

Seed priming methods tested on *Salvia officinalis* L. germination according to BBCH scale

Valentina A. STOIAN¹, Ștefania GÂDEA^{1*}, Roxana VIDICAN²,
Claudia BALINT³, Vlad STOIAN², Anamaria VÂTCĂ^{4*},
Mădălina TRUȘCĂ¹, Melinda HORVAT⁵, Bojana BROZOVIĆ⁶,
Dorin CAMEN⁷, Sorin D. VÂTCĂ¹

¹University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Faculty of Agriculture, Department of Plant Physiology, Calea Mănăștur 3-5, 400372 Cluj-Napoca, Romania; valentina.stoian@usamvcluj.ro; stefania.gadea@usamvcluj.ro (*corresponding author); ioana-madalina.trusca@student.usamvcluj.ro; sorin.vatca@usamvcluj.ro

²University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Faculty of Agriculture, Department of Microbiology, Calea Mănăștur 3-5, 400372 Cluj-Napoca, Romania; roxana.vidican@usamvcluj.ro; vlad.stoian@usamvcluj.ro

³University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Faculty of Agriculture, Department of Engineering and Environmental Protection, Calea Mănăștur 3-5, 400372 Cluj-Napoca, Romania; claudia.balint@usamvcluj.ro

⁴University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Faculty of Animal Science and Biotechnologies, Department of Management and Economics, Calea Mănăștur 3-5, 400372 Cluj-Napoca, Romania; anamaria.vatca@usamvcluj.ro (*corresponding author)

⁵University of Medicine and Pharmacy Iuliu Hațieganu Cluj-Napoca, Faculty of Medicine, Department of Infectious Diseases, Babeș Street 8, 400012 Cluj-Napoca, Romania; melinda.horvat@umfcluj.ro

⁶Josip Juraj Strossmayer University of Osijek, Faculty of Agrobiotechnical Sciences Osijek, Vladimira Preloga 1, HR-31000 Osijek, Croatia; bojanat@fazos.hr

⁷Banat's University of Agricultural Sciences and Veterinary Medicine "King Michael I of Romania" from Timisoara, Faculty of Horticulture and Forestry, Calea Aradului 119, RO-300645 Timișoara, Romania, dorincamen@usab-tm.ro

Abstract

Seed dormancy is a major impediment for the production of *Salvia officinalis* L. (sage) seedlings. This study aims to test seed priming methods to break the dormancy of sage seeds in controlled conditions. Seeds were subjected to four treatments respectively hydropriming, magneto-priming, electro-priming and control with no seed priming techniques. During germination development stage all parameters were registered according to BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) standardized scale. Daily assessments were made, germination indices were calculated, new germination secondary stages were observed and described, and daily range for each secondary stage were obtained. All priming methods had different effect on sage seeds. The hydropriming treatment was the most effective with 70% seeds germinated in 10 days. Sage seeds from magneto-priming determine more than 50% seeds to germinate in only 8 days. Control and electropriming treatment showed a similar value of seed germination, set around 64-65%. In control, electro- and hydropriming treatments are necessary 6 days for the achievement of more than 50% seed germination, while for magneto-priming are necessary 8 days. Hydropriming has the highest germination index, significantly higher than control and magneto-priming. During the germination, hydropriming shows a

Received: 07 Feb 2024. Received in revised form: 19 Apr 2024. Accepted: 21 May 2024. Published online: 03 Jun 2024.

From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

gradual transition of seeds from one BBCH sub-stage to another, while electro- and magneto-priming induce a heterogenous variation through the entire process. Overall, the hydropriming treatment registered better results of sage germination compared to the control treatment.

Keywords: BBCH growth scale; seed germination; hydropriming; magneto-priming; electro-priming

Introduction

Medicinal aromatic plants (MAPs) are cultivated on a small area worldwide (Chrysargyris *et al.*, 2022). This group of plants presents a various number of species with very different biological characteristics. In general, MAPs can be used as green (Maleš *et al.*, 2022), dried (Taban *et al.*, 2021), preserved (Barata *et al.*, 2016), chemically and thermally processed (Rahmati *et al.*, 2022) or raw materials in various industries (Lubbe *et al.*, 2011). The directions in which the MAPs production is oriented, show a high diversity of species, active components, numerous specific agro-ecological growing conditions, and market prices. In a world where the significance of crop production cannot be overstated, it is evident that unconventional techniques deserve careful consideration as a viable solution for augmenting food resources and revitalizing some plant varieties (Porto *et al.*, 2019; Rifna *et al.*, 2019; Bhusal *et al.*, 2020; Ercan *et al.*, 2022). The researcher's efforts, who have tested different factors that can affect the germination process (Raccuia *et al.*, 2016; Lamichhane *et al.*, 2018), discovered methods that could improve plant growth and development. These methods hold the potential to enhance plant growth rates by accelerating the critical physiological processes within seeds, particularly beneficial for the cultivation of MAPs, ensuring a reliable and sustainable yield. In light of these findings, the exploration of unconventional approaches is not only relevant but also essential in addressing the pressing challenges of modern agriculture and food security.

Germination, one of the most important and complex physiological process for MAPs production is characterized by the activation of the germplasm (Bhardwaj *et al.*, 2016; Moldovan *et al.*, 2022). It was stated that testa or the seed coat of several MAPs plants could contain substances that inhibit natural germination as jasmonic acid, abscisic acid, benzoic acid, and cinnamic acid (Bhardwaj *et al.*, 2016). Until now, it is unclear what cycles of dormancy or nondormancy does sage have, the germination patterns depend upon species and regulated by temperature (Bai and Romo, 1994). The germination pattern of a plant represents the most important factor for providing healthy seedlings, particularly for MAPs used in the healthcare system (Bhardwaj *et al.*, 2016). Also, the seed germination process is framed as a key in plant life strategy, especially the transition from one developmental stage to the following one (Bhardwaj *et al.*, 2016; Zavareh *et al.*, 2008). The most recent scale for assessing primary and secondary stages of plants development is represented by the BBCH scale (Meier, 2018).

A global comeback of MAPs strategies is urgently needed for assuring seed germination as a biological key on plant life cycle (Liopa-Tsakalidi *et al.*, 2011) because of overexploitation (Catană *et al.*, 2020) or low soil fertility (Zare *et al.*, 2011). Since in agriculture, the seed germination is considered very important to obtain vigorous plants and at the end of vegetation period high yields, in recent decades, seed priming, a seed invigoration method, has become a popular method for increasing germination rates and increasing crop production (Malarkodi *et al.*, 2022). Seed priming techniques stimulates and promotes seed germination by soaking seeds in different agents as a controlled hydration (Farooq *et al.*, 2006; Zare *et al.*, 2011). The germination mechanisms affected by the priming techniques are related with reduced time of seed imbibition, breaking endosperm physical resistance, enhancing radicle growth from the pericarp, increase embryo activity and radicle emergence, and passing the germination barriers overall (Elouaer and Hannachi, 2012; Ibrahim *et al.*, 2016; Ghasemi *et al.*, 2021). Hydropriming, is a simple, acceptable, efficient technique, also environmentally friendly, with economic benefits because of water use for stimulating seeds to germinate (Zare

et al., 2011). Early studies highlighted that hydropriming for 24 hours improved *Foeniculum vulgare* Mill. (fennel) (Hoseini *et al.*, 2013), *Tanacetum cinerariifolium* Trev. (pyrethrum) (Li *et al.*, 2011), and *Thymus vulgaris* L. (thyme) (Moori and Ahmadi-Lahijani, 2020) germination, 48 hours were needed for optimal germination of *Achillea millefolium* L (Nejad *et al.*, 2022), *Ocimum basilicum* L. (Stoian *et al.*, 2022) *Nigella sativa* L. (black cumin) (Fallah *et al.*, 2018), and *Satureja montana* L. (winter savory) (Vidak *et al.*, 2022). Contradictory results were obtained for *Catharanthus roseus* L. (Madagascar Periwinkle) under salinity stress (15 hours) (Ghasemi *et al.*, 2021), and for *Matricaria chamomilla* L. (chamomile) primed for 48 and 72 hours (Falahhosseini *et al.*, 2017). Other stimulation methods of seed germination used laser (Abdani Nasiri *et al.*, 2018; Mardani Korrani *et al.*, 2023), microwave (Viliche Balint *et al.*, 2016), electric (Stoian *et al.*, 2022; Kumar and Pandey, 2021), magnetic field (Abdani Nasiri *et al.*, 2018; Ercan *et al.*, 2022) or cold plasma (Porto *et al.*, 2019; Singh *et al.*, 2022) for dormancy breaking and obtaining healthy seedlings with high resistance to the pest and diseases and also to the negative environmental factors that could affect the optimum growth and development (Rifna *et al.*, 2019).

Salvia officinalis L. having the common name of “Sage” (Arraiza *et al.*, 2012) is a plant in the Mint family Lamiaceae, subfamily Nepetoideae, tribe Mentheae, and can be found in Europe around the Mediterranean Sea, in Southeast Asia, and Central and South America (Jakovljević *et al.*, 2019). Its importance consists in MAPs value, frequently used as a spice in Mediterranean cookery, for food industry, and as a traditional medicine for several infectious diseases treatment (Delamare *et al.*, 2007; Pióro-Jabrucka *et al.*, 2010; Bouajaj *et al.*, 2013; Jakovljević *et al.*, 2019). The seed or planting material is important in its reproduction under production conditions. Common sage is a thermophilic plant, and it was found that seed germination starts at a temperature of 8-10 °C but also at higher temperatures like 25-28 °C, germinates in 6 days (Sharifi-Rad *et al.*, 2018) or in the range of 10–15 days (Farooqi *et al.*, 2005) with increased seedling growth in the presence of constant light (Paiva *et al.*, 2016). Little information about seed germination with priming methods is available. Sage seeds were treated using hormoprimer with gibberellic acid and increased germination was obtained (Abdani Nasiri *et al.*, 2018). Priming with hydrogen peroxide (H₂O₂) improved sage seedling growth under salinity stress together with seed biochemical activity and enhanced seed germination (Mardani Korrani *et al.*, 2023). Nanotechnology with ZnO nanoparticles application determined more than 90% germination capacity of sage (Gunes *et al.*, 2021). Laser stimulation was successful for sage seed germination rate and percentage, seed vigor, fast emergence, seedling length, biomass accumulation, chemical properties, and stress resistance (Abdani Nasiri *et al.*, 2018; Mardani Korrani *et al.*, 2023). Seed priming of sage with a magnetic field at 15 Mt increased seedling length (Abdani Nasiri *et al.*, 2018), and at 125 Mt enhanced seed germination rate and capacity (Flórez *et al.*, 2012). The germination of sage is difficult, poor, and problematic; therefore, different priming methods need to be tested on *Salvia officinalis* L. seeds.

The general aim of this study was to assess different priming methods on common sage seeds germination in growth chamber under controlled condition. All the further specific objectives were formulated as questions as follows: **(i)** Are priming treatments the solution for improving some germination parameters of sage seeds? **(ii)** Which is the best priming treatment for sage seeds that could improve some germination parameters? **(iii)** Could a seed priming treatment reduce a germination stage time with increasing the germinated seeds percent? **(iv)** What is the day’s range for each secondary stage of principal stages germination?

Materials and Methods

The experiment was conducted in a growth chamber with 24 hours - constant light from 20 neon’s of 18 W at 40% humidity and 20 ± 2 °C fixed temperature. A standard germination test was performed with 100 sage seeds in 4 replications, for each treatment. The seed priming methods tested were hydropriming (H),

electro-priming (E), magneto-priming (M), and no seed priming as a control (C). All seeds were sterilized with bleach and distilled water solution of 50% (v/v) before the experimental set-up (Lindsey III *et al.*, 2017; Stoian *et al.*, 2022). Hydropriming was done for 48 h with distilled water (Farooq *et al.*, 2006). For priming with a homogenous electric field, the seeds were exposed 20 minutes between two plates at a distance of 15.8 cm between them to a 25V capacitor (Radu *et al.*, 2015; Fallah *et al.*, 2018). The seeds were placed for priming in a pair of Helmholtz coils for 20 minutes. The coil was securely mounted on a wooden holder, completely devoid of any metal components. Its alignment was set to north-south, with careful attention paid to minimizing the angle between the coil's axis and the vertical line, aiming to closely match the orientation of the Earth's geomagnetic field. The uniform magnetic field with the intensity of 0.22×10^{-3} T was created and magnetized the seeds (Pop *et al.*, 2015). Daily assessments were performed during germination for 14 days. The growth stages of germination (BBCH 0) were noted according to the BBCH scale (Meier, 2018) for each replication. The BBCH 06 and 09 secondary stages were completed and detailed in three respectively two extra secondary stages with the help of a decimal code (Zavareh *et al.*, 2008). The seed features of each germination secondary stages were captured using an Optika stereomicroscope (8MP camera) to highlight the essential identification patterns for an accurate seed's visual assessment. Also, the representative days for passing in the following stage was set after observations of principal stage germination.

The experimental trial was set up using a local wild variety of sage (*Salvia officinalis* L.). The seeds were obtained from Mihai Viteazu County, Romania country from current production. The seeds of *Salvia officinalis* L. were previously stored at 20 ± 2 °C in paper bags until testing with priming techniques. A set of germination parameters were calculated.

The GI (germination index) emphasizes the germination speed and percentage. Higher GI represents higher germination rate and percentages (Kader, 2005).

$$GI = (14 \times n1) + (13 \times n2) + \dots + (1 \times n14) \quad (1)$$

where **n1–n14** represent the number of seeds germinated on first day until the 14th day and the multiply number **1–14** represent the weights for each day.

The SRP (sub-stage repartition percentage) was proposed in this article to highlight germinated seeds percentages of each secondary stage of BBCH scale for each day. This parameter also offers information about the germination rate and capacity.

$$SRP (\%) = \frac{ns}{nt} \times 100 \quad (2)$$

where **ns** represent the number of seeds germinated on a sub-stage and **nt** was total number of germinated seeds. The **nt** was determined on a daily basis, and **ns** was determined by the number of sub-stages identified on each assessment day.

Germination peak emphasizes the accumulated number of germinated seeds, in the point of maximum before the germination rate starts to decrease (Adams and Farrish, 1992).

The **Gval** (germination value) represents a combined score from germination rate and complexity (Czabator, 1962).

$$Gval (\%) = MDG \times PV \quad (3)$$

where **MDG** represents mean daily germination and **PV** is the germination peak value.

The **MGT** (mean germination time) highlights the speed of germination stage. Higher values represent seeds with low germination (Kader, 2005).

(4)

$$\text{MGT (\%)} = \frac{\sum f \times x}{\sum f}$$

where f are the seeds germinated in day x , the result represents percentages.

The **CVt** (coefficient of variation of the germination time) was determined by the following expression (Ranal *et al.*, 2009). It is representative for the germination uniformity, and allows comparisons regardless of the mean germination time magnitude.

$$\text{CVt (\%)} = \frac{St}{MGT} \times 100 \quad (5)$$

where **St** is standard deviation of the germination time and **MGT** is mean germination time.

Data from the germination stage was compiled and analyzed to highlight the differences in germination parameters induced by priming methods treatments. The RStudio software (R Studio, MA, USA) version 2022.02.3 (R Core Team, 2021) was used to compute averages and standard errors (SE). Following steps included ANOVA and post hoc LSD test and the package used was “agricolae” (de Mendiburu, 2021). Principal component analysis (PCA), in “vegan” package (Oksanen *et al.*, 2019), was performed for highlighting the distribution of each germination secondary stage to all the treatments and from the days with most significant changes in seed germination.

Results

Sage growth according to BBCH scale for germination

The first result of this study comprises representative imagistic valuable characteristics for each secondary stages of the germination principal stage according to BBCH scale (Figure 1). An important observation is represented by the difficulty to differentiate the first three secondary stages respectively BBCH 00-03. Considering the fact that is harsh, difficult, and almost impossible to distinguish the germination secondary stages from BBCH 00 to BBCH 03, these supplementary sub-stages are important to take into consideration in assembling an updated BBCH scale for sage. The assessment following the BBCH scale is important because it represents the newest growth scale and in time could provide a uniformity in the phenology data. Also, further models could be developed based on data series obtained on a standardized growth scale.

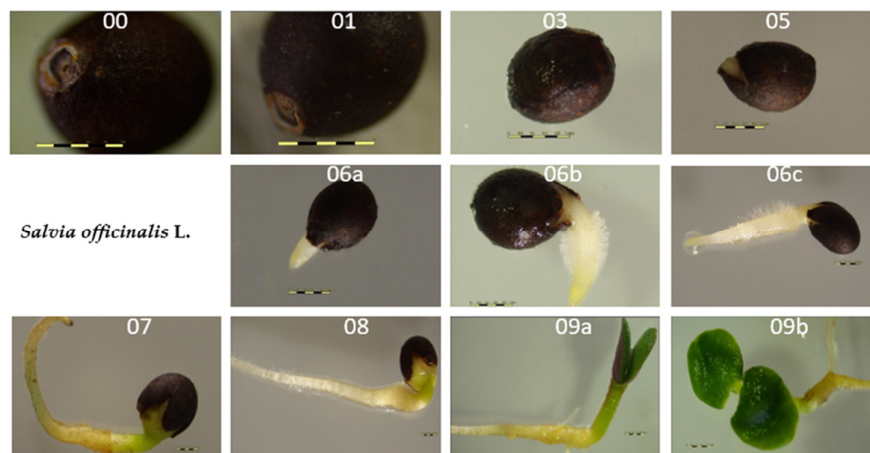


Figure 1. All germination secondary stages according to BBCH for sage (the scale represents in each picture 1 mm); Each secondary stage is described in details in Table 1

The germination principal stage could be assessed from the BBCH 05 when the radicle starts to emerge from seed pericarp. The seed tegument cracks and it is quite easy to observe the strong swollen emergent radicle. The secondary stages from BBCH 06a up to BBCH 06c were newly added to Meier scale for sage. These sub-stages were differentiated first by the radicle growth (06a), then by the white bushy root hair appearance (BBCH 06b), and last for the radicle elongation from the root hair zone (06c). The second change was made for BBCH 09 where it was newly added the emergence with folded cotyledons (09a) and at the end of germination principal stage the completely unfolded cotyledons (09b). Only for the germination principal stage it was added newly information in purpose of updating the BBCH scale for sage.

The sage seeds were almost spherical-shaped, dark-brown coloured, pubescent here and there with short hair from place to place under the seed pericarp. The seed length was ranging between 2.3-2.7 (± 0.05 SE) mm and the width was between 2.0-2.3 mm (± 0.06 SE). After hydropriming for 48 hours these seed sizes changed to 2.8-3.0 (± 0.09 SE) mm for length and 2.5-2.7 mm (± 0.06 SE) for width.

Starting with BBCH 00, breaking seed dormancy happens and the beginning of the seed imbibition (Table 1). The following secondary stages are marked by the seed power to develop from its own chemical components to an emerging seedling.

The experimental conditions enhanced seed metabolic activity in BBCH 05 in 4 days in average. The radicle elongation appeared in 6 days. For cotyledon appearance only 8 days were needed. The end of germination principal stage was observed after 10 days in average, then the completely unfolded cotyledons started to open in an angle higher than 90° to make space for the first true leaves appearance and development. After 14 days from the beginning of germination, the first true leaves appeared.

Table 1. Germination of sage according to BBCH growth scale (Sub-stages, description, and number of days in continuous light)

BBCH Code -two digit	Description according to BBCH general extended scale [35]		Additional sub-stages and description for sage	Period (day's range)
Principal growth stage 0: Germination				
00	Dry seed		Inactive seed/Seminal dormancy	1-10
01	Beginning of seed imbibition		Beginning of seed imbibition	ND
03	Seed imbibition complete		Seed imbibition complete	ND
05	Radicle emerged from seed		Radicle emerged from seed + a clear crack and white radicle top is visible on seed	3-5
06	Elongation of radicle, formation of root hair and/or lateral roots	06a	Elongation of the radicle	4-5
		06b	Root hair zone formation	5-6
		06c	Radicle continues its straight growth from root hair zone	6-7
07	Hypocotyl with cotyledons or shoot breaking through seed coat		Hypocotyl with cotyledons breaking through seed coat + the hypocotyl arc green zone appearance	7-8
08	Hypocotyl with cotyledons growing towards soil surface		Hypocotyl with cotyledons growing towards soil surface + 50–80% cotyledons surface visible still kept under seed coat	8-9
09	Emergence: cotyledons break through soil surface	09a	Emergence: cotyledons break through soil surface + folded cotyledons	9-11
		09b	+ completely unfolded cotyledons	13-10

*Note: ND=could not be differentiated.

The effect and differences induced by treatments on seed germination

All four tested treatments acted differently on the daily germination potential of *Salvia officinalis*, a phenomenon visible on the germinated seeds number and the time for half and final germination (Table 2.). In the control treatment, only 5% from the seeds were germinated after 72 hours from the beginning of the experiment (D3). A third of the tested seeds had germinated in D5, in a significantly higher percentage compared to D3. After 6 days from the beginning of the experiment, more than 50% of the seeds germinated, and the final germination was achieved in D10. The increases between these two dates were not significant, and were limited to near 10%.

Table 2. Daily limits of germination stimulated by applied treatments

	C	E	H	M
D2			2.67	
D3	5.33±1.33 ^c	5.33±3.52 ^c	15.67±4.17 ^c	4.67±1.66 ^b
D4	17.33±11.30 ^{bc}	22.00±3.05 ^{bc}	41.67±6.83 ^{bc}	15.67±5.78 ^{ab}
D5	36.00±8.32 ^{ab}	54.67±7.26 ^{ab}	66.00±7.57 ^{ab}	33.33±13.1 ^{ab}
D6	54.67±3.52 ^a	56.00±7.23 ^a	71.33±5.20 ^a	41.33±12.8 ^{ab}
D7	54.67±3.52 ^a	57.33±6.35 ^a	71.33±5.20 ^a	51.33±5.78 ^a
D8	62.67±3.52 ^a	57.67±6.38 ^a	71.67±4.91 ^a	58.00±1.52 ^a
D9	64.00±2.30 ^a	60.00±5.29 ^a	71.67±4.91 ^a	
D10	65.33±2.66 ^a	64.33±8.68 ^a	72.00±4.61 ^a	
D11				
D12				
D13				
D14				

*Note: Note: Mean ± S.E. followed by different letters presented significant differences at $p < 0.05$ (LSD test) among the days within each treatment. Assessment days–D; C – Control, E – Electro-priming, H – Hydropriming, M – Magneto-priming.

The use of electro-priming conducted to a similar result in germination after 72 h (D3), compared to control. The first difference was observed in D4, when the seeds germinated with more than 5%. Even this value was considered not significant compared to D3 (from control), it has more than doubled after another 24 h (D5). This treatment reached 50% of germinated seeds after 5 days, and the increases was between the range of 2-3% at each 2 days until D10. The maximum germination percent was 64, which represented almost 2/3 of the total seeds.

Both hydro- and magneto-priming methods induced very different germination processes, with differences between the days of the experimentation. Hydropriming was the most favorable priming treatment, with more than 70% of germinated seeds. This treatment set the germination time to 10 days, with significant changes between the number of germinated seeds in D2 and D3 compared to the day's range between D6-D10(14). It was the only treatment that stimulates the germination within the first 24 h, when 2-3% of seeds started this physiological process. More than 15% of the seeds had germinated within the first 72 h (D3), a value which was completed by another 25% of seeds in D4. Another 25% increase in germinated seeds was observed in D5, when 2/3 of seeds started this process. Magnetic field acts differently on sage germination, with faster germination rates but an overall lower germination potential. The value recorded after 72 h (D3) and 96 h (D4) was similar to the control and the electric treatment. After another 24 h (D5), the number of germinated seeds doubled, and starting with this point the increase was within 8-10% until the end of germination which took place on day D8 of experimentation.

Based on germination speed, combined with the day of the half and final germination percentage, the treatments showed multiple differences (Table 3).

Table 3. Differences in germination parameters induced by treatments

P/Treat	C	E	H	M
D5	36±8.32ab	54.66±7.26ab	66±7.57a	33.33±13.1b
D6	54.66±3.52ab	56±7.23ab	71.33±5.20a	41.33±12.8b
D8	62.66±3.52a	57.66±6.38a	71.66±4.91a	58±1.52a
D10	65.33±2.66a	64.33±8.68a	72±4.61a	58±1.52a
GI	16.52±1.30b	17.92±2.30ab	25.06±3.47a	14.63±1.35b
Peak	11.64±1.09b	13.66±1.81ab	17.44±1.28a	10.52±1.30b
Gval	58.17±3.99b	71.98±17.0ab	97.37±13.0a	46.95±6.07b
MGT	0.23±0.03b	0.29±0.01b	0.31±0.02a	0.23±0.03b
CVt	32.55±4.09ab	47.30±7.43a	31.91±3.40b	24.66±1.75b

*Note: Mean ± S.E. followed by different letters presented significant differences at $p < 0.05$ (LSD test) among the treatments within each table line. Legend: D – Assessment days, C – Control, E – Electro-priming, H – Hydropriming, M – Magneto priming. GI – germination index, Peak – germination peak, Gval – germination value, MGT – mean germination time, CVt – coefficient of variation of the germination time.

The hydropriming was the first treatment that reached more than 50% of germinated seeds from the total seed pool after 5 days of experimentation. This treatment differs significantly compared to magneto-priming, while both control and electro-priming were assessed as non-significant. After 24 h (D6), only magneto-priming registered less than 50% of germinated seeds, significantly lower compared to hydropriming. This last treatment reached 71% of germinated seeds, with more than 15–17% seeds compared to the control and electro-priming treatments. Both D8 and D10 represent the final of the germination principal stage, D8 for magneto-priming and D10 for the rest of the treatments. For both days, there were not identified any significant differences between the applied treatments.

Based on the germination pattern identified within the entire experiment, only a reduced number of germination parameters presented significant differences. The mean germination rate (MGR) was set in a range of 0.23-0.31 day⁻¹, with the highest value in the hydropriming treatment. The differences between control, electro- and magneto-priming for this parameter were non-significant, which indicates a similar potential of activating the seeds that can germinate. A different phenomenon was observed for the coefficient of variation (CVt), which reaches the highest value in the electro-priming treatment. The maximum value observed in this treatment doubled compared to magneto-priming, and with more than 15% higher compared to the control and hydropriming. Both of these two last treatments exhibited similar values for CVt, which indicates similar percent of germinated seeds daily, from the total number of germinated seeds. The germination index (GI), which presents the possible number of days necessary for 100% germination, shows significant differences between treatments. The fastest treatment was considered magneto-priming, with less than 15 days necessary to complete seeds germination. A similar value was recorded in the control treatment, and a slightly one (17.92) for the electric treatment. Both of these treatments showed no significant differences compared to magneto-priming. The longest period for a complete germination was associated with hydropriming, significantly higher than control and magneto-priming treatments.

Both Peak and Germination values presented highly significant differences between treatments. The peak value was recorded in hydropriming, with 4-7 days longer than the other three treatments. As a similar trend was visible for germination value, with more than 97 units for hydropriming, significantly higher compared to control (less than 60 units) and magneto-priming (less than 50 units).

Pattern of BBCH stages shaped by applied treatments

The information on embryos growth and development which was provided by the analysis of BBCH sub-stages in completed when the numerical approach is also assessed (Figure 2).

The germination is not a homogenous process, having a gradual development of seeds in different sub-stages during the period of 14 days of experimentation. This context reveals the importance of recording each seed from a pool in its specific germination sub-stage to have a realistic idea of the entire process flow. The use of a matrix for recording sub-stages ensures a good methodological system, that provides a daily image of seed number in each of the sub-stages of germination. Several benefits are achieved through this approach:

- the matrix shows the number of seeds that did not start the germination;
- each substage is visible and the number of days necessary for a number of seeds to reach a specific sub-stage is recorded;
- significant changes between days in terms of sub-stages are clearly visible in the records matrix;
- the number of seeds that remain in lower sub-stages when more than 50% seeds are germinated is clear and provide a useful information regarding the homogeneity of this process;
- as a practical approach, the matrix of sub-stage recording act as a tool for scheduling the germination for the production of fresh plants, based on the seed pool germination potential.

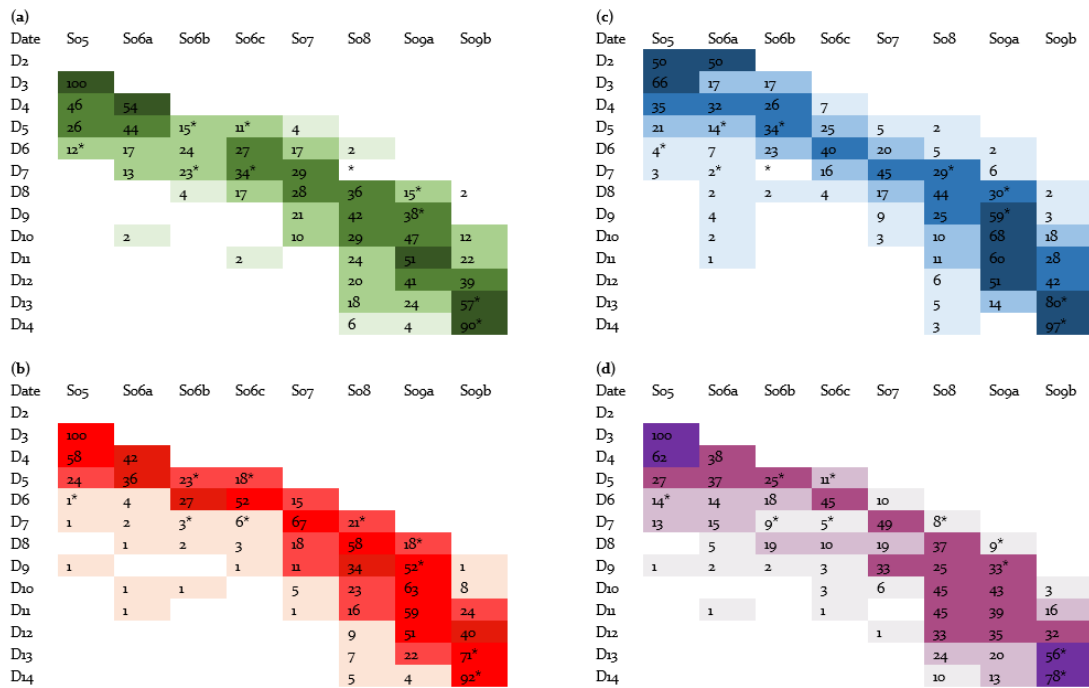


Figure 2. Daily percent of germinated sage seeds in S05-S09 sub-stages according to BBCH scale (a-control-color green; b-electro-priming-color red; c-hydropriming-color blue; d-magneto priming-color magenta); Legend: * - indicates significant differences at $p < 0.05$; color codes: darkest >50%; intensity color 25–50%; low intensity colors 10-25%; and light colors <10%

The observations on BBCH scale, related to the number of germinated seeds in each experimental day showed a different pattern for each treatment (Figure 2 a-d).

In D2, only hydropriming present germinated seeds, located in BBCH 05 and 06a, the rest of the treatments did not show any germination in this day. Starting with D3, both control, electro- and magneto-priming had all seeds in BBCH 05, with 24 h lag compared to hydropriming. For this last treatment, seeds

germinated in D2 reached BBCH 06a and 06b, while a new set of seeds entered in BBCH 05. During D4 of the experiment, was observed that most of the control seeds were in an advanced stage (BBCH 06a) compared to electric and magnetic field, while hydropriming showed a constant activation of seeds and a balanced placement in sub-stages. During D5, none of the treatments showed more of 50% germinated seeds in one BBCH sub-stage. In this day, the control seeds were in the sub-stage range BBCH 05-07, up to BBCH 08 in hydropriming and restricted to BBCH 06c in electric and magneto-priming. This showed the slower germination process in the last two treatments. Starting with D6, the differences in the sub-stage pattern between treatments were more visible. Control presented more than 50% seeds in one sub-stage only in the last two days of the experiment. The D7 was the first day when BBCH 05 was not recorded in this treatment. The general pattern of sub-stages showed a one (maximum two) sub-stages rate of increase in 24 h up to D12, when only BBCH 08, 09a and 09b were recorded. Two exceptions were visible in this variant, in D10, when 2% of the total daily germinated seeds were recorded directly in the BBCH 06a, which advanced two sub-stages in 24 h.

Electro-priming treatment presented a two days' lag in the new seed's germination, starting with D6. In this day, 1% of the total germinated seeds were in BBCH 05, a phenomenon replicated with the same percent in D7 and D9 (where the lag was observed). These seeds advanced in the next sub-stage within 24 h, but after this period the advance consisted in multiple sub-stages in 24 h. The peak for BBCH 08 was achieved in D8, while for BBCH 09a in D10. Both seeds sub-stages were present between 4-5% in the last day of the experiment.

For hydropriming treatment, both D6 and D7 represent the last days when BBCH 05 was recorded, with less than 5% of the total daily germinated seeds present in this sub-stage. Starting with D8 until D11, all the newly germinated seeds entered directly in BBCH 06a, followed by a high advance from this sub-stage up to BBCH 07 and 08 sub-stages within the next 24 h. The BBCH 08 was visible until the end of the experiment, in less than 5% of the germinated seeds. This treatment presented the highest share of seeds in BBCH 09b, which sustain the unitary ending character of the germination process.

The most interesting treatment was magneto-priming, with the lowest number of germinated seeds and the highest germination speed. In both D6 and D7, a similar pattern of germinated seeds and sub-stages allocation was observed. The values recorded for BBCH 05 were 3 times higher than hydropriming in these days. For D9 and D11, a pattern similar with electric field was observed, but with a forced advance from one sub-stage to another within 24 h. During D6-D12, in magneto-priming no peak higher than 50% share of daily germinated seeds was visible for only one sub-stage. Only in the last two days of the experiment, more than 55% of germinated seeds were placed in the final sub-stage (BBCH 09b) of this process, while in D14 this value increased with 23%.

Significant differences between the applied treatments, in the number of seeds in each sub-stage, were recorded only in a reduced number of sub-stages. Middle germination interval sub-stages (BBCH 06b and 06c) presented significant differences in D5 and D7, while for the advanced sub-stages, these differences occurred gradually. For BBCH 08 in D7 were the highest differences between treatments, while in the next 24 and 48 h these differences were visible in the number of seeds that entered in BBCH 09a. The last two days (D13 and D14) exhibited the highest differences within the entire experiment, with large ranges between seeds that entered in the final sub-stage (BBCH 09b). These last differences, were due to the number of activated seeds by each treatment, which also induced a different development pattern.

Key-moments in sage germination

The extraction of the key-moments in the germination process permitted the assessment of both sub-stages pattern and total number of germinated seed in one PCA ordination for each treatment (Figure 3 a-d).

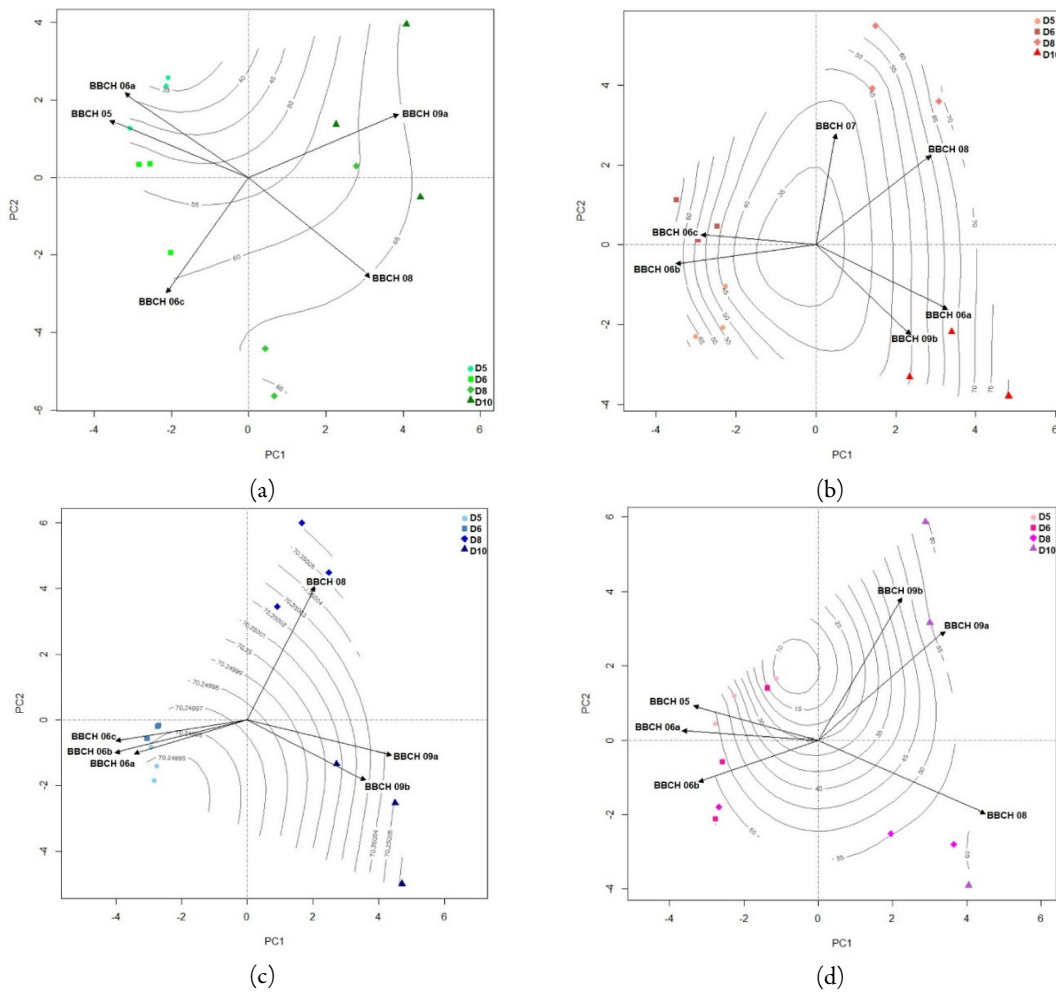


Figure 3. PCA for all treatments in selected significant days respectively (D5, D6, D8 and D10) and the germination secondary stages observed
 (a) –Control [variance explained by axis: Axis 1=52.53%; Axis 2=23.21%]; (b)- Electro-priming [variance explained by axis: Axis 1=62.05%; Axis 2=18.97%]; (c)- Hydropriming [variance explained by axis: Axis 1=68.45%; Axis 2=18.37%]; (d) Magneto-priming [variance explained by axis: Axis 1=56.18%; Axis 2=18.02%]. Isolines represent seed percentages for each secondary stage of all treatments.

The selection of D5 and D10 was done for their first 50% of germination and the final value of germination. Additionally, D6 was considered the control 50% germination and D8 the final of germination for magneto-priming.

For these days, in the control variant (Figure 3a), the number of germinated seeds was in the range of 35-65%, with a more pronounced presence of BBCH 05 and 06a in D5. The sub-stage patterns in this day indicate a stability of germination process, while the position of BBCH 06c vector indicates the possibility of a great change in the lower sub-stages until D6, with the activation of new seeds. In D8 and D10, there was visible a high fluctuation of sub-stage patterns, with BBCH 08 vector oriented between D8 points, and BBCH 09a vector oriented inside the D10 points. This indicated a continuous presence of BBCH 08 sub-stage while the germination process advanced, and a continuous change in the number of seeds that entered in the final germination sub-stage (BBCH 09a).

The absence of BBCH 06b and 09b vectors indicates the short-term character of the first sub-stage, and the low number of seeds that can enter BBCH 09b within the first 10 days from the germination beginning.

Electric field showed a different PCA projection, with the absence of BBCH 06 and 06a vectors (Figure 3b). A circular isoline projection is visible for the total number of germinated seeds, with a clear separation between D5 and D6, respectively D8 and D10. Both D5 and D6 are located in the left part of the ordination, in a reduced area and BBCH 06b and 06c vectors are oriented within this group of points. This indicates a 24 h change within these two sub-stages due to the application of electric field. At the opposite, D8 point are located in the ++ quadrat of the ordination, in a condensed area and within the angle described by BBCH 07 and 08 vectors. The vectors position indicates a seed advance potential in this day to one or another from these sub-stages. Both BBCH 09a and 09b vectors are oriented inside the D10 group of points, which indicates the presence and the continuous seeds advance to the final germination process.

Hydropriming treatment (Figure 3c) implies a more stable ordination compared to electric treatment. The first two days are located in the same area, with all BBCH 06 vectors oriented within this group. This indicates a similar flow of seeds that enter in BBCH 06 secondary-stage until D6 and the presence of all phases (BBCH 06 a, b and c). The angle formed by BBCH 08 vector with the 09a and 09b vectors is larger than in electric field, and indicates a higher difference in terms of the time between D8-D10. The differences between the position of points on isolines is moderate in terms of the PCA ordination, indicating a slight difference in the sub-stage allocation patterns in the last two days. Starting with D10, a visible change is in seeds that enter either BBCH 09a or 09b, indicating a potential pause of more than 24 h of seeds in these sub-stages.

The magnetic field produced a high variation within daily sub-stage pattern (Figure 3d) of germinated seeds. The BBCH 06c and 07 vectors are not significant for the ordination, both D5 and D6 being positioned at high distances on isolines. The semi-circular shape of isolines sustain the opposite character of daily recorded sub-stage patterns. The position of D8 points indicates a transient sub-stage pattern, with additional specific sub-stage features, positioned outside of the connective isolines between D5, D6 and D10. The presence of BBCH 08 vector indicates a high change potential of this sub-stage in D8. Both BBCH 09a and 09b vectors are oriented toward D10 points, indicating that seeds that complete this germination time reach the final sub-stages of this process. The difference in the position of each point from D10 indicates a potential different pattern of seeds in lower sub-stages (BBCH 05-08) at 10 days from the beginning of germination.

Discussion

The effects of priming treatment on sage seeds and thus on the germination process has been little investigated (Sharma *et al.*, 2019). It was observed after this experiment that sage seeds could be considered as a part of four different categories based on daily registered germination percentages: *a* – seeds with a rapid germination potential, which activates this process within the first 2 days; *b* – seeds with a medium range time for germination, which are visible within the first 6 days; *c* – seeds with a lower germination time, that require 10 days for starting this process; *d* – inactive seeds, which cannot break their dormancy. The phenomenon could be explained by the control treatment that showed a rapid germination potential within the first 6 days of the experiment when more than 50% of the seed pool started this process. The final germination value was set to almost 2/3 of the seeds, but the increase is of only 10% of seeds. In literature were proposed five dormancy classes respectively physiological type, morphological type, morpho-physiological, physical and combinational. The most common type is represented by the physiological dormancy, all further types have different levels and types except physical dormancy (Beweley, 1997). All the seeds shortly after seed imbibition, exhibit the dormancy resume with promoting organelles changes from the embryo cells (Kozłowski and Pallardy, 1997). The embryo self-supports the nutritional requirements and the seedling are developing from the endosperm reserve materials like starch, proteins and lipids by translocating directly to the active growth areas (Khajeh-Hosseini *et al.*, 2010).

Hydropriming technique determine different seeds germination percentages and therefore other germination-based categories. More than 15% of seeds had a rapid-range germination potential, and another

46% a mid-range. This treatment is good to rapidly activating the germination process in sage seeds, with more the 72% of seeds germinating within first ten days. Usually, emergence of the radicle is the criterion for germination in general (Heslop-Harrison, 1972). The entire process is fully developed when the embryo has cotyledons, radicle and a relatively small amount of endosperm (Khajeh-Hosseini *et al.*, 2010). Once the seeds germinate, the root formation happens, and the next step is to develop the young seedling (Berger *et al.*, 2006). In some condition, like in this experiment, at a point, the germination—seedling stage has a pause indicated by decreasing of germination parameters (Baskin and Baskin, 2004). The recent studies highlight the beneficial effect of hydropriming on sage seed germination and seedling growth and development (Sharma *et al.*, 2019; Ozden *et al.*, 2017; Tahaei *et al.*, 2016).

The magnetic field cause a fastest germination process, only 8 days were necessary for this process to be completed. More than 40% of seeds were considered rapid- and medium-range seeds. The disadvantage of this treatment is that activates with 15% less seeds than hydropriming and even 7% less seeds compared to control. It is a treatment that speed the germination process, but for less than 2/3 of seeds, which makes it the least favorable treatment. The endosperm growth is influenced by the seed integuments, the latter ones regulate the growth by a sporophytic effect (Berger *et al.*, 2006). Between these two constituents existed a mechanistic connexion more likely being affected by biophysical forces. Hereby the endosperm could be affected by internal mechanical tensions and the magnetic field applied to seeds (Berger *et al.*, 2006). The seed germination represents principal physiological processes influenced by the magnetic field (Abdani Nasiri *et al.*, 2018). The seed's reaction to the magneto priming may differ depending on the field intensity, also to the subjected treatment exposure time. The enzymatic intense activity induced by the magnetic field affects the mitotic cycle and promotes seed physiological activity (Abdani Nasiri *et al.*, 2018). Therefore, the scientific perspective offers the response of magneto-priming advantages upon seed germination and seedling growth up to a certainly degree of field intensity. This advantage could also have a turn back opposite effect with affecting seed integrity and embryo damage (Morillo-Coronado *et al.*, 2022), resulting in decreased germination rates.

The electric treatment set the number of seeds in the category *a* to 22%, and the medium-range ones to 34%. Based on these two values, this treatment is able to activate more than half of the seeds within the first 6 days of germination. Low-range seeds are less than 8% from the total pool, which indicates the potential of electric field to activate the sage seeds. Another study found that the optimal electrostatic field for tomato was 2Kv/MM for 20 seconds exposure time with enhancing seed germination and vigour (Gandhare and Patwardhan, 2014). The electric application on seed act toward stimulating dipole-dipole interactions in the embryo. In general, the principal consequence could be seen in different physiological changes as water content availability, biochemical changes including respiration (Dymek *et al.*, 2012; Mahajan and Pandey, 2014; Rifna *et al.*, 2019).

The difference between treatments was visible in D5–D10 range, with one or two days between half and final germination. There was observed a double number of germinated seeds between hydro- and magneto-priming treatments. The D5 indicated a very reduced potential for activating sage seeds by applying a magnetic field. However, after 24 h (D6), the number of newly germinated seeds doubled in magneto-priming compared to hydropriming treatment. Similar results were found on a sage seed germination test where was stated that sage could germinate in five days depending on temperature and light regime (Paiva *et al.*, 2016).

The highest value of new germinated seeds in 24 h was visible in the control treatment, when the increase was almost 20%, 2 to 10 times higher than in other treatments (D5 to D6). The absence of significant differences between treatments was visible starting with D8, when the germinated seeds was close to the final value. In this day, magneto-priming reaches the final germination value, similar to electric treatment. After another 48 h (D10), electro-priming activates another 7% of seeds, which set the final germination value to 64%. A selection of germination parameters showed that sage had a lower value under a 125 mT stationary magnetic field treatment compared to the control. The mean germination time was significantly lower (Flórez *et al.*, 2012). In the same way, as the magnetic influence, the electric field could improve the seed germination

on a very set threshold. The strength of electric field could act toward changing the seed polarity by producing discharges which induce seed ionization (Schmiedchen *et al.*, 2018).

The values of MGT indicates a range of 3-4 days for a sage seed to germinate, this value being higher in hydropriming, due to the increased potential for activating this process. The embryo turgor degree induces the mean germination rate toward different patterns. Usually, this parameter is higher correlated with seeds age (Mavi *et al.*, 2010) and it is a measure of frequency.

An interesting case is the control, which presented slightly higher values compared to magneto-priming treatment. The CVt recorded in the experiment indicates almost 50% of this parameter in the electric treatment. Based on this value, a two-time number of germinated seeds can be achieved within 24 h in the entire period necessary for this process. The low number of germinated seeds in magneto-priming treatment was observed in the CVt value, which indicates more than 96 h necessary for obtaining significant difference. The dispersion of germination over time could be explained by the coefficient of variation and also gives important information about germination uniformity. The physiological quality to overcome dormancy presents sensitiveness upon different treatments, genetic stock and environmental conditions (Ribeiro-Oliveira and Ranal, 2016).

The most interesting case was the variation in GI, which set magneto-priming as the fastest treatment for a complete seed's germination. This value was at opposite with its potential of seed activation, which was lower than 60%. Based on the intersection of both information, magneto-priming represents a good treatment in large pool seeds available (Thakur *et al.*, 2022), when the time is more important than the number of germinated seeds. As an alternative to magneto-priming, both control and electro-priming can be used. If we rank the treatments according to the efficiency of the interaction on sage seeds, the electro and no priming treatments shows a medium to low efficiency on the germination process. These treatments increase the time necessary for complete germination within 2-3 days, but also increase the final number of germinated seeds with 6-7% compared to magneto-priming. In same terms of treatment efficiency, magneto-priming could be classified by time efficiency due to the small number of seeds germinated during the experiment period in a short period of time. This method still could have the advantage of several adaptive changes in the morphological and structural characteristics, metabolites accumulation and sometimes even by gene expression changes (Thakur *et al.*, 2022). Hydropriming can be considered the most performant treatment based on the final value of germinated seeds, but the time necessary for a 100% germination was with 7-10 days, longer than the other treatments. The obtained results could be because of the sufficient time allocated to seeds in the priming period and because of the slow water uptake necessary for the activation of all germination process (Dastanpoor *et al.*, 2013). It is highlighted that in terms of time treatment efficiency this is the best seed priming method. This treatment is very useful when the sufficient germination time is available and it is required a high number of germinated seeds from the seed pool.

Conclusions

Priming methods has great potential for practical application towards improved germination process of sage seeds. In the present experiment, the treatments were raked as following: hydropriming, electro-priming, control and magneto-priming. Germination parameters respectively GI, Germination Peak, Gval registered the highest values in hydropriming treatments. The dispersion of germination CVt was the highest in electro-priming. The results have shown that all the priming tested methods could be also classified as follows: hydropriming with maximum efficiency in terms of seed germinated percentage at the end; magneto-priming was temporal efficient because of the lowest days' number needed to complete seed germination, and electro-priming with medium-low efficiency because of decreased seed germination percentage at the end compared with the control. The updates in the BBCH scale for germination are important for the better description of this process for sage and the detection of physiological characteristics of seeds from this species. The use of a

matrix system for recording daily changes in sub-stages enables the complete description of germination in separate and comparable sequences.

Authors' Contributions

Conceptualization SDV, VAS, MT, CB and VS; Data curation VS and SDV; Formal analysis RV and SG; Funding acquisition AV, MH and VAS; Investigation VS and CB; Methodology SG, RV and CB; Project administration SDV, AV and SG; Resources VAS and RV; Software VS and VAS; Supervision SDC and AV; Validation SDV, AV, SG, BB, MH and RV; Visualization SDV, VAS, VS, RV, DC and CB; Writing - original draft SDV, VAS, VS, MT and CB; Writing - review and editing VAS, VS, RV, MT, BB, DC and CB. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

- Abdani Nasiri A, Mortazaeinezhad F, Taheri R (2018). Seed germination of medicinal sage is affected by gibberellic acid, magnetic field and laser irradiation. *Electromagnetic Biology and Medicine* 37(1):50-56. <https://doi.org/10.1080/15368378.2017.1336100>
- Adams JC, Farrish KW (1992). Seedcoat removal increases speed and completeness of germination of water oak. Tree planters' notes-US Department of Agriculture, Forest Service (USA).
- Arraiza MP, Arrabal C, López JV (2012). Seasonal variation of essential oil yield and composition of sage (*Salvia officinalis* L.) grown in Castilla-La Mancha (Central Spain). *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 40(2):106-108. <https://doi.org/10.15835/nbha4028311>
- Bai Y, Romo JT (1994). Germination of previously buried seeds of fringed sage (*Artemisia frigida*). *Weed Science* 42(3):390-397. <https://doi.org/10.1017/S0043174500076670>
- Barata AM., Rocha F, Lopes V, Carvalho AM (2016). Conservation and sustainable uses of medicinal and aromatic plants genetic resources on the worldwide for human welfare. *Industrial Crops and Products* 88:8-11. <https://doi.org/10.1016/j.indcrop.2016.02.035>
- Baskin JM, Baskin CC (2004). A classification system for seed dormancy. *Seed Science Research* 14(1):1-16. <https://doi.org/10.1079/SSR2003150>
- Berger F, Grini PE, Schnittger A (2006). Endosperm: an integrator of seed growth and development. *Current Opinion in Plant Biology* 9(6):664-670. <https://doi.org/10.1016/j.pbi.2006.09.015>

- Bewley JD (1997). Seed germination and dormancy. *The Plant Cell* 9(7):1055. <https://doi.org/10.1105/tpc.9.7.1055>
- Bhardwaj AK, Kapoor S, Naryal A, Bhardwaj P, Warghat AR, Kumar B, Chaurasia OP (2016). Effect of various dormancy breaking treatments on seed germination, seedling growth and seed vigour of medicinal plants. *Tropical Plant Research* 3(3):508-516. <https://doi.org/10.22271/tpr.2016.v3.i3.067>
- Bhusal D, Thakur DP (2020). Seed hydropriming technique in cereal crops: A review. *Reviews in Food and Agriculture* 1(2):85-88. <http://doi.org/10.26480/rfa.02.2020.85.88>
- Bouajaj S, Benyamna A, Bouamama H, Romane A, Falconieri D, Piras A, Marongiu B (2013). Antibacterial, allelopathic and antioxidant activities of essential oil of *Salvia officinalis* L. growing wild in the Atlas Mountains of Morocco. *Natural Product Research* 27(18):1673-1676. <https://doi.org/10.1080/14786419.2012.751600>
- Catană R, Lazăr M, Holobiuc I, Florescu L (2020). Seed germination of some medicinal plant species for conservative purpose. *Romanian Biotechnological Letters* 25:1621-1627. <https://doi.org/10.25083/rbl/25.3/1621.1627>
- Chrysargyris A, Skaltsa H, Konstantopoulou M (2022). Medicinal and Aromatic Plants (MAPs): The connection between cultivation practices and biological properties. *Agronomy* 12(12):3108. <https://doi.org/10.3390/agronomy12123108>
- Czabator FJ (1962). Germination value: an index combining speed and completeness of pine seed germination. *Forest Science* 8(4):386-396. <https://doi.org/10.1093/forestscience/8.4.386>
- Dastanpoor N, Fahimi H, Shariati M, Davazdahemami S, Hashemi SMM (2013). Effects of hydropriming on seed germination and seedling growth in sage (*Salvia officinalis* L.). *African Journal of Biotechnology* 12(11):1223-1228. <https://doi.org/10.5897/AJB12.1941>
- de Mendiburu, F. (2021). *Agricolae: Statistical Procedures for Agricultural Research*. R package version 1.3-5. Retrieved 2022 October 2nd from: <https://CRAN.R-project.org/package=agricolae>
- Delamare APL, Moschen-Pistorello IT, Artico L, Atti-Serafini L, Echeverrigaray S (2007). Antibacterial activity of the essential oils of *Salvia officinalis* L. and *Salvia triloba* L. cultivated in South Brazil. *Food Chemistry* 100(2):603-608. <https://doi.org/10.1016/j.foodchem.2005.09.078>
- Dymek K, Dejmek P, Panarese V, Vicente AA, Wadsö L, Finnie C, Galindo FG (2012). Effect of pulsed electric field on the germination of barley seeds. *Lwt-Food Science and Technology* 47(1):161-166. <https://doi.org/10.1016/j.lwt.2011.12.019>
- Elouaer MA, Hannachi C (2012). Seed priming to improve germination and seedling growth of safflower (*Carthamus tinctorius*) under salt stress. *EurAsian Journal of BioSciences* 6(1):76-84. <https://doi.org/10.5053/ejobios.2012.6.0.9>
- Ercan I, Tombuloglu H, Alqahtani N, Alotaibi B, Bamhrez M, Alshumrani R, ... Kayed TS (2022). Magnetic field effects on the magnetic properties, germination, chlorophyll fluorescence, and nutrient content of barley (*Hordeum vulgare* L.). *Plant Physiology and Biochemistry* 170:36-48. <https://doi.org/10.1016/j.plaphy.2021.11.033>
- Falahhosseini L, Alizadeh MA, Vazan S (2017). Priming effect of on the enhancement of germination traits in aged seeds of chamomile (*Matricaria chamomilla* L.) seeds preserved in medium and long-term storage. *Journal of Medicinal Plants and By-Product* 6(1):1-9. <https://doi.org/10.22092/JMPB.2017.113144>
- Fallah S, Malekzadeh S, Pesarakli M (2018). Seed priming improves seedling emergence and reduces oxidative stress in *Nigella sativa* under soil moisture stress. *Journal of Plant Nutrition* 41(1):29-40. <https://doi.org/10.1080/01904167.2017.1381719>
- Farooq M, Basra SMA, Afzal I, Khaliq A (2006). Optimization of hydropriming techniques for rice seed invigoration. *Seed Science and Technology* 34(2):507-512. <https://doi.org/10.15258/sst.2006.34.2.25>
- Farooqi AA, Sreeramu B, Srinivasappa KN (2005). *Cultivation of spice crops*. Universities press. India, Hyderabad.
- Flórez M, Martínez E, Carbonell MV (2012). Effect of magnetic field treatment on germination of medicinal plants *Salvia officinalis* L. and *Calendula officinalis* L. *Polish Journal of Environmental Studies* 21(1).
- Gandhare WZ, Patwardhan MS (2014). A new approach of electric field adoption for germination improvement. *Journal of Power and Energy Engineering* 2(4):13-18. <http://dx.doi.org/10.4236/jpee.2014.24003>
- Ghasemi N, Omid H, Bostani A (2021). Morphological properties of *Catharanthus roseus* L. seedlings affected by priming techniques under natural salinity stress. *Journal of Plant Growth Regulation* 40:550-557. <https://doi.org/10.1007/s00344-020-10118-z>

- Gunes Z, Toncer O, Eren A (2021). Effects of ZnO nanoparticles produced with green synthesis on germination and seedling of *Salvia officinalis* L. seeds. Journal of Elementology 26(3). <https://doi.org/10.5601/jelem.2021.26.2.2147>
- Heslop-Harrison J (1972). Sexuality of angiosperms. Plant Physiology: A Treatise VIC:133-289. New York, Ithaca.
- Hoseini M, Kouchebag, SB, Jahandide E (2013). Response of fennel to priming techniques. Annual Research & Review in Biology 3(2):124-130.
- Ibrahim EA (2016). Seed priming to alleviate salinity stress in germinating seeds. Journal of Plant Physiology 192:38-46. <https://doi.org/10.1016/j.jplph.2015.12.011>
- Jakovljević M, Jokić S, Molnar M, Jašić M, Babić J, Jukić H, Banjari I (2019). Bioactive profile of various *Salvia officinalis* L. preparations. Plants 8(3):55. <https://doi.org/10.3390/plants8030055>
- Kader MA (2005). A comparison of seed germination calculation formulae and the associated interpretation of resulting data. Journal and Proceeding of the Royal Society of New South Wales 138:65-75.
- Khajeh-Hosseini M, Nasehzadeh M, Matthews S (2010). Rate of physiological germination relates to the percentage of normal seedlings in standard germination tests of naturally aged seed lots of oilseed rape. Seed Science and Technology 38(3):602-611. <https://doi.org/10.15258/sst.2010.38.3.08>
- Kozłowski TT, Pallardy SG (1997). Growth control in woody plants. Elsevier. USA, California.
- Kumar A, Pandey OP (2021). Causal theory on acceleration of seed germination in the vicinity of high voltage direct current transmission line. Journal of Theoretical Biology 531:110899. <https://doi.org/10.1016/j.jtbi.2021.110899>
- Lamichhane JR, Debaeke P, Steinberg C, You MP, Barbetti MJ, Aubertot JN (2018). Abiotic and biotic factors affecting crop seed germination and seedling emergence: a conceptual framework. Plant and Soil 432:1-28. <https://doi.org/10.1007/s11104-018-3780-9>
- Li J, Yin, LY, Jongsma MA, Wang CY (2011). Effects of light, hydropriming and abiotic stress on seed germination, and shoot and root growth of pyrethrum (*Tanacetum cinerariifolium*). Industrial Crops and Products 34(3):1543-1549. <https://doi.org/10.1016/j.indcrop.2011.05.012>
- Lindsey III BE, Rivero L, Calhoun CS, Grotewold E, Brkljacic J (2017). Standardized method for high-throughput sterilization of *Arabidopsis* seeds. JoVE (Journal of Visualized Experiments) 128:e56587. <https://doi.org/10.3791/56587>
- Liopa-Tsakalidi A, Zakynthinos G, Varzakas T, Xynias IN (2011). Effect of NaCl and GA3 on seed germination and seedling growth of eleven medicinal and aromatic crops. Journal of Medicinal Plants Research 5(17):4065-4073. <http://www.academicjournals.org/JMPR>
- Lubbe A, Verpoorte R (2011). Cultivation of medicinal and aromatic plants for specialty industrial materials. Industrial Crops and Products 34(1):785-801. <https://doi.org/10.1016/j.indcrop.2011.01.019>
- Mahajan TS, Pandey OP (2014). Effect of electric field (at different temperatures) on germination of chickpea seed. African Journal of Biotechnology 13(1). <https://doi.org/10.5897/AJB2013.13345>
- Malarkodi K, Vedhapriya T, Umarani R, Bhaskaran M (2022). Automation of seed priming technology for enhanced seed vigour of blackgram seeds. Legume Research-An International Journal 45(9):1178-1184. <https://doi.org/10.18805/LR-4662>
- Maleš I, Pedisić S, Zorić Z, Elez-Garofulić I, Repajić M, You L, ... Dragović-Uzelac V (2022). The medicinal and aromatic plants as ingredients in functional beverage production. Journal of Functional Foods 96:105210. <https://doi.org/10.1016/j.jff.2022.105210>
- Mardani Korrani F, Amooaghaie R, Ahadi A (2023). He-Ne laser enhances seed germination and salt acclimation in *Salvia officinalis* seedlings in a manner dependent on phytochrome and H₂O₂. Protoplasma 260(1):103-116. <https://doi.org/10.1007/s00709-022-01762-1>
- Mavi K, Demir I, Matthews S (2010). Mean germination time estimates the relative emergence of seed lots of three cucurbit crops under stress conditions. Seed Science and Technology 38(1):14-25. <https://doi.org/10.15258/sst.2010.38.1.02>
- Meier U (2018). Growth Stages of Mono-and Dicotyledoneous Plants. BBCH Monograph. Julius-Kühn-Institut (JKI), Germany, Quedlinburg. <https://doi.org/10.5073/20180906-074619>
- Moldovan C, Nițu S, Hermeziu M, Vidican R, Sandor M, Gâdea Ș, ... Stoian V (2022). Growth characteristics of *Dracocephalum moldavica* L. in relation to density for sustainable cropping technology development. Agriculture 12(6):789. <https://doi.org/10.3390/agriculture12060789>

- Moori S, Ahmadi-Lahijani MJ (2020). Hormoprimering instigates defense mechanisms in thyme (*Thymus vulgaris* L.) seeds under cadmium stress. Journal of Applied Research on Medicinal and Aromatic Plants 19:1002-68. <https://doi.org/10.1016/j.jarmap.2020.100268>
- Morillo-Coronado AC, Martínez-Anzola HG, Velandia-Díaz JD, Morillo-Coronado Y (2022). Effects of static magnetic fields on onion (*Allium cepa* L.) seed germination and early seedling growth. Revista de Ciencias Agrícolas 39(1):30-41. <https://doi.org/10.22267/rcia.223901.169>
- Nejad SR, Bistgani ZE, Barker AV (2022). Enhancement of seed germination of yarrow with gibberellic acid, potassium nitrate, scarification, or hydropriming. Journal of Crop Improvement 36(3):335-349. <https://doi.org/10.1080/15427528.2021.1968553>
- Oksanen J, Guillaume BF, Friendly M, Kindt R, Legendre P, McGlinn D, ... Wagner H. (2019). vegan: Community Ecology Package. R package version 2.5-6. Retrieved 2022 October 2nd from: <https://CRAN.R-project.org/package=vegan>
- Ozden E, Ermiş S, Demir I (2017). Seed priming increases germination and seedling quality in *Antirrhinum*, *Dahlia*, *Impatiens*, *Salvia* and *Zinnia* seeds. Journal of Ornamental Plants 7(3):171-176.
- Paiva EPD, Torres SB, Sá FVDS, Nogueira NW, Freitas RMOD, Leite MDS (2016). Regime de luz e temperatura na germinação de sementes de *Salvia hispanica* L. Acta Scientiarum. Agronomy 38:513-519. <https://doi.org/10.4025/actasciagron.v38i4.30544>
- Pióro-Jabrucka E, Bączek K, Węglarz Z (2010). Intraspecific variability of sage (*Salvia officinalis* L.). Acta Horticulturae 860:87-91. <https://doi.org/10.17660/ActaHortic.2010.860.10>
- Pop MF, Inoan SL, Dinu AI, Criveanu HR (2015). The influence of magnetic field on *Silybum marianum* seed germination. Agricultura-Revistă de Știință și Practică Agricolă 1/2:60-63. <https://doi.org/10.15835/arspa.v93i1-2.11253>
- Porto CL, Sergio L, Boari F, Logrieco AF, Cantore V (2019). Cold plasma pretreatment improves the germination of wild asparagus (*Asparagus acutifolius* L.) seeds. Scientia Horticulturae 256:108554. <https://doi.org/10.1016/j.scienta.2019.108554>
- R Core Team. R: (2021). A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved 2022 October 2nd from: <https://www.R-project.org/>
- Raccuia SA, Puglia G, Pappalardo H, Argento S, Leonardi C, Calderaro P, Melilli MG (2015). Dormancy-related genes isolation in *Cynara cardunculus* var. *sylvestris*. In: IX International Symposium on Artichoke, Cardoon and Their Wild Relatives 1147, pp 315-322. <https://doi.org/10.17660/ActaHortic.2016.1147.44>
- Radu A, Criveanu HR, Inoan SL, Pop FM (2015). The influence of the electric field on the seed germination process for *Paulownia tomentosa* (Thunb.) Steud. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Horticulture 72(1):170-175. <https://doi.org/10.15835/buasvmcn-hort:10972>
- Rahmati E, Khoshtaghaza MH, Banakar A, Ebadi MT (2022). Decontamination technologies for medicinal and aromatic plants: A review. Food Science & Nutrition 10(3):784-799. <https://doi.org/10.1002/fsn3.2707>
- Ranal MA, Santana DGD, Ferreira WR, Mendes-Rodrigues C (2009). Calculating germination measurements and organizing spreadsheets. Brazilian Journal of Botany 32:849-855. <https://doi.org/10.1590/S0100-84042009000400022>
- Ribeiro-Oliveira JP, Ranal MA (2016). Sample size in studies on the germination process. Botany 94(2):103-115. <https://doi.org/10.1139/cjb-2015-0161>
- Rifna EJ, Ramanan KR, Mahendran R (2019). Emerging technology applications for improving seed germination. Trends in Food Science & Technology 86:95-108. <https://doi.org/10.1016/j.tifs.2019.02.029>
- Schmiedchen K, Petri AK, Driessen S, Bailey WH (2018). Systematic review of biological effects of exposure to static electric fields. Part II: Invertebrates and plants. Environmental Research 160:60-76. <https://doi.org/10.1016/j.envres.2017.09.013>
- Sharifi-Rad M, Ozelik B, Altın G, Daşkaya-Dikmen C, Martorell M, Ramírez-Alarcón K, ... Sharifi-Rad J (2018). *Salvia* spp. plants-from farm to food applications and phytopharmacotherapy. Trends in Food Science & Technology 80:242-263. <https://doi.org/10.1016/j.tifs.2018.08.008>
- Sharma Y, Fagan J, Schaefer J (2019). Ethnobotany, phytochemistry, cultivation and medicinal properties of Garden sage (*Salvia officinalis* L.). Journal of Pharmacognosy and Phytochemistry 8(3):3139-3148.

- Singh R, Kishor R, Singh V, Singh V, Prasad P, Aulakh NS, ... Kumar B (2022). Radio-frequency (RF) room temperature plasma treatment of sweet basil seeds (*Ocimum basilicum* L.) for germination potential enhancement by immaculation. *Journal of Applied Research on Medicinal and Aromatic Plants* 26:100350. <https://doi.org/10.1016/j.jarmap.2021.100350>
- Stoian VA, Gâdea Ș, Vidican R, Vârban D, Balint C, Vârcă A, ... Vârcă S (2022). Dynamics of the *Ocimum basilicum* L. germination under seed priming assessed by an updated BBCH scale. *Agronomy* 12(11):2694. <https://doi.org/10.3390/agronomy12112694>
- Taban BM, Stavropoulou E, Winkelströter LK., Bezirtzoglou E (2021). Value-added effects of using aromatic plants in foods and human therapy. *Food Science and Technology* 42. <https://doi.org/10.1590/fst.43121>
- Tahaei A, Soleymani A, Shams M (2016). Seed germination of medicinal plant, fennel (*Foeniculum vulgare* Mill), as affected by different priming techniques. *Applied Biochemistry and Biotechnology* 180:26-40. <https://doi.org/10.1007/s12010-016-2082-z>
- Thakur M, Tiwari S, Kataria S, Anand A (2022). Recent advances in seed priming strategies for enhancing planting value of vegetable seeds. *Scientia Horticulturae* 305:111355. <https://doi.org/10.1016/j.scienta.2022.111355>
- Vidak M, Lazarević B, Nekić M, Šatović Z, Carović-Stanko K (2022). Effect of hormonal priming and osmopriming on germination of winter savory (*Satureja montana* L.) natural population under drought stress. *Agronomy* 12(6):1288. <https://doi.org/10.3390/agronomy12061288>
- Viliche Balint C, Surducun V, Surducun E, Oroian IG (2016). Plant irradiation device in microwave field with controlled environment. *Computers and Electronics in Agriculture* 121:48-56. <https://doi.org/10.1016/j.compag.2015.11.012>
- Zare I, Mohammadi G, Sohrabi Y, Kahrizi D, Khah EM, Yari K (2011). Effect of different hydropriming times on the quantitative and qualitative characteristics of chickpea (*Cicer arietinum* L.). *African Journal of Biotechnology* 10(66):14844-14850. <https://doi.org/10.5897/AJB11.1283>
- Zavareh M, Hoogenboom G, Rahimian MH, Arabd A (2008). A decimal code to describe the growth stages of sesame (*Sesamum orientale* L.). *International Journal of Plant Production* 2(3):193-206. <https://doi.org/10.22069/IJPP.2012.612>



The journal offers free, immediate, and unrestricted access to peer-reviewed research and scholarly work. Users are allowed to read, download, copy, distribute, print, search, or link to the full texts of the articles, or use them for any other lawful purpose, without asking prior permission from the publisher or the author.



License - Articles published in *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* are Open-Access, distributed under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) License.
© Articles by the authors; Licensee UASVM and SHST, Cluj-Napoca, Romania. The journal allows the author(s) to hold the copyright/to retain publishing rights without restriction.

Notes:

- **Material disclaimer:** The authors are fully responsible for their work and they hold sole responsibility for the articles published in the journal.
- **Maps and affiliations:** The publisher stay neutral with regard to jurisdictional claims in published maps and institutional affiliations.
- **Responsibilities:** The editors, editorial board and publisher do not assume any responsibility for the article's contents and for the authors' views expressed in their contributions. The statements and opinions published represent the views of the authors or persons to whom they are credited. Publication of research information does not constitute a recommendation or endorsement of products involved.