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Original Article

Effects of hormone and cold treatments on dormancy breaking of Jerusalem artichoke (*Helianthus tuberosus* L.) tubers

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Abstract

The objective of this research was to determine the effects of gibberellic acid, cytokinin and ethylene and chilling at 5 ^{o}C for 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 weeks on germination of Jerusalem artichoke (*Helianthus tuberosus* L.) tubers. Gibberellic acid, cytokinin, ethylene and a blank control were assigned as factor A, and four Jerusalem artichoke varieties including JA 89, HEL 65, CN52867 and hybrid variety, 50-4 were assigned as factor B. A 4×10 factorial experiment in a randomized complete block arrangement of the treatments with four replications was laid out for the chilling treatment. Data were recorded for germination percentage after 7 days of germination for hormone treatment and for 7 days of germination for chilling treatment. A significant difference of three plant hormones was found for Jerusalem artichoke tuber germination. Gibberellic acid was effective for breaking dormancy of four Jerusalem artichoke varieties, influencing the highest tuber germination percentage from both times of evaluation. For breaking tuber dormancy by chilling, highly significant different periods of chilling were found for a percentage of tuber germination. Ten weeks of chilling in 5 ^{o}C showed the highest germination, 96.3 %. JA 89 and 50-4 exhibited high germination in both breaking dormancy methods.

Keywords: Tuber crop, Endodormancy, Dormancy breakin

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Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.) is a tuber crop originated in the temperate region of North America. It is closely related to sunflower (*H. anuus* L.), and they are the only two species of this genus that are cultivated. While sunflower is grown for its beautiful flowers and oil seed, Jerusalem artichoke is grown mainly for its inulin containing tubers. However, it is a versatile crop that can be used for several purposes.

Inulin is a form of carbohydrate accumulated at high

concentration in Jerusalem artichoke tubers. The carbohydrate functions as soluble dietary fiber, and, thus, it is useful to human health and it is used as a raw material to produce functional food products. Functional food is the food that has more functions than ordinary food as it provides more health benefits other than food nutrients.

Inulin can prevent obesity, diabetes, heart disease, reduces blood cholesterol and enhances the immune system (Frost, 2005). Moreover, the tubers are used as feed additive in animal feed production to reduce the using of antibiotics (Barszcz et al., 2016; Sewaka et al., 2019). In addition, the tubers of JA can be used as a material for biofuel and biochemical production (Gunnarsson et al., 2014).

In temperate regions, where Jerusalem artichoke was domesticated, it is planted during frost free periods and its tubers are naturally vernalized in the soil during the frost period. Because cold periods induce the germination of Jerusalem artichoke tubers in spring, therefore, germination of seed tubers is not a problem. In tropical areas, however, growing Jerusalem artichoke has a problem of low germination of seed tubers. Although seed tubers can germinate, the germination in the tropics is frequently not uniform. Tubers of Jerusalem artichoke have a dormancy period to escape undesirable environmental conditions naturally, mostly during winter season (Kays and Nottingham, 2008). Variation of dormancy period depends on some factors such as genotypes of Jerusalem artichoke, location of production and weather conditions. According to Kays and Nottingham (2008), dormancy in Jerusalem artichoke tubers is thought to be regulated by endodormancy in which the seed tubers are not germinated although the external conditions are favorable for germination.

In potato treatment of seed tubers with some chemicals such as rindite and thio-urea could shorten the dormancy period and increase the number of sprouts (Fazal et al., 2001). Among chemicals, thio-urea has been used for dormancy breaking of tomato nodes (Mani et al., 2014). Application of sodium nitroprusside (SNP) resulted in a rapid release of tuber dormancy in potato (Wang et al., 2020). Treatment of seed tubers with some plant hormones (ethylene, gibberellic acid and cytokinin) and low temperature can overcome dormancy in Jerusalem artichokes (Kantar and Betts, 2012). Gibberellic acid was reported as the most effective plant hormone, which could induce germination in 12 genotypes of Jerusalem artichoke and interspecific hybrids of JA × sunflower (Kantar and Betts, 2012).

Jerusalem artichoke genotypes responded differently to the chemical treatment and cold treatment (Kays and Nottingham, 2008). Genotype-by-hormone interaction was also significant, indicating that genotypes responded differently to plant hormones (Kantar and Betts, 2012). To the best of our knowledge, there have been three studies on dormancy breaking in Jerusalem artichoke. Two studies were conducted on true seed dormancy (Puttha et al., 2014; Wangsomnuk et al., 2015), and another study was conducted on tuber dormancy (Kantar and Betts, 2012). As there were specific responses of Jerusalem varieties to hormone treatment (Kantar and Betts, 2012), the application of the information obtained in previous studies should be verified in new varieties. Furthermore, cold storage at 2 °C which is most suitable for dormancy breaking of Jerusalem artichoke tubers (Kantar and Betts, 2012) is not available in most home refrigerators, and the storage time in the previous study was limited to 10 weeks. Therefore, this study used a storage temperature of 5 °C and extended the storage time for 20 weeks. The question underlying this study is which dormancy breaking methods are most suitable for treating seed tubers of different Jerusalem artichoke varieties. The aim of this study was to determine tuber germination of four Jerusalem artichoke varieties after hormone and cold treatments. The information obtained in this study is important for providing recommendations to Jerusalem artichoke growers.

Material and Methods

Preparation of Jerusalem artichoke seed tubers

Four commercial varieties of Jerusalem artichoke including JA 89, HEL 65, CN 52867 and 50-4 were used in this study. These varieties were maintained at the Agronomy Field, Faculty of Agriculture and Natural Resource, Rajamangala University of Technology Tawan-ok, Chonburi, Thailand, and the plants were harvested at maturity stage after planting. The tubers were washed, and the uniform seed tubers were cut into small pieces with two or three buds. The tuber pieces were incubated under moistened coconut husk in plastic bags for 7-10 days under ambient conditions. The plastic bags were kept opened for good aeration. The tuber pieces with active buds and roots were further germinated in plug

plastic trays containing a mixture 1:1 soil:charred rice husk medium for 7-10 days.

For the first time in the hormonal experiment, the sprouted seedlings at four-leaf stage were then planted in the field in the late rainy season (October) 2017. Water was applied every other day for optimum yield. Fertilizer mixture of N-P-K (formula 15-15-15) was applied at the rate of 156.3 kg ha^{-1} at 1 month after planting. The plants were harvested in March 2018 at maturity stage as indicated by 50% browning of stems and leaves. The tubers were cleaned with tap water, and made ready for the experiments.

For the second time in the hormonal experiment, Jerusalem artichoke was planted in March 2018 and harvested in August 2018. Chilling experiment was also conducted in August 2018. In the first time, the crop grew in the dry season with irrigation and exposed to low temperature and short daylight during December to January and high temperature during late February to March.

In the second time, the tubers harvested in the first time were planted. The crop exposed to high temperature during March to April and high humidity during May to August. The times of experiments were selected because they are the main growing seasons in Thailand.

Hormone treatment

A 4×4 factorial experiment was laid out in a randomized complete block design (RCBD) with four replications for two times. Three chemical plant hormones (gibberellic acid, cytokinin and ethylene) and water (control) were assigned as factor A, and four commercial Jerusalem artichoke varieties including JA 89, HEL 65, CN52867 and 50-4 were assigned as factor B.

The cleaned seed tubers freshly harvested from the field were cut into small pieces with 1 bud/piece. The cut tuber pieces were then soaked with chemical plant hormones and filtered water as control. Gibberellic acid was applied by soaking tubers for 90 to 120 s in a 2% aqueous gibberellic acid solution (4% ProGibb). Cytokinin was applied by soaking the tubers for 90 to 120s in a 2000 ppm aqueous cytokinin solution (6-benzylamino purine). Ethylene was applied by soaking tubers for ten minutes in a 1% aqueous ethephon solution. The concentrations of these hormones were selected because they were effective for dormancy braking of Jerusalem artichoke hybrids in a previous study (Kantar and Betts, 2012).

After the tuber pieces were treated, the tuber pieces were germinated in plug plastic trays for 14 days without incubation under opened greenhouse condition. The germinated tuber pieces were counted daily, and germination percentage was recorded.

Cold treatment

A 10×4 factorial experiment with RCBD arrangement of the treatments and four replications was conducted. RCBD was used because we expected small differences among temperatures in the shelves of the refrigerator. As the tubers were stored for five months, the experiment was not repeated. Ten pre-chilled periods (2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 weeks) were assigned as factor A, and four commercial Jerusalem artichoke varieties previously mentioned in the above hormone treatment heading were assigned as factor B.

After the plants were harvested, the tubers were washed and air-dried at room temperature. The uniform tubers were then packed in transparent sealable plastic bags. There were 50 tubers for each bag. A total number of 160 bags were later stored at 5 °C in a refrigerator for 2 to 20 weeks according to the treatments.

A germination test was carried out at 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 weeks after storage. The chilled tubers were cut into small pieces with 1 bud/piece, and the tuber pieces were germinated in plastic trays containing soil and charred rice husk medium as described previously. Each replication tray contained 100 tuber pieces. The seedlings that emerged above the soil surface are considered germinated. Germination was recorded daily from day 7 to day 14 after planting.

Statistical analysis

Data were analyzed separately for hormone and cold treatment by using STATISTIX 8 software program (Analytical Software, Tallahassee, Florida, USA). As error variances were not homogeneous, the data for hormone treatment were reported separately. Least significant difference (LSD) was used to compare means at 0.05 probability level. Graphs were constructed using Microsoft Excel.

Results

Hormone treatment

Most error variances for the second time were more

than three folds larger than those for the first time and the data were reported separately (Table 1, 2). Hormonal effects, varietal effects and the interaction effects were significant (P≤0.01) for germination percentage evaluated from 7 days to 14 days for both times of the experiment. Hormonal effects contributed to the largest portion of total variations in germination percentage of Jerusalem artichoke tubers for both times of the experiment from 7 days to 14 days.

In general, varietal effects were larger than the interaction effects. However, the interaction effects in the second time of the experiment were larger compared to those in the first time of the experiment. The importance of interaction effects needed a larger and more deliberate experiment to verify the main effects.

Although the effects between two times of hormone treatment on germination percentage were in a similar pattern, they were different in magnitudes of the percentages (Fig. 1). At the first time, all treatments had higher germination percentages than the same treatments at the second time across evaluation times at 7 to 14 days. Germination percentages at the first time were 61.75% at 7 days and 73.18% at 14 days, and germination percentages at the second time were 15.55 at 7 days and 42.19% at 14 days.

In both times of experiment, gibberellic acid had the highest germination percentages across evaluation times, and ethylene had the lowest germination percentages across evaluation times, whereas cytokinin and control were intermediate and similar, when the final percentages at 14 days were considered. Gibberellin seemed to be promising for overcoming seed tuber dormancy of Jerusalem artichoke, whereas cytokinin and ethylene were not favorable.

Jerusalem artichoke varieties were significantly different (p<0.01) for germination percentage in both times of the experiment (Fig. 2). In the first time, germination percentages ranged from 61.6 % in CN52867 to 75.2% in HEL 65, whereas, in the second time, germination percentages ranged from 30.6% in HEL 65 to 55.9% in 50-4. JA 89 and 50-4 showed a consistently high germination percentage across two times, whereas HEL 65 and CN52867 showed interactions between two times.

Differences in the results between two times of the experiment would be due to difference in tuber lots as the tubers were harvested in different growing seasons, which are the main growing seasons in Thailand. The tubers in the dry season (first time) were larger and more uniform than the tubers in the rainy season. However, JA 89 and 50-4 tended to have high tuber germination in both times of the experiment, whereas CN52867 had the lowest tuber germination.

Table-1: Mean squares for germination percentage of four Jerusalem artichoke varieties as affected by four hormone treatments evaluated at 7, 8, 9, 10, 11, 12, 13 and 14 days for first time

SOV	df	Evaluation time							
		7days	8days	9days	10days	11days	12days	13days	14days
Rep	3	198.5	82.6	94.7	117.9	148.1	85.4	67.9	56.9
Hormone)H(	3	11,806.6**	11,818.9**	12,427.1**	12,121.1**	11,984.7**	12,047.8**	12,101.6**	12,081.7**
Variety)V(	3	777.0**	729.6**	608.8**	574.9**	538.6**	425.4**	385.6**	324.8**
H × V	9	415.9**	337.8**	231.3**	222.4**	217.6**	177.2**	167.3**	132.4**
Error	45	43.6	31.4	21.2	17.6	16.8	17.8	21.8	18.7
CV (%)		10.7	8.7	6.9	6.1	5.9	5.9	6.5	5.9

** Significant at 0.01 probability level

Table -2: Mean squares for germination percentage of four Jerusalem artichoke varieties as affected by four hormone treatments evaluated at 7, 8, 9, 10, 11, 12, 13 and 14 days for second time

SOV	df	Evaluation time							
		7days	8days	9days	10days	11days	12days	13days	14days
Rep	3	91.02	123.96	156.6	356.6	634.4	1023.3	986.5	998.96
Hormone)H(	3	1,582.7**	2,577.1**	3,416.0**	4,210.8**	5,088.5**	5,694.1**	6,037.5**	6,189.6**
Variety)V(	3	836.9**	1,307.3**	1,781.6**	1,978.5**	1,746.9**	2,076.4**	1,904.2**	1,984.4**
H × V	9	299.0**	426.0**	530.3**	585.1**	663.89**	740.7**	814.6**	827.4**

Error	45	55.2	87.6	98.6	99.1	126.9	109.7	128.4	116.2
CV (%)		47.8	46.8	40.1	33.6	34.3	28.7	28.6	25.6

**Significant at 0.01 probability level

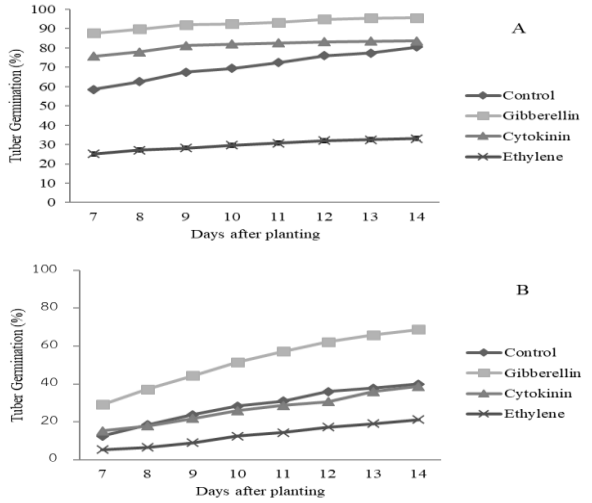

Figure-1. Effect of hormone treatment on germination percentage across four Jerusalem artichoke varieties evaluated at 7 to 14 days after planting for two times (A) first time and (B) second time

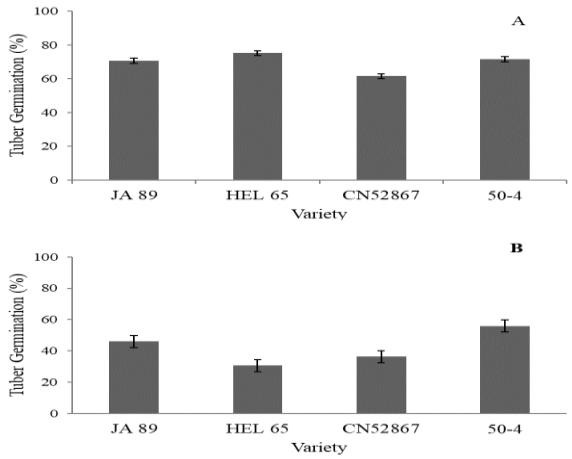

Figure-2. Accumulated germination percentage of four Jerusalem artichoke varieties across four hormone treatments evaluated at 14 days after planting for two times (A) first time and (B) second time

In the first time, all Jerusalem artichoke varieties responded to hormone treatment in a similar pattern depending on the initial percentage (control) of the varieties (Fig. 3). Initial percentages ranged between 51.7% in CN52864 and 87.1% in HEL 65. Gibberellin increased germination percentages in all Jerusalem artichoke varieties. Cytokinin increased germination percentage in JA 89 and CN52864 when initial percentages were low (68.8 and 51.7%), but it did not increase germination percentage in HEL 65 and 50-4 when initial percentages were high (87.1 and 82.1%). Ethylene reduced germination percentage in all Jerusalem artichoke varieties.

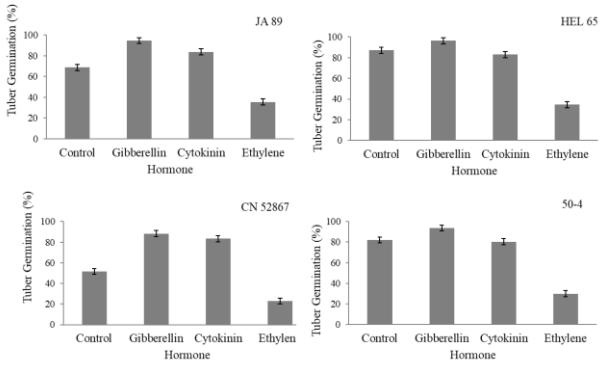

Figure-3. Accumulated germination percentage of four Jerusalem artichoke varieties as affected by hormone treatment evaluated at 14 days after planting at first time

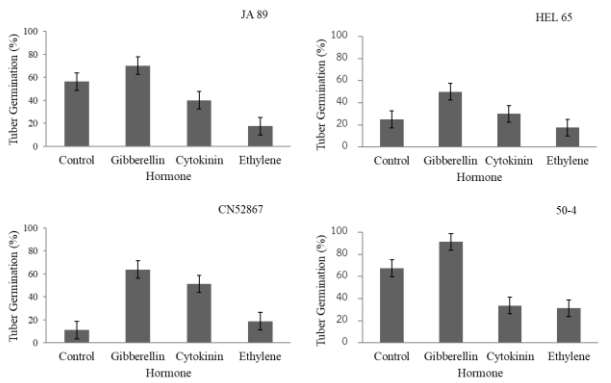

Figure-4. Accumulated germination percentage of four Jerusalem artichoke varieties as affected by hormone treatment evaluated at 14 days after planting at second time

In the second time, Jerusalem artichoke varieties generally responded to hormone treatment similar to that in the first time with small difference (Fig. 4). Initial percentages ranged between 11.3% in CN52867 and 67.5% in 50-4. Gibberellin increased germination percentage in all Jerusalem artichoke varieties. Cytikinin seemed to reduce germination percentage when initial percentages were high in JA 89 (56.3%) and 50-4 (67.5%). However, Jerusalem artichoke variety did not respond to cytokinin when

initial germination percentage was intermediate in HEL 65 (25.0%) and it increased germination percentage when initial percentage was low in CN52867 (11.3%). Ethylene reduced germination percentage when initial percentages were high in JA 89 (56.3%) and 50-4 (67.5%), but Jerusalem artichoke varieties did not respond to ethylene when the initial percentages were intermediate (HEL 65) (25.0%) and low (CN52867) (11.3%).

Cold treatment

Chilling effects, varietal effects and interaction effects were significant (P≤0.01) for the germination percentage evaluated from 7 days to 14 days (Table 3). Chilling effects were larger than varietal effects when the data were evaluated at 7, 8, 9, 10 and 11 days, whereas varietal effects were larger than chilling effects when the data were evaluated at 12, 13 and 14 days. Interaction effects were smaller than chilling effects and varietal effects for all evaluation times.

As control treatment was not included in cold treatment, the germination percentage of 51.8% as an initial germination in hormone treatment in the first time could be used as the control reference because the experiment was conducted at the same time. Chilling treatment could increase germination percentage from 51.8% to 88.2% as early as 2 weeks of chilling storage (Fig. 5). All chilling durations had germination percentages ranging from 64.4% at two weeks to 96.3% at 10 weeks significantly higher than the initial germination percentage (51.8%). The highest germination percentages were obtained at 10 and 16 weeks of chilling treatment (96.3 and 95.9%, respectively).

Significant differences for germination percentage were observed among Jerusalem artichoke varieties (Fig. 6). CN52867 had the lowest germination percentage (75.1%), and it was significantly lower than JA 89, HEL 65 and 50-4, which showed similar performance for germination percentage, ranging from 87.2 to 90.2%.

Germination percentages for control treatment in the first time for hormone treatment, which was evaluated at the same time, were 68.8% for JA 86, 87.1% for HEL 65, 51.7% for CN52867 and 82.1% for 50-4 (Fig. 3), and these values were used as control treatment for each variety. In JA 89, most storage durations from 2 to 19 weeks ranging from 76.4 to 100.0% were higher than initial germination percentage (68.8%) except at 20 weeks of storage (61.3%) (Fig. 7). In HEL 65, only 2 storage durations at 14 and 16 weeks (96.1 and 99.4%, respectively) were higher than initial germination percentage (87.1%). In CN52867, two storage durations at 4 and 6 weeks had lower germination percentages (33.6 to 45.6%) than initial parentage (51.7%), and seven storage durations from 8 to 20 weeks had higher germination percentages (78.4 to 100.0%) than initial percentage (51.7%). In 50-4, germination percentage could reach 100 as early as two weeks of storage. However, there were two storage durations at 4 and 14 weeks which had lower germination percentages (60.1, 87.3 and 76.7%) than initial percentage (82.1%), and seven storage durations at 2, 6, 8, 10, 12, 16, 18 and 20 weeks had higher germination percentages (91.4 to 100.0%) than initial percentage (82.1%).

Table- .3Mean squares for germination percentage of four Jerusalem artichoke varieties as affected by ten chilling durations at 5 °C from 2 to 20 weeks evaluated at 7, 8, 9, 10, 11, 12, 13 and 14 days

SOV	df	Evaluation time							
		7days	8days	9days	10days	11days	12days	13days	14days
Rep	2	126.1	3.4	36.11	64.7	14.6	37.5	24.8	64.5
Chilling period (C)	9	2,584.9**	2,479.3**	2,369.7**	2,069.4**	1,857.9**	1,445.5**	1,178.0**	1,086.5**
Variety (V)	3	1,645.9**	2,131.2**	1867.0**	1,583.3**	1,551.5**	1,609.5**	1,366.4**	1,441.1**
H × V	27	490.1**	605.4**	681.5**	540.03**	531.4**	543.4**	556.8**	499.8**
Error	78	27.7	61.6	72.4	33.9	34.9	34.2	16.2	14.4
CV (%)		11.9	14.2	13.0	8.1	7.9	7.4	4.8	4.4

**Significant at 0.01 probability level

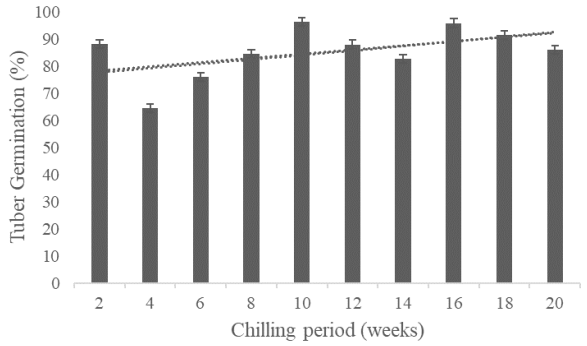

Figure-5. Germination percentage across four Jerusalem artichoke varieties as affected by chilling treatment evaluated at 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 weeks after chilling

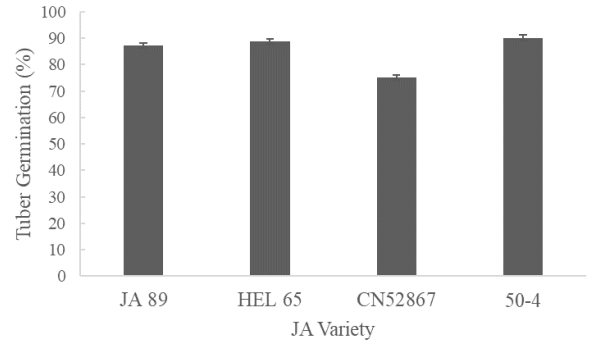

Figure-6. Germination percentage of four Jerusalem artichoke varieties across 10 chilling durations from 2 to 20 weeks

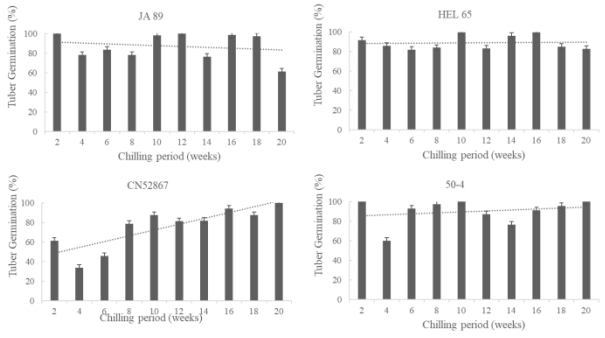

Figure-7. Germination percentage of four Jerusalem artichoke varieties as affected by 10 chilling durations from 2 to 20 weeks

Discussion

Hormone treatment

Hormone treatment has been used successfully for overcoming internal dormancy in many tuber crops and root crops. However, few studies have been conducted in the Jerusalem artichoke and the results were still not conclusive. In this study, gibberellic acid was the best method for overcoming tuber dormancy in Jerusalem artichoke.

In a previous study in interspecific hybrids of JA × sunflower, application of gibberellic acid in seed tubers had faster germination than cytokinin, and application of cytokinin had faster germination than ethylene. Gibberellic acid and ethylene treatment could induce germination of Jerusalem artichoke tubers within 6.5 to 11.5 days and 9.8 to 20.5 days, respectively (Kantar and Betts, 2012). According to Christensen et al. (2020), gibberellic acid at the concentrations of 50, 100, and 150 mg mL^{-1} partially broke dormancy in some accessions of wild potato (*Solanum chacoense*), but it was not able to break dormancy in some accessions. The authors also found that the effects of soaking time and concentration were not different in the accessions with weak dormancy. Haulm treatment of gibberellic acid at concentrations of 750 or 1000 ppm and dipping treatment at concentrations of 40 or 50 ppm could reduce dormancy of potato (Chindi and Tsegaw, 2020). In another study, gibberellic acid was also successfully used in breaking tuber dormancy of potato (Mustefa et al., 2017).

In this study, cytokinin seemed to have rapid germination in the early days especially the first time, but it was similar to control in the final days. In tomato, tuber segments treated with cytokinin at the concentration of 0.1 g L^{-1} or a combination of cytokinin and gibberellin could germinate within 5 days (Rossouw, 2008). Cytokinins and gibberellins are required for bud breaking and sprout growth, respectively (Mani et al., 2014). Low effect of cytokinin in this study would be due to the differences in crop species and concentrations. Dormancy levels could also affect germination when the tubers were treated with cytokinin.

In this study, application of ethylene was not effective and even reduced germination of Jerusalem artichoke tubers. Ethylene has been used to overcome dormant seeds of peanut and induce flowering of pineapple (Liu and Sherif, 2019). Ethylene can be produced by the wounding of plant propagating materials to induce germination such as in sugarcane

and cassava. In this study, the tubers were cut into small pieces, and wounding could generate ethylene. Therefore application of exogenous ethylene could reduce germination. In potato, ethylene was used as a tuber germination inhibitor to prevent sprouting during storage (Dako et al., 2021).

It is clear that gibberellic acid increased germination percentage in four Jerusalem artichoke varieties, whereas ethylene reduced germination percentage in these Jerusalem varieties. However, it is interesting to note here that cytokinin increased germination percentage when germination percentages were low such as in JA 89 and CN52867. Therefore, application of cytokinin is not necessary when germination percentage is high. Gibberellic acid is highly recommended for breaking dormancy in these Jerusalem artichoke varieties. The differential responses of Jerusalem artichoke varieties to hormone treatment require additional studies for newly released varieties to provide the correct recommendations to the growers.

There were interactions between variety and hormone indicating that Jerusalem artichoke varieties responded differently to plant hormones. The importance of interaction effects indicated specific responses of Jerusalem artichoke varieties to hormone treatment. The results were in agreement with those reported previously. Kantar and Betts (2012) found that the interaction occurred between genotypes and hormone treatments. In this study, all varieties, responded similarly to gibberellic acid and ethylene, and interaction occurred when they were treated with cytokinin, which was dependent on initial germination of the control. CN52867 showed good response to cytokinin when initial germination was low. However, all varieties showed good and consistent responses to gibberellic acid.

Cold treatment

Cold treatment is a natural occurring phenomenon for dormancy breaking in Jerusalem artichokes as the tubers are in the soil during a frost period. According to Kays and Nottingham (2008), the optimum temperature for breaking tuber dormancy was reported between 0 and 5^{o}C. In this study, seed tubers of Jerusalem artichoke were stored at 5 ^{o}C. The reason for selecting this temperature is that it is available for most home refrigerators.

High germination percentages of Jerusalem artichoke tubers can be obtained from appropriate storage durations and temperature. In this study, longer periods of tuber chilling tended to have higher germination percentages of Jerusalem artichoke tubers, although high germination percentages could be observed as early as two weeks of storage. The cold storage durations of 30 to 45 days at 0^{o}C were sufficient for dormancy breaking in two Jerusalem artichoke cultivars (Chicago and Blanc Ameliore) (Kays and Nottingham, 2008).

In this study, Jerusalem artichoke varieties showed differential responses to cold treatment for germination percentage. JA 89, HEL 65 and 50-4 had similar performance and they were significantly higher than CN52867. Kantar and Betts (2012) reported that only some genotypes sprouted in response to cold treatment at 2-6 weeks, whereas cold storage for 8 weeks was the shortest treatment under which all genotypes of JA sprouted.

According to Kantar and Betts (2012), Jerusalem artichoke tubers are dormant after production in the late fall until next spring. Under natural conditions of wild species, dormancy release occurs after exposure to winter cold. During frost period, the stems die and the tubers in the soil are stored naturally under low temperature (Kays and Nottingham, 2008). Therefore, cold treatment is not necessary for dormancy breaking.

In this study, Jerusalem artichoke tubers could release dormancy as early as two weeks of storage at 5 ^{o}C. The increases in germination after two weeks were slow and not consistent, and Jerusalem artichoke tubers could be stored at low temperature for five months, and its germination percentage was still high. According to Kantar and Betts (2012), cold treatment at 2 ^{o}C for 8 weeks, where plant growth began 63.6 to 67.5 days after treatment initiation had the highest germination. In practice, storage for two weeks is sufficient for dormancy breaking, and long term storage for 20 weeks is also possible. Cold storage might be used as an alternative means for dormancy breaking if farmers have waiting times of two weeks or more, and cold storage also facilitates continuous production of Jerusalem artichoke tubers to supply the fresh market. If they need continuous planting after harvest, gibberellic acid is recommended.

Seedling vigor is an important criterion to determine quality of seed tubers, good establishment of the crops after transplanting and yield performance. Unfortunately, the effects of hormonal treatment and chilling treatment on seedling vigor parameters were not determined in this study. Currently, several tests

are available for determining vigor, but they relate to seed vigor (Marcos-Filho, 2015). However, the technique of accelerated aging was proposed for evaluation of mother seed tubers of potato (Rykaczewska, 2013). The technique is interesting and tuber vigor of Jerusalem artichoke is worth exploring. Further investigations on this topic are required.

The study was limited to few varieties, and only one concentration of each hormone was investigated. Further studies on varying concentrations of the hormones are still required to provide insight into the effects of hormone on tuber germination of Jerusalem artichoke. The information obtained in this study supported previous findings and also added new information in terms of cold storage and hormone treatments.

Conclusion

Gibberellic acid is recommended for dormancy breaking of Jerusalem artichoke tubers and can facilitate continuous planting after harvest. Application of gibberellic acid resulted in the highest tuber germination percentage in both times of study. However, cold storage can be used as an alternative method for dormancy breaking if farmers have a waiting time of two weeks or more as the result of chilling at 5 ^{o}C for ten weeks showed the highest germination. JA 89 and 50-4 exhibited high germination in both breaking dormancy methods.

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Contribution of Authors

Sennoi R & Puttha R: Planned the study, designed research methodology, prepared materials, conducted study and wrote manuscript
Ruttanaprasert R & Chinaworn S: Data analysis, manuscript critiquing, final reading and approval