11fg | 14.25def | 19dc | 32.75de | 30.5e | 33.75cde |
| | Growth speed (%/day) | | | | | | | | | | | | | | |
| Control | 0.1075e | 0.0175e | 0.46cde | 0.282d | 0.342d | 0.232d | 1.2725de | 1.422dc | 1.1075def | 2.44c | 3.1025b | 1.805de | 4.367e | 4.975cd | 5.265bc |
| KNO3 0,5% | 0.255de | 0.705cd | 0.4225cde | 0.34d | 0.457d | 0.577d | 1.362cd | 1.1925def | 0.98ef | 2.105cd | 2.4675c | 1.4575e | 4.687de | 4.407e | 4.605de |
| KNO3 1% | 0.1075e | 0.845b | 1.635b | 1.42c | 1.565bc | 2.027bc | 1.2625de | 1.185def | 1.66c | 2.6375bc | 2.105cd | 2.33cd | 5.295bc | 4.792de | 4.792de |
| GA3 50 ppm | 0.2875cde | 0.4375cde | 2.245a | 2.155b | 3.25a | 3.2625a | 2.845b | 2.6b | 4.207a | 5.215a | 5.445a | 5.14a | 5.482b | 6.297a | 6.545a |
| Water | 0.3750cde | 0.3075cde | 0.4275cde | 0.3725d | 0.512d | 0.445d | 0.9250f | 1.1825def | 1.1775def | 1.495e | 2.09cd | 2.295cd | 4.712de | 3.82f | 4.38e |

Table 2. Viability and vigor of ground cherries seeds as affected by interaction of seed maturity level with dormancy breaking methods (continued)

| Treatment | After-ripening period (week) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 2 | | | 4 | | | 6 | | | 8 | | |
| | 49 DAA | 52 DAA | 62 DAA | 49 DAA | 52 DAA | 62 DAA | 49 DAA | 52 DAA | 62 DAA | 49 DAA | 52 DAA | 62 DAA | 49 DAA | 52 DAA | 62 DAA |
| | Dry weight of the normal seedlings (g) | | | | | | | | | | | | | | |
| Control | 0.0042c | 0.0002c | 0.0007c | 0.0017e | 0.0065e | 0.002e | 0.219cde | 0.333bc | 0.1925de | 0.3517b | 0.3432b | 0.2082cd | 0.338de | 0.377abc | 0.361bcd |
| KNO3 0,5% | 0.005c | 0.0105c | 0.0037c | 0.0032e | 0.013e | 0.0187e | 0.2797cd | 0.1452e | 0.1402e | 0.2102cd | 0.3387b | 0.1467d | 0.357bcd | 0.316ef | 0.293fg |
| KNO3 1% | 0.0115c | 0.0122c | 0.1505b | 0.165c | 0.1227cd | 0.311ab | 0.237cde | 0.2535cde | 0.276cd | 0.229cd | 0.3422b | 0.2392c | 0.39ab | 0.343cde | 0.346cde |
| GA3 50 ppm | 0.0047c | 0.005c | 0.1977a | 0.2456b | 0.3512a | 0.3142ab | 0.3967b | 0.4412ab | 0.5135a | 0.438a | 0.4442a | 0.4025ab | 0.386ab | 0.389ab | 0.403a |
| Water | 0.007c | 0.005c | 0.008c | 0.023e | 0.044de | 0.005e | 0.1862de | 0.1997de | 0.1602de | 0.1725cd | 0.3345b | 0.2042cd | 0.375abcd | 0.272gh | 0.258h |
| | Dormancy (%) | | | | | | | | | | | | | | |
| Control | 84.75a | 88a | 85.75a | 69b | 76.75a | 80.75a | 21a | 15.75b | 20.75a | 19b | 18.25b | 23a | 2.25ab | 2.75a | 1.25abcde |
| KNO3 0,5% | 18.25cd | 50.25bc | 22.25cd | 14.5c | 70.75b | 5de | 2de | 2de | 2de | 0.75d | 1.75d | 1.75d | 0.5cde | 2abc | 1.5abcde |
| KNO3 1% | 22.75cd | 23cd | 6d | 2.75de | 6.75d | 3.5de | 3de | 2.5de | 2de | 1.5d | 1.75d | 1.5d | 0.5cde | 0.75bcde | 1.75abcd |
| GA3 50 ppm | 67.5ab | 42.75bc | 2d | 0e | 0e | 0.5e | 0.5e | 0.75e | 1.25e | 0e | 0d | 0d | 0e | 0.25de | 0.75bcde |
| Water | 24.5cd | 50bc | 42bc | 15c | 19.25c | 7d | 2.5de | 6.75cd | 11.25bc | 15.75c | 18.75b | 19.25b | 1.5abcde | 2.5a | 2.25ab |
| | Maximum growth potential (%) | | | | | | | | | | | | | | |
| Control | 14d | 11.25d | 12.75d | 30.5e | 22.25f | 18.75f | 77d | 81.75d | 78d | 79.75c | 97a | 74.75d | 95f | 96ef | 98.75ab |
| KNO3 0,5% | 80.5ab | 49bc | 77.25ab | 85c | 28e | 94.25ab | 97.75ab | 96.5ab | 97.25ab | 97a | 97a | 97.5a | 98.25abcd | 96.75bcdef | 97bcdef |
| KNO3 1% | 77ab | 75.75ab | 93.25a | 95.75ab | 92.25b | 95.75ab | 96.5ab | 96.5ab | 97.75ab | 97.25a | 97.75a | 98a | 99.5a | 98.5abc | 97.5abcde |
| GA3 50 ppm | 31.75cd | 57.25bc | 95.75a | 100a | 99.5a | 98.25a | 99a | 96.5ab | 97.25ab | 98.5a | 98.25a | 99.25a | 99.5a | 99.5a | 97.5abcde |
| Water | 74ab | 48.25cb | 55.75bc | 84.25cd | 79.25d | 91.5b | 95.75ab | 92.75bc | 88.25c | 84b | 79/5c | 78.75c | 96.75bcdef | 96.25def | 96.5cdef |

Note: The values within the same column followed by the same letter in each treatment are not significantly different according to DMRT at α=0.05.

## Conclusion

At 0 to 11 weeks in storage that the initial seed ABA concentration was higher than GA, then the ABA level decreased and reached equilibrium with GA level at week 8. The decreases in ABA concentration was followed by increasing seed germination to >80% at week 8 in seeds of all maturity stages. Seeds harvested at 62 DAA that were stored at 25°C have a dormancy persistence of 7 weeks, whereas those stored at 20°C released the dormancy naturally after 8 weeks. The most effective treatment to break ground cherry seed dormancy is by soaking the seeds in 50 ppm $GA_3$ solution for 24 hours.

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