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EFFECT OF pH ON GERMINATION AND SEEDLING GROWTH OF MAIZE

Violeta Mandić[1], Vesna Krnjaja[1], Aleksandar Simić[2], Maja Petričević[1], Marija Gogić[1], Milan Brankov[3], Aleksandar Stanojković[1]

[1]Institute for Animal Husbandry, Autoput 16, 11080, Belgrade-Zemun, Serbia
[2]Faculty of Agriculture, University of Belgrade, Nemanjina 6, 11080 Belgrade-Zemun, Serbia
[3]Maize Research Institute „Zemun Polje", Slobodana Bajića 1, 11185 Belgrade-Zemun, Serbia
Corresponding author: Violeta Mandić, violeta_randjelovic@yahoo.com
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Abstract: Soil pH is one of the most important limiting factors for crop cultivation, including maize. About 30-40% of the world's arable land is acidic, and over a billion ha is alkaline. Today, there are 205 million ha of arable land under maize in the world, so it ranks third in area after rice and wheat. Maize hybrids have wide genetic variability and high pH tolerance. We tested the tolerance of maize hybrids seedlings of ZP 4708 and ZP 5797 to pH 5, 6, 7, and 8. Results showed that hybrid ZP 4708 has a higher adaptability to low and high pH, due to the higher value of germination energy (GE), shoot length (ShL), shoot fresh weight (ShFW), shoot dry weight (ShDW), germination rate index (GRI), and seedling vigor index (SVI) than hybrid ZP 5797. Results further showed, on average for hybrids, that pH 5 and pH 8 significantly decreased the GE, root length (RL), ShL, root fresh weight (RFW), ShFW, root dry weight (RDW), shoot fresh weight (ShDW), and SVI. These parameters did not differ significantly between pH 6 and pH 7. Seed germination was not affected by the pH, indicating that the seed vigor of both hybrids supports full germination potential. However, it could be expected that exposure to the lowest and highest pH values of the medium could affect seedlings growth in the field conditions, even though germination is high. SVI showed a positive and significant correlation with all investigated parameters, except germination (G) and relative seedling water content (RSWC).

Key words: correlation, germination, maize, pH, seedling

Introduction

Maize is one of the top-produced crops in the world. Its chemical composition makes it suitable for human consumption, animal feed, and industrial uses. The total world production of maize in 2021 was 1210 billion tons on about 205 million ha *(FAO, 2023)*. Serbian production of maize in 2022 was 4.283.293

tons on 952.216 ha *(Statistical Yearbook of the Republic of Serbia, 2023)*. However, there are many limiting factors for cultivation, including soil pH. Soil with a pH of 4.5-5.5 is strongly acidic, pH 5.6-6.5 slightly acidic, pH 6.6-7.3 neutral, and pH 7.4-8.4 slightly alkaline *(Ahmed et al., 2018)*. Maize thrives best on soil between 6.5 and 7.0 pH. The tolerance degree to soil acidity depends on the maize genotype, the concentration of hydrogen and aluminum ions, and the physicochemical soil properties. On soils with a reaction pH<5, due to aluminum and manganese toxicity, the root system and plant growth are reduced *(Rahman et al., 2018)*, with occurrence of phosphorus deficiency. The result is a yield reduction in over 69% *(Tandzi et al., 2015)*. On such soil, it is necessary to carry out amelioration measures such as calcification, humification, and application of phosphorus and microelements fertilizers. By growing tolerant hybrids, the harmful effects of acidic soil reactions on maize production can be mitigated. On the other hand, alkaline soils reduce the maize yield by 20–46% *(Fu et al., 2017)*, due to root poisoning by ions and osmotic imbalance, which reduces its growth, inhibits biomass and plant growth, and causes wilting and eventual death of plants *(Guo et al., 2014)*. Germination and early seedling growth are the most important factors to achieve the appropriate number of plants per unit area and yield *(Amini et al., 2015)*.

According to *Kolasinska et al. (2000)*, germination test results in laboratory conditions correlate well with emergence in the field. This provides a good basis for predicting seed and seedling performance under field conditions. In this regard, laboratory experiments that are faster and cheaper were settled to test maize hybrids regarding the various soil pH. This research aimed to determine to what extent the pH value of the medium influences the differences and possible advantages of germination and initial seedling development (vigor) of two maize genotypes.

Materials and Methods

Laboratory experiments were conducted at the Institute for Animal Husbandry in Belgrade, Republic of Serbia in 2023. New hybrids ZP 4708 and ZP 5797 selected in Maize Research Institute "Zemun Polje" were used as material. The seeds were first sterilized with 1% sodium hypochlorite for 5 minutes, washed 3 times in sterile distilled water (pH 7), and dried. Each treatment contained 100 seeds per application placed on filter paper in a sterilized plastic box with a cover to prevent water loss (15cm x 21cm x 4cm). The pH 5 and pH 6 solutions were made by adding 0.1 M hydrochloric acid solution to distilled water. The pH 8 solution was made by adding 0.1 M sodium hydroxide to distilled water. The filter papers were soaked with 10 ml of media. Experiments were carried out at 20 °C for 10 days.

In the study, a randomized complete block design with four replicates was used, i.e. a 2 × 4 design (factor hybrid with 2 levels and factor pH with 4 levels).

Germination e Germination energy (GE) and germination (G) were determined according to ISTA Rules on the fourth and seventh days, respectively *(ISTA 2019)*. Other quantitative parameters (root length - RL, shoot length - ShL, root fresh weight - RFW, shoot fresh weight - ShFW, root dry weight - RDW, and shoot dry weight - ShDW) were determined ten days after sowing. Rate germination index (RGI), seedling vigor index (SVI), and relative seedling water content (RSWC) were calculated by the formulas described in research by *Mandić et al. (2014)*:

$$\text{RGI} = \frac{\text{No. of seeds germinated at 3 day}}{\text{No of seeds germinated at 7 day}} \times 100$$

SVI = (Root length + Shoot length) x Germination percentage

$$\text{RSWC} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

The data analysis was processed in Statica version 13 (StatSoft, Tulsa, Oklahoma, USA) while comparing the means using Tukey's test at a 5% level. Pearson's correlation coefficient was run to measure the relationship between the parameters.

Results and Discussion

Results of ANOVA showed that hybrid had a highly significant effect on GE, ShL, ShFW, ShDW, RGI, and SVI (Table 1). These parameters were higher in the hybrid ZP 4708 than in ZP 5797. Thus, GE was higher for 42.5%, ShL for 1.15 cm, ShFW for 29.1 mg, ShDW for 2.3 mg, RGI for 61.1%, and SVI for 210.6 than in ZP 5797 (54.38, 3.44 cm, 99.4 mg, 11.2, 49,4%, and 1374,4, respectively). *Tandzi et al. (2018)* also reported that maize hybrids have different levels of pH tolerance. *Torres et al. (2019)* stated that genetic diversity can be established already on seed and seedling traits. According to *Egli and Rucker (2012)*, maize hybrid seeds with a high vitality index germinate more uniformly and in less favorable environmental conditions, which we observed in our research. It should be noted that although we only focused on the effect of pH on these hybrids, the results are useful for future field experiments related to the expansion of the area of their cultivation.

Table 1. The effects of hybrid and pH on germination energy (GE), germination (G), root length (RL), shoot length (ShL), root fresh weight (RFW), shoot fresh weight (ShFW), root dry weight (RDW), shoot dry weight (ShDW), rate germination index (RGI), seedling vigor index (SVI), and relative seedling water content (RSWC) of maize

Parameters	Hybrid (H)	pH				Means
		5	6	7	8	
GE, %	ZP 4708	96.25^{a}	96.25^{a}	97.50^{a}	97.50^{a}	96.88^{a}
	ZP 5797	37.50^{c}	61.25^{b}	68.75^{b}	50.00^{bc}	54.38^{b}
	Means	66.88^{b}	78.75^{ab}	83.12^{a}	73.75^{ab}	75.63
G, %	ZP 4708	100.00	100.00	100.00	98.75	99.69
	ZP 5797	100.00	96.25	98.75	98.75	98.44
	Means	100.00	98.12	99.38	98.75	99.07
RL, cm	ZP 4708	9.22	11.69	13.27	11.08	11.31
	ZP 5797	8.45	11.11	12.10	10.46	10.53
	Means	8.84^{b}	11.40^{a}	12.68^{a}	10.77^{ab}	10.92
ShL, cm	ZP 4708	4.19	5.00	5.62	3.56	4.59^{a}
	ZP 5797	1.99	4.04	4.17	3.58	3.44^{b}
	Means	3.09^{c}	4.52^{ab}	4.90^{a}	3.57^{bc}	4.02
RFW, mg	ZP 4708	136.9	246.1	277.9	184.9	211.4
	ZP 5797	135.3	242.8	232.8	183.5	198.6
	Means	136.1^{c}	244.4^{ab}	255.4^{a}	184.2^{bc}	205.0
ShFW, mg	ZP 4708	115.8^{abcd}	146.3^{ab}	183.1^{a}	68.8^{cd}	128.5^{a}
	ZP 5797	52.7^{cd}	122.5^{abcd}	117.0^{abcd}	105.3^{bcd}	99.4^{b}
	Means	84.2^{b}	134.4^{a}	150.0^{a}	87.1^{b}	113.95
RDW, mg	ZP 4708	20.4	28.3	31.8	23.2	25.9
	ZP 5797	15.3	27.9	29.0	23.5	23.9
	Means	17.8^{c}	28.1^{ab}	30.4^{a}	23.3^{bc}	24.9
ShDW, mg	ZP 4708	11.8	14.6	16.8	11.0	13.5^{a}
	ZP 5797	7.3	13.2	12.7	11.8	11.2^{b}
	Means	9.6^{c}	13.9^{ab}	14.7^{a}	11.4^{bc}	12.4
RGI, %	ZP 4708	77.5	85.0	82.5	74.7	79.9^{a}
	ZP 5797	16.2	20.9	26.6	11.5	18.8^{b}
	Means	46.9	53.0	54.6	43.1	49.4
SVI	ZP 4708	1341.0	1668.0	1889.2	1441.8	1585.0^{a}
	ZP 5797	1044.2	1457.1	1606.2	1390.0	1374.4^{b}
	Means	1192.6^{c}	1562.5^{ab}	1747.8^{a}	1415.9^{bc}	1479.7
RSWC, %	ZP 4708	87.5	89.2	88.8	85.2	87.7
	ZP 5797	88.2	88.7	88.0	85.8	87.7
	Means	87.9	89.0	88.4	85.5	87.7

Factor	GE	G	RL	ShL	RFW	ShFW	RDW	ShDW	RGI	SVI	RSWC
H	**	ns	ns	**	ns	*	ns	**	**	**	ns
pH	*	ns	**	**	**	**	**	**	*	**	ns
H × pH	*	ns	ns	ns	ns	*	ns	ns	ns	ns	ns

The testing the effects of pH on maize seedling parameters in laboratory conditions, we concluded that pH greatly affects the germination energy, growth,

and development of seedlings. This study demonstrated that the germination energy, seedling performances, RGI, and SVI were significantly dependent on pH media. The G, RGI, and RSWC were non-significant. Data also showed that maximum GE (83.12 %), RL (12.68 cm), ShL (4.90 cm), RFW (255.4 mg), ShFW (150.0 mg), RDW (30.4 mg), ShDW (14.7 mg), SVI (1747.8) were attained at optimal, pH 7. The values of these parameters were not significantly different from those at pH 6 (GE – 78.75 %, RL – 11.40 cm, ShL – 4.52 cm, RFW – 244.4 mg, ShFW – 134.4 mg, RDW – 28.1 mg, ShDW – 13.9 mg, and SVI – 1562.5). The values of investigated parameters were reduced when the pH reaction was at pH 5, and pH 8. The minimum values of (GE – 66.88 %, RL – 8.84 cm, ShL – 3.09 cm, RFW – 136.1 mg, ShFW – 84.2 mg, RDW – 17.8 mg, ShDW – 9.6 mg, and SVI – 1192.6) were recorded at pH 5.

Results showed that the seeds of the tested hybrids can germinate in a wide range of pH from 5 to 8, but the best performances of the seedlings are in the pH 6 and pH 7 treatments. Similarly, *Sikalengo (2016)* reports that the maize germination and dry matter content are reduced in soil with pH 5.0 and pH 8.5. The research by *Neina (2019)* and *Msimbira et al. (2023)* has shown that a slightly acidic pH value of the medium slightly increases the germination of maize seeds and has a significant role in interactions with the environment.

The effect of hybrid × pH interaction was the most important in the expression of GE and ShFW. Hybrid ZP 4708 had the highest GE value in all pH media. The highest average value of GE was in hybrid ZP 4708 at pH 7 and pH 8 medium (97.5 %), and the lowest in hybrid ZP 5797 at pH 5 medium (37.5 %). In both hybrids, ShFW varied significantly depending on the pH of the medium. Hybrid ZP 4708 had the highest ShFW value in the pH 7 treatment (183.1 mg), and hybrid ZP 5797 had the lowest value in the pH 5 treatment (52.7 mg).

On the other hand, seed germination was not affected by the pH, indicating that the germination potential of both hybrids was high. However, seedling parameters of the tested hybrids depended to a large extent on the medium pH. Exposure to the lowest and highest pH values of the medium resulted in similar performance of the hybrids suggesting that seedling development is highly affected by extreme pH, even though germination was high.

GE shows a strong, positive, and highly significant correlation with RGI (0.89**), RL with SVI (0.95**), RDW (0.85**), and RFW (0.83**), ShL with ShDW (0.94**), SVI (0.89**), and ShFW (0.84**), RFW with RDW (0.88**), SVI (0.84**), and ShDW (0.80**), ShFW with ShDW (0.88**), RDW and ShDW (0.88**), and SVI (0.86**), and ShDW with SVI (0.89**), Table 2. Also, *Vengilat et al. (2019)* have found that SVI positively correlated with RL and ShL. However, these authors also have found a positive correlation between G and RL, G and ShL, and G and SVI, which is contrary to our results. *Arshad et al (2020)* have found a significant positive correlation between ShFW and ShL (0.68**) and RFW and RDW (0.50*), while *Naseem et al (2020)* between RL and ShL (0.81*). According

to our results, seedling root and shoot parameters and SVI are important for high crop population density under various pH conditions.

Table 2. Relationship of germination and seedling growth parameters under pH media

Parameters	GE	G	RL	ShL	RFW	ShFW	RDW	ShDW	RGI	SVI
G	0.18									
RL	0.36*	-0.06								
ShL	0.54**	-0.015	0.71**							
RFW	0.21*	-0.11	0.83**	0.72**						
ShFW	0.38*	-0.08	0.64**	0.84**	0.71**					
RDW	0.34	-0.18	0.85**	0.76**	0.88**	0.75**				
ShDW	0.46**	-0.09	0.76**	0.94**	0.80**	0.88**	0.88**			
RGI	0.89**	0.23	0.30	0.49**	0.19*	0.36*	0.25	0.39*		
SVI	0.48**	0.06	0.95**	0.89**	0.84**	0.76**	0.86**	0.89**	0.43*	
RSWC	-0.05	0.08	0.12	0.27	0.34	0.12	0.08	0.15	0.06	0.20

Germination energy (GE), germination (G), root length (RL), shoot length (ShL), root fresh weight (RFW), shoot fresh weight (ShFW), root dry weight (RDW), shoot dry weight (ShDW), rate germination index (RGI), seedling vigor index (SVI), and relative seedling water content (RSWC) of maize

Conclusion

Both hybrids ZP 4708 and ZP 5797 can successfully grow on media with a pH value in the range of 5.0 to 8.0. However, maize hybrids do not have the same ability to adapt to such conditions. Results showed that maize hybrid ZP 4708 has better seedlings performance (GE, ShL, ShFW, ShDW, GRI, and SVI) compared to hybrid ZP 5797. Results further showed that the GE, RL, ShL, RFW, ShFW, RDW, ShDW, and SVI did not differ between treatments pH 6 and pH 7. Accordingly, a slightly acidic pH value of the medium could increase the growth of seedlings. The decrease (pH 5) and increase in pH level (pH 8) decreased the seedling growth. The practical importance of the achieved results indicated that the new hybrid ZP 4708 showed better performances of seedlings on slightly acidic to neutral levels media (pH 6 and pH 7) and could be expected to achieve better emergence, crop growth, and suitable plant density at different pH values.

UTICAJ pH VREDNOSTI NA KLIJANJE I RAST KLIJANACA KUKURUZA

Violeta Mandić, Vesna Krnjaja, Aleksandar Simić, Maja Petričević, Marija Gogić, Milan Brankov, Aleksandar Stanojković

Rezime

pH zemljišta je jedan od važnih ograničavajućih faktora za gajenje useva, a samim tim i kukuruza. Oko 30-40% svetskih obradivih površina je kisele reakcije, a preko milijardu ha je alkalno. Danas je u svetu 205 miliona ha obradivih površina pod kukuruzom, tako da on zauzima treće mesto po površini posle pirinča i pšenice. Hibridi kukuruza imaju široku genetsku varijabilnost i toleranciju za pH. Ispitivali smo toleranciju klijanaca novih hibrida kukuruza ZP 4708 i ZP 5797 na pH 5, 6, 7 i 8. Rezultati su pokazali da hibrid ZP 4708 ima bolju sposobnost adaptacije na nisku i visoku pH vrednost jer je imao veću energiju klijanja (EK), dužinu stabla (DS), svežu masu stabla (SvMS), suvu masu stabla (SuMS), indeks klijavosti (IK) i vigor indeks (VI) od hibrida ZP 5797. Rezultati su dalje pokazali, u proseku za hibride, da su niski (pH 5) i visoki pH nivo medijuma (pH8) značajno smanjili EK, dužinu korena (DK), DS, svežu masu korena (SvMK), SvMS, suvu masu korena (SuMK), SuMS i VI. Ovi parametri se nisu razlikovali između tretmana pH 6 i pH 7. pH medijuma nije uticala na klijanje semena što ukazuje da snaga semena oba hibrida podržava pun potencijal klijanja. Međutim, izlaganje najnižim i najvišim pH vrednostima medijuma je dovelo do toga da nije moguće očekivati jake klijance, iako je klijavost visoka. VI je pokazao pozitivnu i značajnu korelaciju sa svim ispitivanim parametrima, osim sa klijanjem semena i relativnim sadržajem vode u klijancima.

Ključne reči: korelacija, klijavost, kukuruz, pH, klijanac

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