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# Physiological evaluation of *Sonchus oleraceus* L. seeds with different pre-germinative treatments under high tropical latitudinal conditions

Evaluación fisiológica de semillas de *Sonchus oleraceus* L. mediante diferentes tratamientos pre-germinativos en condiciones latitudinales de trópico alto

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## ABSTRACT

### Keywords:

Dormancy  
Germination physiology  
Gibberellins  
Scarification  
Sowing depth

*Sonchus oleraceus* L. is an invasive species that negatively affects the quality and yield of different crops. This research aimed to evaluate the physiological behavior of seeds from the weed *S. oleraceus* L., which were subjected to different treatments in three experiments. In experiment 1, different gibberellic acid (GA) concentrations were applied (0, 200, 400, and 600 mg L<sup>-1</sup>). In the second experiment, apical, basal, and apical-basal cut treatments were carried out on the seeds. In a third experiment, seeds were placed at different sowing depths (0.5, 1, 2, 5, and 10 cm) in peat as the substrate. The results indicated that GA at concentrations higher than 200 mg L<sup>-1</sup> inhibited seed germination and, consequently, seedling growth. Germination was similar between the 200 mg L<sup>-1</sup> GA treatment and the control, but germination occurred faster in the control. The apical-basal cut in the seeds generated the highest percentage of germination, the highest average speed of germination, and a significantly lower time of germination than the control; however, the longest shoot was observed in the seeds without a cut, and the longest root was detected in the seeds with the basal cut. Seedling emergence was affected by sowing depth, where it was significantly greater at 0.5, lesser at 2 cm, and, at greater depths, seedlings did not emerge.



## RESUMEN

### Palabras clave:

Latencia  
Fisiología de germinación  
Giberelinas  
Escarificación  
Profundidad de siembra

*Sonchus oleraceus* L., es una especie invasiva que afecta negativamente la calidad y el rendimiento de diferentes cultivos. El objetivo de esta evaluación fue evaluar el comportamiento fisiológico de las semillas de la maleza *S. oleraceus* L., para lo cual, las semillas fueron sometidas a diferentes tratamientos en tres experimentos. En el experimento 1 se aplicaron diferentes concentraciones de ácido giberélico (0, 200, 400 y 600 mg L<sup>-1</sup>). En el segundo experimento se realizaron tratamientos de despunte apical, basal, y apical-basal, más un control. En un tercer experimento las semillas se sometieron a diferentes profundidades de siembra (0,5, 1, 2, 5 y 10 cm) en turba como sustrato. Los resultados indicaron que el ácido giberélico en concentraciones superiores a 200 mg L<sup>-1</sup> presentó un efecto inhibitorio de germinación y, por tanto, del crecimiento de las plántulas. La germinación con 200 mg L<sup>-1</sup> de GA y el control fue similar, pero en el control la germinación ocurrió más rápido. Por su parte, el despunte apical-basal generó el mayor porcentaje de germinación, la mayor velocidad media de germinación, y un tiempo significativamente inferior al control; sin embargo, la mayor longitud de parte aérea fue presentada en las semillas sin despunte, y la mayor longitud de raíz en el despunte basal. La emergencia de las plántulas disminuyó en función de la profundidad de siembra, ya que fue significativamente mayor en 0,5, menor a 2 cm y en profundidades mayores no se logró emergencia de las plántulas.

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**S***onchus oleraceus* L. (Asteraceae) is an herbaceous species with medicinal properties (Alothman et al. 2018). In folk medicine, the leaf infusions of *S. oleraceus* are employed to treat headaches, hepatitis, bacterial infections, and inflammations, since this species possesses strong anti-inflammatory effects (Vilela et al. 2009); its latex is known for antibacterial properties (Ghaffaripour et al. 2021). It gained attention in agriculture because it is a noxious invasive weed as a result of its genetic diversity and morphological features, together with herbicide resistance (Khalsa et al. 2021; Peerzada et al. 2021; Chauhan and Jha 2020). It is highly competitive, difficult to control in the field, and tends to adapt well to varied crop regions because of its germination and growth in broad temperature regimes and soil conditions (Rojas-Sandoval et al. 2015; Manalil et al. 2018; Ali et al. 2020). It is widely distributed worldwide (Morrison et al. 2021; Peerzada et al. 2021) and, in Colombia, is found in the highlands in various crops (Gámez et al. 2018; Moreno-Preciado and Balaguera-López 2021; Martínez et al. 2022).

*S. oleraceus* L. is an annual plant that reproduces only by seeds (Khalsa et al. 2021). Its seeds need light to germinate and can germinate at any time of the year (Rojas-Sandoval et al. 2015) and have the potential to emerge all year round from the top 2 cm layer of soil, but emergence is favored when seeds are sown 1 cm deep (Widderick et al. 2010). Khalsa et al. (2021) compiled germination studies on *S. oleraceus* for temperate and subtropical climate conditions, which evidenced different environmental requirements for seeds to germinate. Under tropical conditions, there are few reports, but the germination percentage can be between 41 and 72.5% (Martínez et al. 2022). According to Savaedi et al. (2019), seed germination is highly sensitive to environmental factors. Under high tropical conditions, the details of the germination physiology of this species are unknown. At the same time, this information could be beneficial in comprehensive weed management (Niño-Hernández et al. 2020) optimizing germination when *S. oleraceus* is cultivated as a medicinal species.

The light requirement for germination and germination dependence on chemical signals from the environment (nitrate, gibberellins, ethylene, karrikins, and others) are some of the factors that could trigger germination in small seeds with few storage reserves (Baskin and Baskin 2014),

such as those of *S. oleraceus*. If they germinate too deep in the soil, their nutrient reserves are insufficient to sustain the seedling growth to successfully emerge at the soil surface (Fenner 2012). Typically, weed seeds are dormant to ensure their survival by avoiding unfavorable conditions (Bera et al. 2020). They can present physiological dormancy, where applying gibberellins can stimulate germination (Lutts et al. 2016; Savaedi et al. 2019). Gibberellins are hormones that control seed germination through the activation of hydrolytic enzymes and, in photoblastic species, reactions mediated by PhyA and PhyB phytochromes (Barros-Galvão et al. 2019; Savaedi et al. 2019; Castro-Camba et al. 2022). Nevertheless, some seeds require scarification processes to guarantee the entry of water and oxygen to the embryo, such as when they present physical dormancy (Baskin and Baskin 2014).

Therefore, this research aimed to evaluate the physiological behavior of *S. oleraceus* seeds with different pre-germinative treatments under high tropical latitudinal conditions.

## MATERIALS AND METHODS

### Location and plant material

The research was carried out in the Plant Physiology laboratory of the Faculty of Agricultural Sciences of the Pedagogical and the Technological University of Colombia, Tunja Headquarters, located at 5°33'20.1" N, 73°21'18.0" W, and 2,782 meters above sea level (masl).

For the collection of *S. oleraceus* seeds, visits were made in July, 2018 to crops in the municipalities of Duitama, Nobsa, Paipa, and Tibasosa in traditional agricultural fields of broccoli (*Brassica oleracea* var. *italica*), cauliflower (*B. oleracea* var. *botrytis*), lettuce (*Lactuca sativa* L.), cabbage (*B. oleracea* var. *capitata*), and spinach (*Spinacia oleracea* L.), in addition to harvested fields. Once the species was identified by its leaves, growth habit, and flower, floral structures in optimal health and maturity were harvested; that is, all flowers that were about to release the seeds were collected, identifying this stage by exposure of the pappus since this structure disperses seeds through the air. To facilitate the seed counting and selection methodology, the pappus was removed from the seeds, which facilitated the release of the seeds in a group and allowed the collection of more than 80 seeds per inflorescence. The weight of 1,000 fresh seeds without pappus was 0.2782 g, and the length of each seed

was approximately 3 mm (Figure 1). These seeds were deposited in a resealable bag, thus, making a mixture of seeds between the different crops and municipalities of origin, to guarantee a representative sample of land with an agricultural tradition in the department and, simultaneously, facilitate subsequent handling.

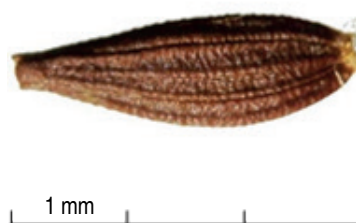
The harvested seeds were left to dry at room temperature ( $18\pm 1.9$  °C) and stored under dark conditions in paper bags for 30 days. The seed sample was used to carry out three experiments, each under a completely randomized design, as described below:



**Figure 1.** Adult plants and mature sexual propagules of *S. oleraceus* grown in high tropical latitudinal conditions.

### Experiment 1

The seeds were imbibed in solutions with different concentrations of gibberellins (0, 200, 400, and 600 mg L<sup>-1</sup> of GA<sub>3</sub>), which were based on the reports of Niño-Hernández et al. (2020). Four replicates per treatment were used, and each of the 16 experiment units consisted of a Petri dish with 100 seeds. Each gibberellin solution was prepared in distilled water and with the product ProGibb® 10 SP (Bayer S.A, Colombia), whose active ingredient is gibberellic acid (100 g kg<sup>-1</sup>). The treatments were applied daily to the Petri dishes to moisten the absorbent paper.



### Experiment 2

For this experiment, a cut was made to the seeds in the apical part (insertion zone with the pappus), basal part (insertion zone with the floral receptacle), and apical-basal part, and a group of seeds was left intact, without any cut (control), for a total of four treatments with four replicates. Each experiment unit was made up of 100 seeds. Once this procedure was carried out, the seeds were placed in Petri dishes with distilled water and absorbent paper.

### Experiment 3

Five treatments corresponding to the sowing of *S. oleraceus* seeds at different depths (0.5, 1, 2, 5, and 10 cm) were evaluated, each treatment presented four replicates.

Each replicate consisted of 100 seeds sown in 0.5 L pots with PRO-MIX blonde peat as the substrate, whose physicochemical properties are reported in Moreno et al. (2009). The sowing of each seed was carried out through a 5 mm diameter tube that was inserted into the substrate to the depth required in each treatment. After sowing, the seeds were covered with the same substrate. The substrate was kept moist at field capacity with daily irrigation with distilled water, following the gravimetric method, adapted from Segura et al. (2011).

All the experiments had natural light ( $211 \mu\text{mol m}^{-2} \text{s}^{-1}$ ) conditions, with a photoperiod of 12 h and an average temperature of  $18\pm 1.9$  °C, which is considered a favorable

temperature for seed germination of this species (Gresta et al. 2010).

### Physiological variables

The germination readings and the time in which this occurred were recorded every two days from the germination of the first seed until constant germination (no further germination obtained). This was at 18, 16, and 34 days for experiments 1, 2, and 3, respectively. A seed was considered germinated when the already visible radicle measured at least 2 mm in length. In the sowing depth experiment, the percentage of seedling emergence was measured, understood as the emergence of the hypocotyl on the surface of the substrate. From these data and with the formulas used by Porras et al. (2020), the following variables were calculated: the germination percentage, mean germination speed (germinated seeds  $d^{-1}$ ), and mean germination time (d).

In experiments 1 and 2, the length (mm) of the aerial part and roots were measured on ten seedlings in each experiment unit. The shoot and root length were measured with the help of a Mitutoyo digital caliper with an approximation of 0.05 mm.

### Statistical analysis

The accumulated germination was adjusted to the logistic model according to the methodology used by Cepeda et

al. (2021) and Maestre et al. (2023); the first derivative of the model calculated the germination rate as a function of time. This procedure was carried out with R Studio.

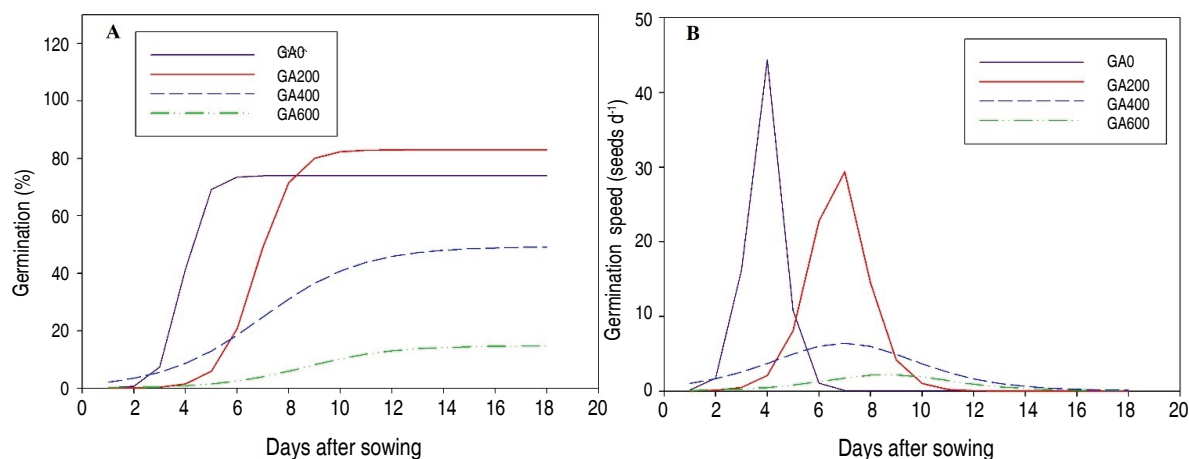
The data were subjected to tests of normality of errors (Shapiro-Wilk) and homogeneity of variances (Levene). With these assumptions, an analysis of variance was carried out. In the case of significant differences ( $P < 0.05$ ), a mean comparison test was performed using the Tukey test ( $P < 0.05$ ) or regression analysis. These analyses were performed with the statistical program SPSS V.19.

## RESULTS AND DISCUSSION

### Experiment 1

#### Effect of gibberellic acid

For germination behavior, a logistic model was adjusted at all concentrations (Figure 2 and Table 1). The seeds of the control treatment were characterized by rapid germination during the first seven days, at which time 73.88% of the seeds germinated. The highest speed (44.37 germinated seeds  $d^{-1}$ ) was obtained four days after sowing. Afterward, germination remained more or less stable until 18 days. With 200  $mg L^{-1}$  of  $GA_3$ , the germination began two days later, but the final germination was similar, with a high germination speed for several days. With 600  $mg L^{-1}$ , the percentage and speed of germination were significantly lower throughout the study (Figure 2).



**Figure 2.** Effect of different doses of gibberellic acid (0, 200, 400, and 600  $mg L^{-1}$ ) on accumulated germination (A) and the germination speed (B) of *S. oleraceus* seeds.

**Table 1.** Fitting equations to the logistic model for the percentage germination of *Sonchus oleraceus*.

| Experiment and treatments                      |  |         |                |
|--|--|---------|----------------|
| Doses of GA <sub>3</sub> (mg L <sup>-1</sup> ) | Equations  | RMSE    | R <sup>2</sup> |
| 0  | $Y = 73.92701 / (1 + e^{-2.43708 \cdot (d-3.89981)})$  | 5.734** | 0.99           |
| 200  | $Y = 83.01280 / (1 + e^{-1.46250 \cdot (d-6.75061)})$  | 0.931** | 0.99           |
| 400  | $Y = 49.22702 / (1 + e^{-0.52103 \cdot (d-6.97901)})$  | 1.909** | 0.99           |
| 600  | $Y = 14.70987 / (1 + e^{-0.60196 \cdot (d-8.66652)})$  | 0.770** | 0.99           |
| Type of scarification                          |  |         |                |
| Control  | $Y = 42.09100 / (1 + e^{-0.97774 \cdot (d-9.13908)})$  | 2.089** | 0.99           |
| Apical   | $Y = 68.81148 / (1 + e^{-1.78114 \cdot (d-7.88151)})$  | 1.862** | 0.99           |
| Basal  | $Y = 68.77001 / (1 + e^{-0.39613 \cdot (d-4.68048)})$  | 5.965** | 0.97           |
| Apical-Basal                                   | $Y = 82.54229 / (1 + e^{-0.79438 \cdot (d-5.01683)})$  | 4.193** | 0.99           |
| Sowing depth (cm)                              |  |         |                |
| 0.5  | $Y = 44.82591 / (1 + e^{-0.34541 \cdot (d-7.78351)})$  | 4.030** | 0.96           |
| 1  | $Y = 30.06247 / (1 + e^{-0.20734 \cdot (d-13.86410)})$ | 1.549** | 0.99           |
| 2  | $Y = 3.72262 / (1 + e^{-0.54904 \cdot (d-10.95104)})$  | 0.261** | 0.99           |

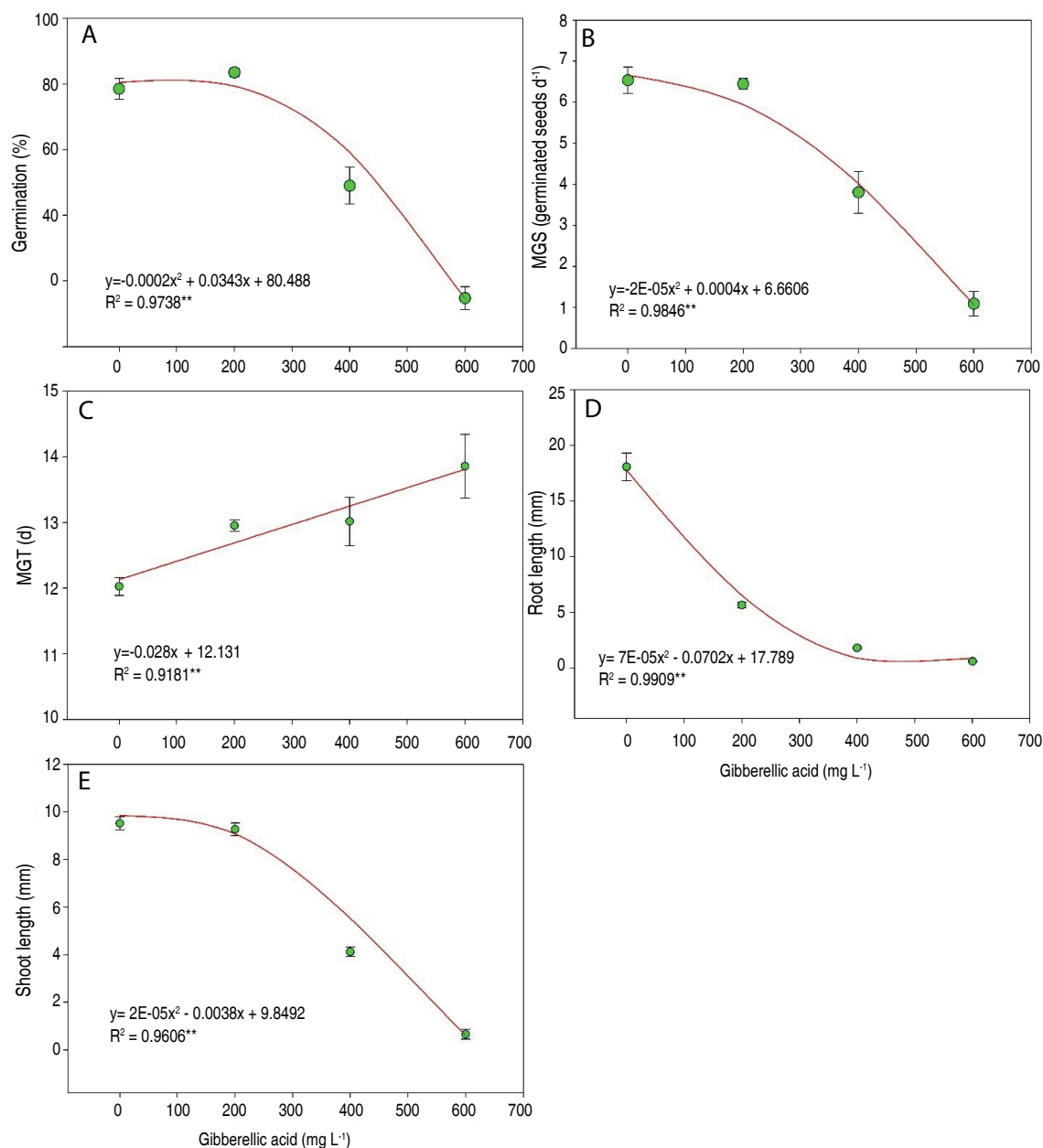
\*\* Significant models ( $P < 0.01$ ). RMSE: root means square error.

The final germination percentage presented statistical differences ( $P < 0.05$ ) between the concentrations of GA<sub>3</sub>. It was higher with 0 (78.5±3.1%) and 200 mg L<sup>-1</sup> of GA<sub>3</sub> (83.5±5.61%) and lower with 600 mg L<sup>-1</sup> (14.75±3.5%); this behavior was adjusted to a quadratic equation (Figure 3A). The mean germination speed (MGS) was also adjusted to the same type of regression. The highest speed was observed with 0 and 200 mg L<sup>-1</sup> of GA<sub>3</sub> (Figure 3B). The mean germination time (MGT) presented significant differences, and a linear behavior was observed that depended on the increase in GA<sub>3</sub>, which was higher with 600 mg L<sup>-1</sup> (Figure 3C).

The length of the main root was significantly greater in the control seedlings and decreased quadratically as the concentration of GA<sub>3</sub> decreased (Figure 3D). The length of the aerial part was greater with 0 and 200 mg L<sup>-1</sup> of GA<sub>3</sub>, but with 400 and 600 mg L<sup>-1</sup> of GA<sub>3</sub>, this parameter was significantly reduced, described by a second-degree polynomial (Figure 3E).

In the control seeds, endogenous gibberellins can be responsible for inducing germination; these plant hormones, particularly GA<sub>1</sub> and GA<sub>4</sub> induce germination through the activation of hydrolytic enzymes that degrade reserve polysaccharides in the endosperm, such as amylases,

and structural polysaccharides of seed coats (Castro-Camba et al. 2022; Gong et al. 2022). Additionally, seeds that germinate faster have the possibility of starting root growth and shooting first, for this reason, in the control treatment, seedlings were also larger in size (Figure 3D, E). However, the applications exceeding 200 mg L<sup>-1</sup> GA<sub>3</sub> reduced the seed germination percentage in *S. oleraceus* and seedling growth. The adverse effects of GA<sub>3</sub> on seed germination are not frequent but have been reported previously for various species. *S. oleraceus* could react negatively to GA<sub>3</sub> because the 13-hydroxylation pathway negatively affects its biological activity (Magome et al. 2013). To respect, Lee et al. (2022) found that GA<sub>3</sub> did not promote germination while combining GA<sub>1</sub> and GA<sub>4</sub> effectively broke *Amsonia elliptica* seed dormancy. In coffee seeds, GA applications resulted in the release of one or more compounds from the endosperm that further induced cell death in the embryo (Da Silva et al. 2005). These authors argued that the GA-caused inhibition occurs very late during germination and immediately before radicle protrusion. In particular, the mechanism of the GA-induced inhibition of coffee seed germination may involve the release of mannose as the result of mannan degradation by GA, where mannose accumulation could inhibit ATP synthesis and hexose metabolism in seeds (Da Silva et al. 2005).



**Figure 3.** Effect of different concentrations of gibberellic acid (0, 200, 400, and 600 mg L<sup>-1</sup>) on germination percentage (A), mean germination speed (B), mean germination time (C), length of root (D), and length of shoot (E) of *S. oleraceus*. Vertical bars for each mean indicate the standard error (n=4). \*\*significant regression ( $P < 0.01$ ).

The GA<sub>3</sub> treatments of 125, 250, and, especially, 500 mg L<sup>-1</sup> of seeds of *Ferocactus histrix* and *F. latispinus* (Cactaceae) had adverse effects on their germination percentages and germination speed, which might be attributed to the use of the supra-optimal concentrations of GA<sub>3</sub> (Amador-Alfárez et al. 2013). GA<sub>3</sub> had no positive effects on germination

percentage and germination dynamics in *Euptelea pleiospermum* seeds, while light and KNO<sub>3</sub> positively affected germination (Wei et al. 2010). In *Hepatica asiatica* seeds, applications of gibberellic acid (GA<sub>3</sub>) promoted embryo growth, reducing morphological dormancy, but had no positive effect on radicle protrusion (Chon et al.

2015). Additionally, the interaction with other hormones might modify the effects of GA on seed germination. Thus, GA<sub>4+7</sub> and cytokinin mixture delayed seed germination and reduced seedling formation in eggplant (Neto et al. 2017).

The duration and the temperature of seed storage may also diminish the effects of GA treatment on seed germination (Rivera et al. 2011). In sweet corn, GA applications at a rate of 10-20 mg L<sup>-1</sup> lost their positive effect on seed germination when the storage time exceeded 60 days, especially when the seeds were stored at 25 °C (Rivera et al. 2011). Some of these processes may have occurred in *S. oleraceus* seeds; however, other studies at the molecular level are needed to understand in more detail the GA inhibition of germination observed in these seeds.

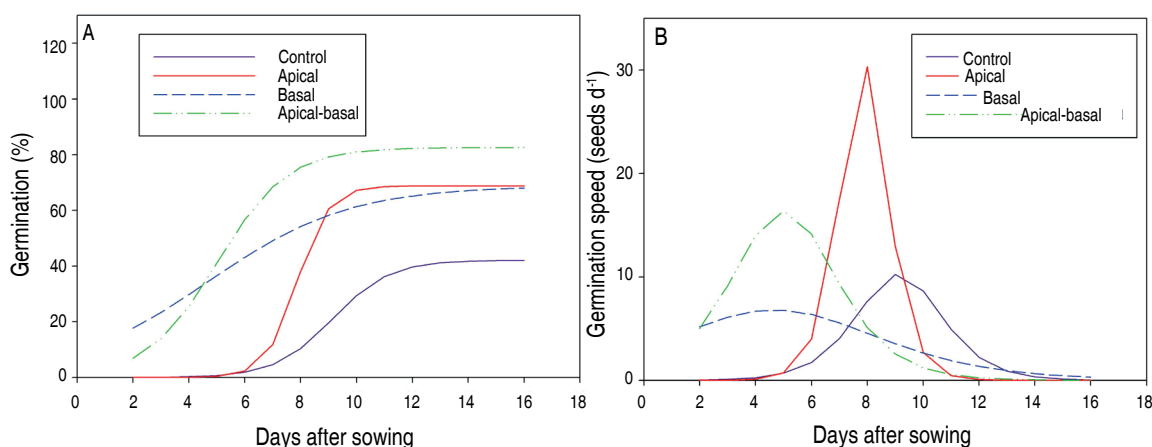
## Experiment 2

### Type of scarification

For germination behavior in all treatments, initial

germination was slow, which then had a marked increase, and, at the end of the experiment, it was slower (Figure 4A and Table 1). Greater germination was observed with the basal-apical cut, with a representative speed in the first 11 days. With the apical cut, germination started late but most of the seeds germinated quickly. For this reason, the peak germination speed was the highest (30.3 germinated seeds d<sup>-1</sup> on day 8) but extended for a short time. The seeds with a basal cut constantly germinated throughout the experiment, which is why the speed was similar in most of the experiments. However, it was the lowest, even below the control, which might indicate that the embryo received mechanical damage during the basal cut. Nevertheless, this last treatment germinated slower at a lower percentage and only had a representative speed at nine days (Figure 4B).

The final percentage of germination was significantly different between treatments, being higher in the seeds



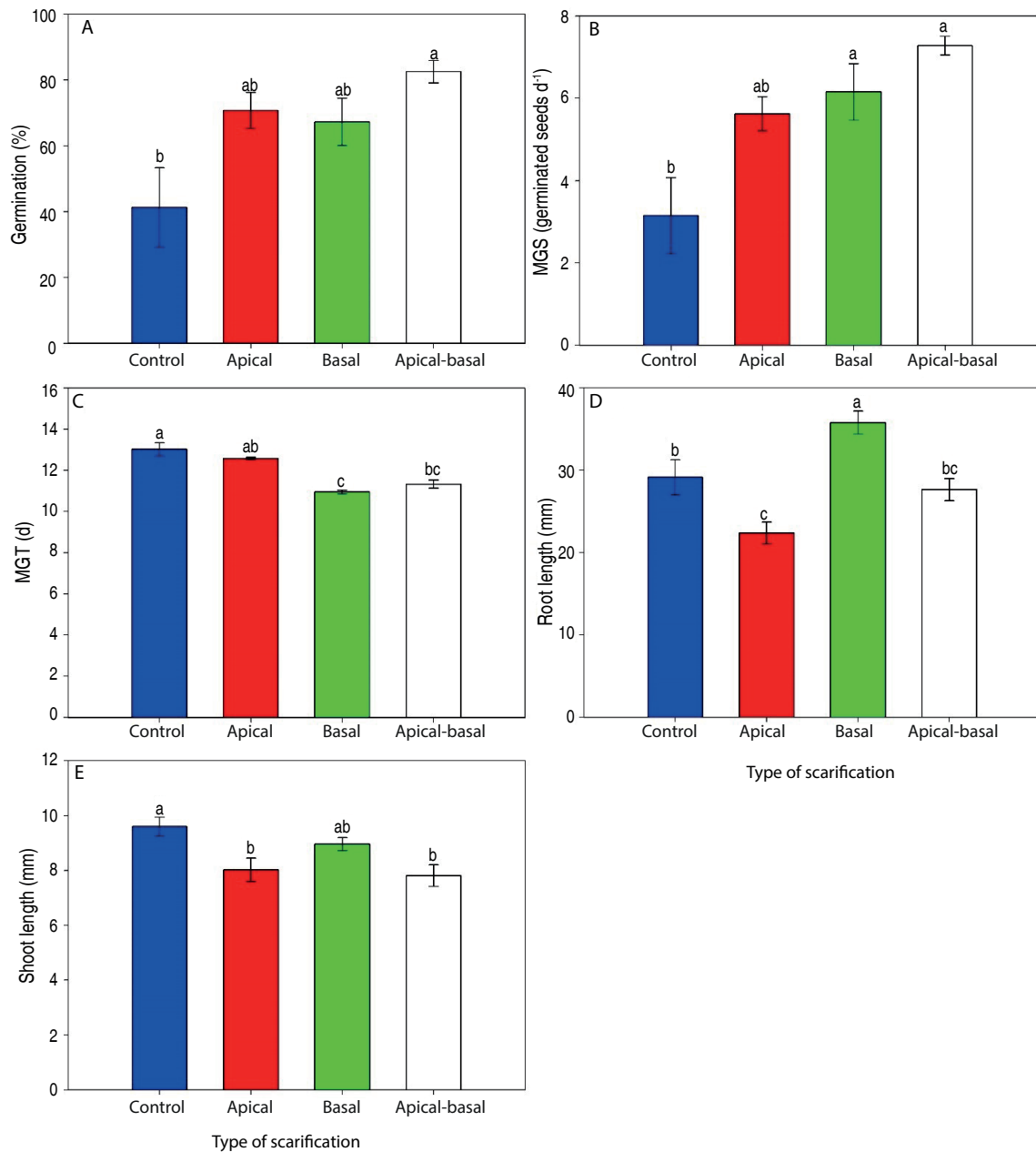
**Figure 4.** Effect of scarification type on accumulated germination (A) and the germination speed (B) of *S. oleraceus* seeds.

with the two cuts ( $82.5 \pm 3.4\%$ ) and lower in the control seeds (Figure 5A). MGS was significantly higher with the basal and apical-basal cut, and the control presented the lowest value (Figure 5B). The most favorable response for MGT was obtained with the basal cut as it presented less time ( $10.95 \pm 0.09$  d), followed by the seeds with the apical-basal cut. The opposite response was obtained with the control seeds (Figure 5C).

Root length was significantly affected by the cut type. It was more significant with the basal cut ( $35.8 \pm 1.4$  mm) and

less with the apical cut (Figure 5D). The control seedlings had the highest growth for shoot length with significant differences in the treatments with an apical cut and an apical-basal, which presented lower values (Figure 5E).

The germination percentages were different in the experiments (Figures 3, 7, and 5) but were close to previous reports for the tropics, which indicated that germination in this species can be between 41 and 72.5% (Martínez et al. 2022). However, in Australia, 65 to 100% of *S. oleraceus* seeds germinated (Widderick et al. 2004).



**Figure 5.** Effect of scarification type on germination percentage (A), mean germination speed (B), mean germination time (C), length of root (D), and length of shoot (E) of *S. oleraceus*. Means followed by different letters indicate significant differences according to the Tukey test ( $P < 0.05$ ). Vertical bars for each mean indicate the standard error ( $n=4$ ).

The results suggest the presence of exogenous, probably physical dormancy in *S. oleraceus* seeds, since the basal, apical, and, especially, joint apical-basal cuts accelerated seed germination because a cut in the seed coat allows the uptake of water and oxygen into the seed in less time

(Baskin and Baskin 2014). Physical dormancy is one of the most common types of dormancy in plant species, where the seed or fruit coats are water-impermeable and unable to imbibe water, limiting the germination process (Baskin and Baskin 2014). For this reason, scarification is one of

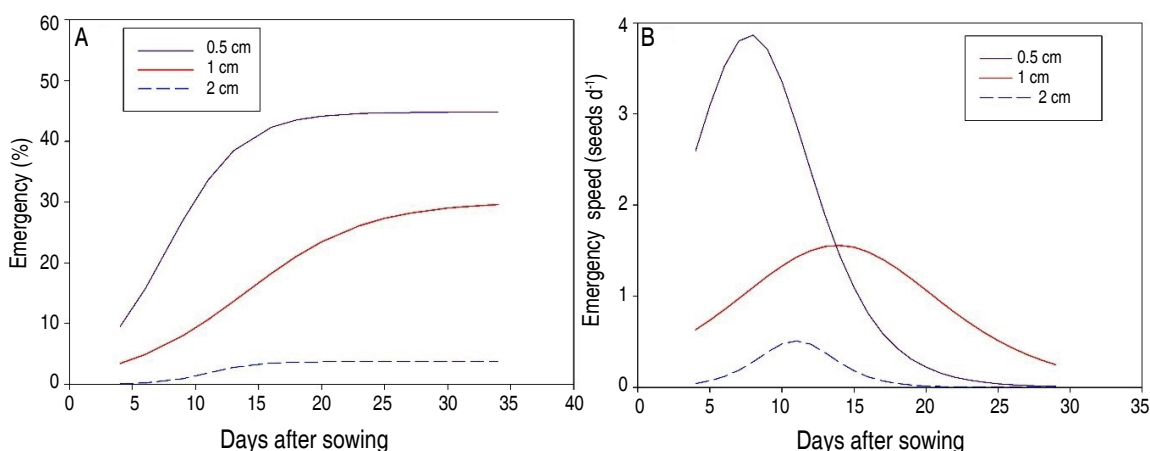
the main methods to break this dormancy (Arceo-Gómez et al. 2022; Guo et al. 2022). In nature and field crops, *S. oleraceus* can overcome physical dormancy through day/night temperature changes, high rainfall, microbial activity, soil acidity, or even passage through the digestive tract of some animals, among others, as reported for other species (Baskin and Baskin 2014). If this does not occur, the germination percentages that the species normally present may be sufficient, compensated for by the high number of seeds the plant produces, but also by its easy dispersion (Andrade et al. 2022). It has been reported that the average number of seeds per capitulum in this species is around 140 and the mean number of capitula per plant is 4.4 (Cici and Van Acker 2009).

The basal and apical cuts allow more uptake of water and oxygen to the seeds, which probably explains the higher and faster germination found in *S. oleraceus*. However,

it remains unexplained how seedlings obtained with this treatment had a short length since it would be expected that they would be larger as they germinate faster. Partially similar results were found in *Passiflora edulis* Sims and *Passiflora ligularis* seeds, where a basal cut increased germination over the control (Gutiérrez et al. 2011).

### Experiment 3 Sowing depth

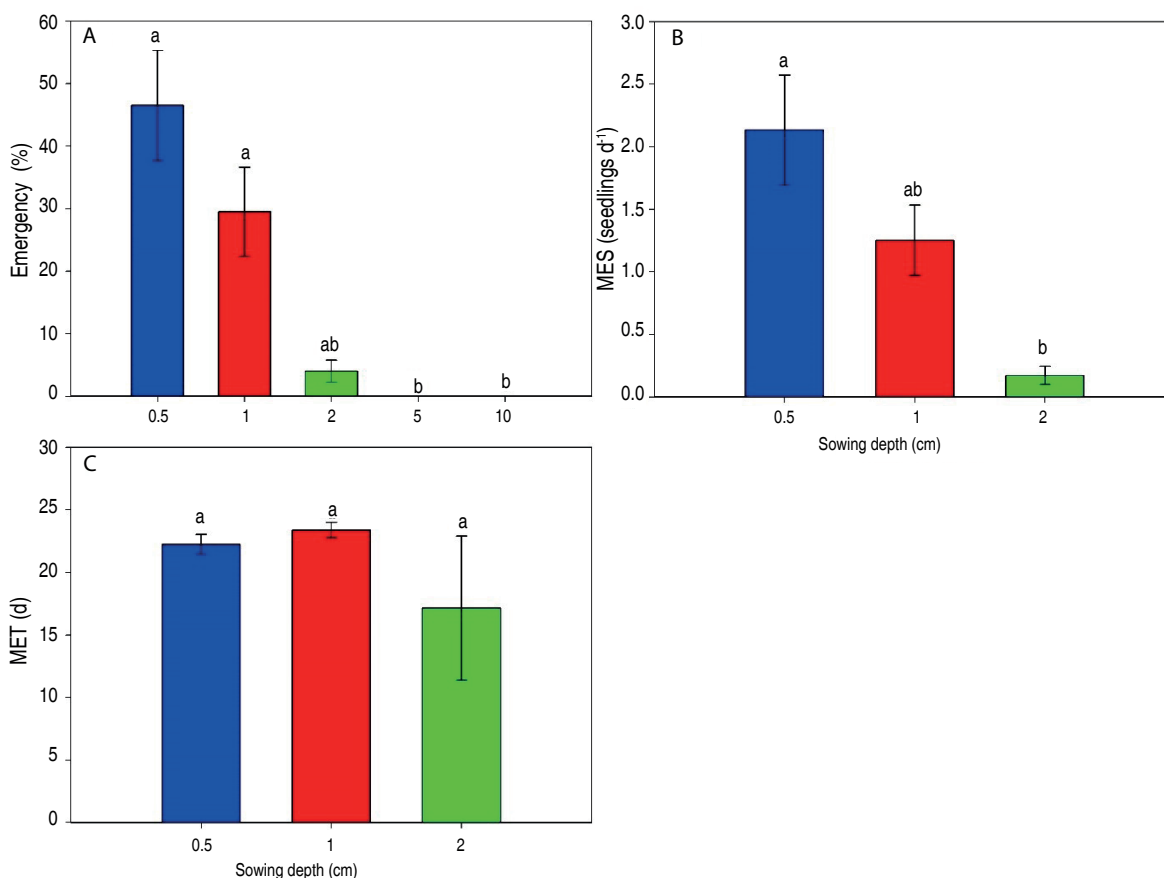
For germination behavior, the seeds sowed at shallow depths had high percentages of emergence in the first 16 days, which then tended to stabilize until the end of the experiment. This also coincided with a higher speed of emergence, with a maximum peak at eight days. As the depth increased, the percentage and speed of emergence decreased considerably, mainly at a depth of 2 cm (Figure 6). At the three depths, the logistic model described the emergence behavior (Figure 6A and Table 1).



**Figure 6.** Effect of sowing depth on accumulated emergence (A) and the emergence speed (B) of *S. oleraceus* seedlings.

The final emergence percentage presented statistical differences ( $P < 0.01$ ), and there was a tendency for less emergence with a greater depth. Seedling emergence was no longer evident, even at depths greater than 2 cm (Figure 7A). For this reason, depths 5 and 10 cm in MES and MET were not included. The MES was statistically higher at a depth of 0.5 cm ( $2.13 \pm 0.44$  emerged seedlings  $d^{-1}$ ). The planting depth of 2 cm generated the lowest speed with  $0.17 \pm 0.07$  emerged seedlings  $d^{-1}$ . MET had no statistical differences; the times were between 22 and 23 d (Figure 7C).

This reduction in the germination percentage and emergence rate at a greater depth could have been caused by external factors, including changes in light regime or lowering temperature with sowing depth (Baskin and Baskin 2014). However, according to Gresta et al. (2010), *S. oleraceus* seeds from Mediterranean populations were indifferent to light conditions during germination and maintained germination over 90% at temperatures between 10 and 35 °C. In this case, it may have been the factor of seed size (small seed reserves) that was responsible for the reduced seed



**Figure 7.** Effect of sowing depth on emergence percentage (A), mean emergence speed (B), and mean emergence time (C) of *S. oleraceus*. Means followed by different letters indicate significant differences according to the Tukey test ( $P < 0.05$ ). Vertical bars for each mean indicate the standard error ( $n=4$ ).

germination (Fenner 2012). Since *S. oleraceus* achenes are small (1 wide and 2-4 cm long), insufficient seed reserves might have limited the seedling emergence from the greatest depth.

The results obtained for *S. oleraceus* agree with Manalil et al. (2018), who indicated that light favored germination, which occurred at the first depths (0.5 to 2 cm). In this respect, Widderick et al. (2010) indicated that *S. oleraceus* can emerge all year round from the top 2 cm layer of soil, where emergence is favored more when seeds are 1 cm deep. *S. oleraceus* seeds found at depths greater than 2 cm, similar to those reported in another species, can remain viable for a variable time and may eventually germinate when the soil layer is turned, a common situation in different agricultural soils. Other seeds can fall to greater depths through the soil

pores and finally die if the soil is not disturbed for several years (Baskin and Baskin 2014). Therefore, zero-tillage is an effective method for managing this species since most of the seeds remain in the uppermost 2 cm soil layer, and the seed bank can become smaller with increasing soil depths (Khalsa et al. 2021). On the other hand, Widderick et al. (2010) reported that, in eastern Australia, 2% of seeds were viable on the soil surface after six months, and 12% remained intact at a depth of 10 cm after thirty months. Although germination is increased by light, low germination is possible under darkness, indicating the potential of this species to emerge under conditions of shallow burial or residue cover (Manalil et al. 2018).

Similar to what was found in *S. oleraceus*, Niño-Hernández et al. (2020) reported that *Amaranthus hybridus* tends to

have a greater germination capacity when it is found at a shallower depth in the soil (3 cm). On the other hand, Li et al. (2020) reported that *Periploca sepium* seeds germinated faster at 2 cm, while at depths of 4-5 cm, the speed decreased considerably.

## CONCLUSIONS

Gibberellic acid concentrations higher than 200 mg L<sup>-1</sup> had an inhibitory effect on germination and, consequently, on seedling growth, unusual behavior in nature. Apical-basal cuts on the seeds generated the highest germination percentage (82.5±3.4%), and the process occurred faster than in the control. Seedling emergence was affected by planting depth, where *S. oleraceus* germinated at depths less than 2 cm, at greater depths, seedlings did not emerge. With 0.5 cm the highest percentage was obtained, corresponding to 46.5±8.8%. The results indicated that *S. oleraceus* presents physical dormancy and requires light to germinate. In all experiments, the logistic model described the behavior of germination percentage as a function of time. These results contribute to the knowledge of the physiology and ecology of this species and may be useful for integral management strategies for this weed.

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