Research Article

Sylvia Lewandowska*, Michał Łoziński, Krzysztof Marczewski, Marcin Kozak, Knut Schmidtke

Influence of priming on germination, development, and yield of soybean varieties

<https://doi.org/10.1515/opag-2020-0092>

received November 30, 2020; accepted December 21, 2020

Abstract: A two-factorial field experiment with soybean (*Glycine max* (L.) Merrill) was conducted in a randomized block design, with four replications. The tested factors were seed priming method and genotype responses. There had been seven soybean varieties (Aldana, Aligator, Annushka, Augusta, Lissabon, Mavka, and Merlin) and each of them had control (unprimed) and seed primed groups. The aim of this study was to determine the effect of hydropriming on germination ability and emergence under field conditions, on the growth and development of selected soybean varieties. Shortly before harvest, 10 randomly selected plants were collected from each plot, and their morphological and yield-related traits were measured. In addition, the seed yield was assessed. On the basis of statistical analysis, significant differences were found between the applied hydropriming method and the control group in regard to morphological traits. Seed treatment resulted in a slight increase in harvested seed yield, which is within error margin. The seed yield of Aligator increased significantly by 0.5 t ha^{-1} , indicating a genotype-specific different reaction to seed priming in terms of yield.

Keywords: soybean, seed priming, germination, emergence, yield

1 Introduction

Soybean (*Glycine max* (L.) Merr.) is a globally important crop providing fixed N and high-quality protein and oil (Holmberg 1973; Kamp et al. 2010; Kusano et al. 2015; Lewandowska and Michalak 2019). Crop rotation with soybean increased yield of many crops (Lauer et al. 1997; Kelley et al. 2003), improved the energy of crop production systems (Rathke et al. 2007), and reduced weed occurrence (Jedruszczak et al. 2005). According to Lewandowska (2016), for many farmers the production of this plant is a “godsend” of defective rotation to which belongs mainly cereals, maize, and rapeseed. The inclusion of soybean cultivation in crop sequences is an important and valuable element (Michalak et al. 2018). However, one of the important issues that still needs to be improved is seed emergence (Wang et al. 1996). One of the possibilities to improve this aspect is seed priming known as a process of regulating the germination by managing the temperature and seed moisture content. Then the seed is taken through the first biochemical processes within the initial stages of germination. The process involves advancing the seed to an equal stage of the germination process, to enable fast and uniform emergence when planted. Seed priming involves taking seed through the early stages of the germination process (Varier et al. 2010). Therefore, new methods with plant growth-promoting/stimulating properties are being sought. This paper focuses on priming, which is known as one of the solutions that can stimulate plant growth. Stimulation of seeds using different methods of priming as a way to increase their vigor for fast and strong plant development, optimized harvest efficiency, and quality of stimulation has caught the interest of many scientists. Crop yield can be maximized by the establishment of an adequate and uniform plant population for which

* **Corresponding author: Sylvia Lewandowska**, Department of Genetics, Plant Breeding and Seed Production, Wrocław University of Environmental and Life Sciences, Plac Grunwaldzki 24A, 50-363, Wrocław, Poland, e-mail: sylvia.lewandowska@upwr.edu.pl

Michał Łoziński: Faculty of Agriculture/Environment/Chemistry, Dresden University of Applied Science, 01069, Dresden, Germany

Krzysztof Marczewski: Department of Genetics, Plant Breeding and Seed Production, Wrocław University of Environmental and Life Sciences, Plac Grunwaldzki 24A, 50-363, Wrocław, Poland

Marcin Kozak: Institute of Agroecology and Plant Production, Wrocław University of Environmental and Life Sciences, Plac Grunwaldzki 24A, 50-363, Wrocław, Poland

Knut Schmidtke: Faculty of Agriculture/Environment/Chemistry, Dresden University of Applied Science, 01069, Dresden, Germany; Research Institute of Organic Agriculture (FiBL), 5070, Frick, Switzerland

good quality seed is a prerequisite. The gains from agromonic inputs are drastically reduced if the seed is of poor quality, resulting in a poor stand. Pre-sowing seed treatment including priming is known to improve seed performance in the field (Pill et al. 1991; Parera and Cantliffe 1994; Pill and Necker 2001; Nawaz et al. 2013; Paparella et al. 2015). Seed priming is a treatment commonly applied in agriculture, horticulture, and forestry to improve the germination of the seeds. This technique involves controlled seed hydration sufficient to permit pre-germinative metabolic events to proceed, but insufficient to allow radicle protrusion (Lutts et al. 2016). Radicle protrusion is considered as the completion of germination. After priming, seeds are dried back to their initial water content. Such treated seeds can be stored and/or sown via conventional techniques. Priming treatment has beneficial effects on the vigor and viability of seeds which is manifested by improved germination performance (increased germination rate, reduced time to achieve 50% germination – T50, increased total germination percentage, and greater uniformity of germination) and seedling growth especially under adverse environmental conditions. A wider discussion on the impact of priming on seed germination, seedling growth, and development was addressed by Kubala et al. (2013). The effectiveness of the priming process depends mainly on the selection of appropriate conditions for seeds of a given species or even a genotype. Factors affecting the success of conditioning include the following: light, temperature, time, and drying method of seeds after application (Cantliffe et al. 1981; Chiu et al. 2005; Di Girolamo and Barbanti 2012; Rajjou et al. 2012). It is necessary to add that the amount of time it takes to prime seeds is also dependent on the plant species, because the priming process is customized to each relevant crop (Kubala et al. 2013). According to McDonald (2000), drying affects the efficiency of seed conditioning more than any other factor. Storage of seeds after priming precedes their drying process to the initial level of moisture content. It should be emphasized that both the time and temperature of drying have a decisive influence on the subsequent

development of seeds, because benefits of conditioning may be lost during the drying process (Schwember and Bradford 2005).

The aim of the present study was to examine the effect of one of the physiological methods, hydropriming on germination ability and emergence under field conditions, on the growth and development of selected soybean varieties.

2 Methods

Soybean seeds cv. Aldana, Aligator, Annushka, Augusta, Lissabon, Mavka, and Merlin were used in the present study, because they were of different maturity groups and were most popular among farmers. Based on the seven soybean varieties, the examined factors were in order as follows: I – control group (unprimed seeds) and II – tested group (hydroprimed seeds). The seeds were subjected to the hydropriming process at 25°C. Twenty-five seeds were sequentially placed in plastic cuvettes on a moistened sand substrate between two microfiber layers covered by another sand layer. For a single sample tested for 24 h, 25 of the seeds were sown in 1,000 g of dry sand mixed with 0.1 dm³ of water. The microfiber layers in the experiment were used to separate sand from seed material. Then the seeds were covered with a second microfiber layer, the sand was again laid down, and the sample was gently pressed. In addition, to limit water evaporation, the cuvette was covered with food foil. After priming, the seeds were sown in field conditions.

In 2017 at the Agricultural Experimental Station in Pawlowice belonging to Wrocław University of Environmental and Life Sciences (Poland), a two-factorial field experiment was carried out in randomized block design in four replications (Table 1). The experiment was established on autogenous soil made of light clay. Soil pH in 1 M KCl was slightly acidic, and the content of phosphorus, potassium, and magnesium (Mehlich-3 method) was from

Table 1: Experimental design

Replications	Unprimed and primed (') seeds of seven varieties													
IV	1'	1	6'	2'	3'	5	4'	7	7'	3	5'	6	2	4
III	7'	3'	1	5	4	7	5'	6'	3	2	2'	1'	6	4'
II	5'	2'	4'	1	3	2	5	1'	6	4	6'	3'	7'	7
I	1	5	2	6	7	5'	2'	3	4'	7'	3'	4	1'	6'

high to very high (Table 2). Winter wheat was a previous crop to soybean. The size of a single plot was 6 m^2 ($1.5 \times 4 \text{ m}$). The field experiment consisted of 56 plots in total (28 plots unprimed seeds and 28 primed seeds of seven tested varieties). Sowing density was 70 seeds/ m^2 , row spacing – 15 cm, and sowing depth – 3 cm. The experiment was sown on 27 April with the plot seeder Tool Carrier 2,700. Directly before sowing the seeds were inoculated additionally by HiStick containing the beneficial bioactive organisms – *Bradyrhizobium japonicum*. Boxer 800 EC herbicide at $4 \text{ dm}^3 \text{ ha}^{-1}$ ($3,200 \text{ g ha}^{-1}$ pro-sulfocarb) was used for the first time straight after soybean sowing and the second time a month later with Corum 5,024 SL at $0.625 \text{ dm}^3 \text{ ha}^{-1}$ (300 g ha^{-1} benta-zone and 14 g ha^{-1} imazamox) and Select Super 120 EC at $0.8 \text{ dm}^3 \text{ ha}^{-1}$ (96 g ha^{-1} clethodim). The harvest was done on 29 September 2017 by plot combine Wintersteiger Elite.

The weather conditions during the growing period were not favorable for soybean cultivation because in spring low temperatures and high rainfall were noted, which decreased soybean emergence in the field. Average monthly temperatures were higher than the long-term mean for period 1981–2010 in March, May, June, July, and August. Total monthly sums of rainfall were higher compared to long-term average in April, July, and September. Particular attention should be paid to low average temperature in the second and third decade of April and May, as well as the high rainfall in the third decade of April and first of May (Table 3). Excessive rainfall straight after sowing caused soil crusting that impeded seedling emergence.

The effectiveness of priming was assessed on the basis of morphological and yield-related traits: plant height (cm), number of first branches, first pod height (cm), pod number per plant, seed number per plant, seed number per pod, seed weight per single pod (g), seed weight per plant (g), and 1,000 seed weight (g). Shortly before harvest 10 randomly selected plants were collected from each plot. The data of the studies were statistically analyzed by analysis of variance (ANOVA), at the significance level of 0.05 by using Fisher's test.

Table 2: Soil's abundance in macroelements (mg kg^{-1}) and soil pH value (1 M KCl)

Replications	pH in 1 M KCl	P	K	Mg
I	5.7	83.0	200.4	141.9
II	5.7	92.0	219.9	132.0
III	5.6	83.5	223.8	148.6
IV	5.7	88.8	223.8	123.6

Table 3: Weather conditions (2017) at Pawlowice experimental field

Month	III	IV	V	VI	VII	VIII	IX
Decade	Temperature ($^{\circ}\text{C}$)						
I	6.2	11.0	9.4	17.2	18.2	22.1	14.7
II	5.4	6.1	16.0	18.1	18.6	18.9	12.8
III	8.6	6.7	17.0	20.0	20.0	17.5	12.2
Monthly average	6.8	7.9	14.2	18.5	19.0	19.4	13.3
Average long term for period 1981–2010	3.8	8.3	14.1	16.9	18.7	17.9	13.6
Decade	Rainfall (mm)						
I	9.8	14.2	13.9	0.5	43.0	6.9	35.4
II	19.8	13.8	0.9	0.1	0.9	35.7	12.7
III	1.5	29.0	9.3	51.9	68.3	1.0	17.6
Total	31.1	57.0	24.1	52.5	112.2	43.6	65.7
Average long term for period 1981–2010	31.7	30.5	51.3	59.5	78.9	61.7	45.3

The AWA program (Bartkowiak 1978) was applied for calculations.

3 Results and discussion

The field trial showed significant effects of both the genotype and the seed treatment (priming) (Table 4), although a significant interaction between the cultivar and the seed treatment was only observed with regard to the grain yield of soybeans (Figure 1). Seed priming resulted in a significant increase of 1.7 cm in first pod height on average for the cultivars, which should help eliminate losses during harvest. This trait is very desirable from the agronomic point of view (Kowalczyk 1999; Milan et al. 2005) as it still generates losses during harvesting period. Therefore, a continuous breeding study has been carried out aiming to increase first pod height (Thompson and Nelson 1998; Mikel et al. 2010). On the contrary, seed priming significantly reduced the number of productive pods per plant, the number of seeds per plant, and the seed weight produced per plant (Table 4). However, the mean plant height, the number of branches, the number of seeds per productive pod, the seed weight per productive pod, and 1,000 seed weight were not affected by priming. For six soybean cultivars, seed treatment resulted in a slight increase in grain yield. However, the grain yield of Aligator increased significantly by 0.5 t ha^{-1} (Figure 1), indicating a genotype-specific different reaction to seed priming. Similar conclusions were made by Arif et al. (2008), Mohammadi (2009),

Table 4: Effect of seed priming and soybean variety on morphological and yield-related traits. Superscripts represent significance groups

	Cultivar	Plant height (cm)	No. of first branches	First pod height (cm)	Pod number/plant	No. of seeds/plant	No. of seeds/productive pod	Seed weight/plant (g)	Seed weight/productive pod (g)	1,000 seed weight (g)
Cultivar	Aldana	29.9 ^b	2.8	4.0 ^a	54.4 ^{bc}	108.9	2.0	20.94 ^{ab}	0.38 ^{abc}	190.4 ^{ab}
	Aligator	38.0 ^{ab}	3.7	5.3 ^{ab}	72.2 ^{ab}	151.3	2.1	28.73 ^a	0.40 ^{ab}	189.0 ^{ab}
	Annushka	39.6 ^a	2.5	7.8 ^b	37.2 ^c	77.0	2.1	12.45 ^b	0.33 ^c	159.8 ^c
	Augusta	37.7 ^{ab}	3.7	4.7 ^a	60.6 ^{abc}	125.0	2.1	20.87 ^{ab}	0.34 ^{bc}	165.1 ^c
	Lissabon	40.3 ^a	5.0	5.7 ^{ab}	86.2 ^a	184.8	2.1	31.24 ^a	0.36 ^{abc}	169.6 ^{bc}
	Mavka	35.4 ^{ab}	2.7	5.0 ^a	52.7 ^{ab}	111.9	2.1	21.73 ^{ab}	0.41 ^a	195.0 ^{ab}
	Merlin	38.0 ^{ab}	3.5	5.5 ^{ab}	62.2 ^{abc}	134.1	2.2	21.68 ^{ab}	0.35 ^{bc}	162.4 ^c
Control		36.0	3.6	4.6	70.9	147.7	2.1	26.01	0.36	174.2
Priming		37.9	3.3	6.3	50.7	107.4	2.1	19.03	0.37	177.6
<i>F</i> value cultivar (C)		2.75	6.45	3.48	5.01	5.27	0.95	4.71	4.78	8.23
<i>P</i> value cultivar		0.0250	<0.0001	0.0075	0.0007	0.0005	0.4713	0.0011	0.0010	<0.0001
LSD _{Variety} Tukey		9.19	1.4984	2.78	30.396	65.515	0.32	12.33	0.0635	23.016
test (5%)										
<i>F</i> value treatment (T)		1.35	1.35	12.53	14.95	12.75	0.21	10.82	1.38	0.69
<i>P</i> value treatment		0.2510	0.2515	0.0011	0.0004	0.001	0.6468	0.0021	0.2478	0.4099
<i>F</i> value interactions (C × T)		1.19	0.43	1.10	0.84	0.62	1.27	0.67	0.19	0.74
<i>P</i> value interactions (C × T)		0.3305	0.8528	0.3788	0.5496	0.7105	0.2942	0.6765	0.9764	0.6188

Figure 1: Effect of seed priming and soybean variety on seed yield (mean + standard error; treatment: $P < 0.0001$; variety: $P < 0.0001$; interactions $T \times V$: $P < 0.0001$).

and Nawaz et al. (2013). They indicated that priming was always better than non-treated seeds. The higher grain yields of the seed treated soybeans must be a consequence of higher plant density at the time of plot harvest sown with primed soybeans. On the contrary, the higher insertion of the first pods of primed soybeans may also have led to a lower retention of unrecorded pods in the field. With the exception of the number of seeds per

productive pod, significant variety differences were found between the varieties for all parameters tested (Table 4 and Figure 1). These results demonstrate the comparatively large genetic variability that exists between the tested varieties of different maturity groups.

Soybean sowing was carried out in difficult conditions. The very wet weather caused problems with soil cultivation. After sowing, because of rain, soybean emergence was further complicated, forming a crust in the top layer. However, of the assumed 70 seeds/m², the final density decreased to half. It was worth mentioning that when soybean is sown in very low density per square meter, it has strong ability to produce lateral branches. As a result, the number of pods increases visibly (Ball et al. 2001; De Bruin and Pedersen 2009; Liu et al. 2010; Carciochi et al. 2019). Therefore, it is impossible to estimate the yield by multiplying the assumed plant density by seed weight per plant.

4 Conclusions

The study revealed that seed priming method effected significantly on first pod height which is a desired trait from breeding point of view. Furthermore, a positive reaction of genotypes to priming was noted. Seven tested

cultivars showed an increase in seed yield but only Aligator responded statistically significant. Therefore, specific procedure precisely adapted to the cultivar is required to achieve an increase in yield through priming.

Author contributions: K. S. – conceptualization; S. L. and M. K. – project administration; M. Ł., S. L., and M. K. – resources; M. Ł., S. L., K. S., and M. K. – methodology; S. L. – writing and original draft preparation; S. L. and K. M. – writing—review and editing; K. M. and S. L. – visualization. All authors have read and agreed to the published version of the manuscript.

Funding and acknowledgment: The authors would like to thank Wrocław University of Environmental and Life Sciences for funding this research – B010/0015/20.

Conflict of interest: The authors declare no conflict of interest. The funders had no role in the design of the study, in the collection, analyses or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

Data availability statement: All data generated or analyzed during this study are included in this published article.

References

- Arif M, Jan MT, Marwat KB, Khan MA. Seed priming improves emergence and yield of soybean. *Pak J Bot.* 2008;40(3):1169–77.
- Ball RA, McNew RW, Vories ED, Keisling TC, Purcell LC. Path analyses of population density effects on short-season soybean yield. *Agron J.* 2001;93:187–95.
- Bartkowiak A. Analiza wariancji dla układów ortogonalnych. Program AWA [w:] Opismerytoryczny programów statystycznych opracowanych w Instytucie Informatyki Uniwersytetu Wrocławskiego. Wydawnictwo Uniwersytetu Wrocławskiego. 1978;43–60.
- Cantliffe DJ, Shuler KD, Guedes AC. Overcoming seed thermodynamicity in a heat sensitive romaine lettuce by seed priming. *Hortscience.* 1981;16:196–8.
- Carciochi WA, Schwalbert R, Andrade FH, Corassa GM, Carter P, Gaspar AP, et al. Soybean seed yield response to plant density by yield environment in North America. *Agron J.* 2019;111(4):1923–32.
- Chiu KY, Chen CL, Sung JM. Why 20 degrees C-primed sh-2 sweet corn seeds were of higher quality than 20 degrees C-primed seeds: some physiological clues. *Seed Sci Technol.* 2005;33:199–213.
- Di Girolamo G, Barbanti L. Treatment conditions and biochemical processes influencing seed priming effectiveness. *Ital J Agron.* 2012;7(2):178–88.
- De Bruin JL, Pedersen P. New and old soybean cultivar responses to plant density and intercepted light. *Crop Sci.* 2009;49(6):2225–32.
- Holmberg SA. Soybeans for cool temperature climates. *Agr Hort Genet.* 1973;31(1–2):1–20.
- Jedruszczak M, Wesołowski M, Bujak K. Crop rotation function of regulator towards weeds in crop conopies. *Fragm Agron.* 2005;2:81–9.
- Kamp JALM, van BS, Timmer RD, van RP. Verkenning naar de mogelijkheden van eiwithoudende teelten in Europa. Edited Lelystad. 2010.
- Kelley KW, Long Jr JH, Todd TC. Long-term crop rotations affect soybean yield, seed weight, and soil chemical properties. *Field Crop Res.* 2003;83(1):41–50.
- Kowalczyk J. Pattern of seed losses and damage during soybean harvest with grain combine harvesters. *Int Agrophys.* 1999;13:103–7.
- Kubala SZ, Wojtyła Ł, Garnczarska M. Kondycjonowanie jako strategia uszlachetniania nasion. *Postępy Biologii Komórki.* 2013;40(2):215–30.
- Kusano M, Baxter I, Fukushima A, Oikawa A, Okazaki Y, Nakabayashi R, et al. Assessing metabolomics and chemical diversity of a soybean lineage representing 35 years of breeding. *Metabolomics.* 2015;11:261–70.
- Lauer J, Porter P, Oplinger E. The corn and soybean rotation effect. *Field Crop.* 1997;28:426–514.
- Lewandowska S. Perspectives of soybean cultivation in Poland. *Agric XXI Century Probl Challenges.* 2016. p. 162–9
- Lewandowska S, Michalak I. Effect of algal extracts on germination ability of different varieties of soybean. Seed and seedlings. XIV scientific and technical seminar. Czech University of Life Sciences Prague. Proceedings. 2019. p. 84–90
- Liu B, Liu X-B, Wang C, Jin J, Herbert SJ, Hashemi M. Responses of soybean yield and yield components to light enrichment and planting density. *Int J Plant Prod.* 2010;4(1):1–10.
- Lutts S, Benincasa P, Wojtyła Ł, Kubala SZ, Roberta P, Lechowska K, et al. Seed priming: new comprehensive approaches for an old empirical technique. In: Araujo S, Balestrazzi A, (eds). *New challenges in seed biology – basic and translational research driving seed technology chapter: 1.* London: IntechOpen; 2016.
- McDonald MB. Seed priming. In: Black M, Bewley JD, (eds). *Seed technology and its biological basis.* Sheffield: Sheffield Academic Press; 2000. p. 287–325
- Michalak I, Lewandowska S, Detyńska J, Olsztyńska-Janus S, Bujak H, Pacholska P. The effect of macroalgal extracts and near infrared radiation on germination of soybean seedlings: preliminary research results. *Open Chem.* 2018;16(1):1066–76.
- Mikel MA, Diers BW, Nelson RL, Smith HH. Genetic diversity and agronomic improvement of North American soybean germplasm. *Crop Sci.* 2010;50:1219–29.
- Milan Z, Jasmina Z, Ljiljana S, Nenad P. Combining abilities of inheriting first pod height of some French bean lines -Phaseolus vulgaris L. *Genetika.* 2005;37:65–70.
- Mohammadi GR. The effect of seed priming on plant traits of late-spring seeded soybean (*Glycine max* L.). *Am Eurasian J Agric Env Sci.* 2009;5(3):322–6.
- Nawaz J, Hussain M, Jabar A, Nadeem GA, Sajid M, Substain M, et al. Seed priming – a technique. *Int J Agric Crop Sci.* 2013;6:1373–81.

- [27] Paparella S, Araujo S, Rossi G, Wijayasinghe M, Carbonera D, Balestrazzi A. Seed priming: state of the art and new perspectives. *Plant Cell Rep.* 2015;34:1281–93.
- [28] Parera CA, Cantliffe DJ. Presowing seed priming. *Hortic Rev.* 1994;16:109–41.
- [29] Pill WG, Frett JJ, Morneau DC. Germination and seedling emergence of primed tomato and asparagus seeds under adverse conditions. *Hortscience.* 1991;26:1160–2.
- [30] Pill WG, Necker AD. The effects of seed treatments on germination and establishment of Kentucky bluegrass (*Poa pratense* L.). *Seed Sci Technol.* 2001;29:65–72.
- [31] Rajjou L, Duval M, Gallardo K, Catusse J, Bally J, Job C, et al. Seed germination and vigor. *Annu Rev Plant Biol.* 2012;63:507–33.
- [32] Rathke GW, Wienhold BJ, Wilhelm WW, Diepenbrock W. Tillage and rotation effect on corn-soybean energy balances in eastern Nebraska. *Soil Res.* 2007;97:60–70.
- [33] Schwember AR, Bradford KJ. Drying rates following priming affect temperature sensitivity of germination and longevity of lettuce seeds. *Hortscience.* 2005;40:778–81.
- [34] Thompson JA, Nelson RL. Utilization of diverse germplasm for soybean yield improvement. *Crop Sci.* 1998;38:1362–8.
- [35] Varier A, Kuriakose Vari A, Dadlani M. The subcellular basis of seed priming. *Curr Sci India.* 2010;99(4):450–6.
- [36] Wang Q, Zhang F, Smith DL. Application of GA3 and kinetin to improve corn and soybean seedling emergence at low temperature. *Env Exp Bot.* 1996;36(4):377–83.