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Sensitivity of Maize Growth Stages to Excess Soil Moisture Stress

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ABSTRACT

Background: Waterlogging is a significant obstacle to sustainable maize production. Hence, this study aimed to determine the effects of seven days of waterlogging at different maize growth stages, to determine the most sensitive growth stage that affects maize growth and yield, to determine the inter-phenotypic relationship of maize traits and identify maize traits conferring tolerance to waterlogging.

Methods: The study was conducted using a randomized complete block design with three replications. All data gathered were analyzed using ANOVA and significant differences among treatment means were compared using Tukey's HSD. The association of maize traits was computed using the Pearson Product Moment Correlation and the strength of the relationship of correlated maize traits was determined using the Rumsey scale.

Result: The result shows that waterlogging can increase the number of adventitious roots during the vegetative and reproductive stages. It induces severe leaf chlorosis when waterlogging occurs at the tasseling stage compared to the other growth stages. The tasseling stage obtained the lowest survival rate and chlorophyll content, shortest ear length, lightest one thousand seed weight, smallest ear diameter, low number of kernels and kernel rows per ear. The maize tasseling stage exhibited a 58.30% yield reduction under waterlogging conditions, making it the most sensitive stage. Maize with greener leaves and longer nodal roots were positively correlated with survival rate (r=0.89). The findings suggest that leaf greenness and nodal root length are reliable indicators for selecting waterlogging-tolerant maize varieties.

Key words: Adaptive traits, Climate change, Climate resilience, Corn, Waterlogging.

INTRODUCTION

Maize (*Zea mays* Linn.) is an important cereal crop worldwide. It serves as a staple food, feeds for the poultry and livestock and is an essential ingredient in various industrial products (Gazal *et al*., 2017). Also, the crop can be grown in a wide array of agro-climatic conditions extending from subtropical to cooler temperate regions. Thus, unavoidably, the crop remains open to varied types of biotic and abiotic stresses. One of the abiotic stresses of climate change is excessive and erratic rain patterns that cause waterlogging in the maize production area. The waterlogging of the maize field can cause excess soil moisture stress, which is an essential constraint for maize production and productivity in Asian regions (Lone and Warsi, 2009).

Climate change is a significant issue that requires agriculture to exert efforts to adapt and mitigate its impact. Excessive and erratic rain patterns have shifted the agriculture paradigm, particularly maize production. According to reports, waterlogging affects 10% of the world's land surface (Setter and Waters, 2003), making it difficult for agricultural crop production to achieve food security and sustainability objectives. About 15% of the land used to grow maize is impacted by flooding and waterlogging in South and Southeast Asia alone (Rathore *et al*., 1998, as referenced by Esteban and Baldo, 2024). When crops experience waterlogging stress, about 15% to 80% of yield reduction will be observed, depending on the species, soil type and duration of the stress (Zhou, 2010). This scenario would significantly impact the export, food and feed industries and the source of income for millions of corn farmers around the globe (Esteban and Baldo, 2023; Esteban and Baldo, 2024). This scenario negatively impacted the export, food and feed industries and corn farmers' income source. Thus, this negative implication on maize production will not contribute to the attainment of Sustainable Development Goals (SDGs) of the UN particularly SDG 1 (Zero Hunger).

Waterlogging can happen in any growth stage of maize and affect its productivity. There are several studies conducted on the maize subjected to waterlogging stress. According to Zaidi *et al*. (2007), the V2 leaf stage is the most sensitive to waterlogging. In addition, Kavita *et al*. (2018) screened maize lines for waterlogging at the V2 leaf stage and knee-high stage, which were compared with normal conditions. While previous studies focused on early vegetative stages (V2), limited information exists

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on the reproductive stages' response to waterlogging and associated yield reduction. However, these studies should have included the other critical growth stage of maize that determines overall yield performance. Kaur *et al.* (2019) also screened waterlogging tolerant maize at the V2 leaf stage. However, the yield performance of the screen maize lines to waterlogging was not obtained since this parameter is an important agronomic trait of maize that should be included.

For a comprehensive understanding of maize growth response to waterlogging, it is necessary to include data on the reproductive stage, yield and yield components since most research focused on the growth response. Also, there is a need for more information on maize waterlogging studies because most research has focused on drought and insect resistance development. This study addresses the threat of climate change to maize production. Developing climate readiness, which refers to the ability of a crop to withstand and adapt to the changing climate conditions, by understanding the behavior of maize to waterlogging, is essential to improving maize productivity despite the challenge of climate change.

Elucidating the growth response to waterlogging is essential for consistent maize production. Hence, this research aimed to study the effects of seven days of waterlogging at different maize growth stages, determine the most sensitive growth stage that affects maize growth and yield, determine the inter-phenotypic relationship of maize traits and identify maize traits conferring tolerance to waterlogging.

MATERIALS AND METHODS

The researchers conducted the study at the Research Area of the College of Agriculture and Related Sciences, University of Southeastern Philippines, Tagum-Mabini Campus, Mabini Unit, Pindsan, Mabini Davao de Oro, Philippines, from October 2023 to May 2024. The study was laid out using a randomized complete block design (RCBD) with three replications. The study was focused on maize growth stages exposed to seven days of waterlogging as the treatment. The researchers selected open-pollinated white maize for its adaptability to local climate and soil conditions.

The researchers used black plastic pots measuring 50 × 50 cm as growing containers. The pots were filled with garden soil sourced from the research area. The soil was sieved through a fine mesh (2 × 2 cm) to remove stones, pebbles and other materials that could hinder maize growth. The soil was sun-dried for three days to eliminate harmful microorganisms. Each plastic pot received approximately 18 kg of the prepared soil as growing media. The researchers obtained a composite soil sample that to the Regional Soils Laboratory in Davao City, Phillipines for physico-chemical analysis. The result of soil analysis is crucial understanding nutrient composition and pH levels, guiding fertilization management and ensuring optimal conditions for the maize plants.

Total quantity of phosphorus, potassium and half of the total nitrogen (120-60-60) was applied at the basal stage, with the remaining nitrogen applied in two equal splits at knee height and flowering stages based on the result of soil analysis. Each plastic pot was sown with two maize seeds. After seven days of seedling emergence, the researchers retained only one healthy and vigorous seedling in each pot, resulting in 20 sample maize plants per treatment per replication. The different maize growth stages were exposed to seven days of waterlogging, maintaining a water level of three centimeters above the soil surface throughout the waterlogging period. When evaporation caused the water level to drop below the three-centimeter mark, they added water to maintain the desired level. After the waterlogging period, the researchers drained the water from all treated pots.

The researchers randomly selected ten maize plants from each treatment per replication as data plants for the recording of observations from the twenty sample plants. The maize plans were scored for visual damage using a scoring system developed by Esteban and Baldo (2024) specifically for this waterlogging study. This system, designed for scientific precision, provided a quantitative measure of visual damage. The researchers recorded the leaf visual scores after the waterlogging treatment, applying a scale from 1 to 9, where lower scores indicated higher tolerance to waterlogging stress based on visual phenotyping. In addition to leaf scores, agronomic parameters, including percentage survival, number and length of nodal roots, plant height, ear length, ear diameter, ear weight, thousand seed weight, number of kernels per ear, number of kernel rows, percentage yield reduction and total chlorophyll content were also collected during the conduct of the study. The researcher followed standard data collection procedures throughout the process to minimize experimental bias.

The researchers analyzed all gathered data using Analysis of Variance (ANOVA). Significant differences among treatment means were computed using Tukey's Honest Significance Difference at a 5% probability level. The association of maize traits was computed using Pearson Product Moment Correlation. The strength of correlated traits maize is determined using the Rumsey Scale. All the analysis were run using the Statistical Tool for Agricultural Research (STAR), developed by IRRI.

RESULTS AND DISCUSSION

Maize growth stage response to waterlogging

The results of this study revealed significant impacts of waterlogging stress on maize growth across all developmental stages. Seven days of waterlogging led to notable reductions in survival percentage, root length and plant height while inducing leaf chlorosis and increasing the number of nodal roots (Table 1). Among the growth stages, the tasseling stage was particularly vulnerable to waterlogging stress, exhibiting the most severe decline in growth performance. When waterlogging stress was imposed at the tasseling stage, the survival rate reached

60.22%. Visual leaf ratings consistently indicate that plants at tasseling exhibit severe chlorosis and reduced plant height, suggesting lower tolerance to waterlogging stress. In addition, by the seventh day of waterlogging, the nodal root length at the tasseling stage measured 37.31 cm, a significant difference from the nodal root lengths observed at other maize growth stages. This significant difference underscores the impact of waterlogging stress on maize growth. In contrast, no significant difference in nodal root numbers were observed at the reproductive stage under non-waterlogged conditions, with values ranging from 33.04 to 37.71. However, nodal root numbers at vegetative growth stages were significantly lower compared to the reproductive stage. This result indicates that the developmental stages of maize are also a factor in the number of nodal roots developed since it is expected that the older growth stages have a higher number of nodal roots. However, it is clearly shown in this result that the development of nodal roots is an adaptive maize response to waterlogging stress.

Waterlogging stress triggered the development of nodal roots, an adaptive response in maize, showcasing the resilience of the plant. Our findings corroborate Kaur *et al.* (2020), who reported that maize nodal roots develop as an adaptive response to waterlogging stress. Also, this response, as found by Kaur *et al*. (2020), led to increased nodal root formation, especially at the older growth stages. These nodal roots, a mechanism for improved waterlogging tolerance, allow the plant to continue aerobic respiration by accessing atmospheric gases, thereby mitigating the effects of anaerobic stress. This adaptation, also noted by Esteban and Baldo (2024), aligns with earlier research by Armstrong and Drew (2002), as cited by Zaidi *et al*. (2007), which identified surface rooting as a common strategy in wetland species to withstand flooding. The formation of aerenchyma cells in the root system also helps crops to survive during the waterlogging period (Duman *et al*., 2017). In addition to the morphological adaptations, waterlogging stress was observed to induce leaf chlorosis and reduce total leaf chlorophyll content. This was particularly evident at the tasseling stage, where chlorophyll loss was most pronounced, resulting in stunted growth and lower yield. A similar result was also observed in the findings of Saikia *et al*. (2021) that greengram chlorophyll declines when exposed to waterlogging. Meanwhile, the induced leaf chlorosis can be attributed to stomatal closure, as Malik *et al*. (2001) reported, which limits oxygen and carbon dioxide exchange, thereby decreasing photosynthesis. This finding supports the work of Lizaso and Ritchie (1997), highlighted the role of abscisic acid (ABA) in regulating stomatal behavior under waterlogged conditions, leading to reduced chlorophyll and premature leaf senescence. Similarly, reduced chlorophyll content due to oxidative stress from waterlogging was observed in studies by Wang *et al*. (2012), further explaining the diminished photosynthetic efficiency and growth decline.

Moreover, the tasseling stage experienced marked reductions in yield components such as ear length, diameter, weight, thousand seed weight and kernels per ear (Table 2). These observations suggest that tasseling is the most sensitive stage under waterlogging stress, as corroborated by Ren *et al*. (2014), who reported delayed silking and growth retardation under similar conditions. Interestingly, maize plants subjected to waterlogging stress at reproductive stages, particularly during tasseling and silking, experienced the most significant yield reductions, up to 58.30%. This was evidenced by the elongation of the anthesis-silking interval (ASI), which impaired successful pollination and reduced kernel formation. The extended ASI under waterlogged conditions is consistent with previous studies, including those by Paril *et al*. (2017), who identified this as a critical factor in yield decline. The reproductive stages' heightened sensitivity to waterlogging is likely due to the direct impact on reproductive processes, leading to increased barrenness in maize ears, as Ren *et al*. (2014) and Esteban (2024) noted.

The study also highlighted that while maize plants at vegetative stages showed some ability to recover from waterlogging stress, yield reduction was still significant. It shows that waterlogging stress reduced yield from 20.14% to 58.30% depending on the growth stages. Older growth stages exhibited a smaller percentage of yield loss compared to younger ones, aligning with findings by Shin *et al*. (2016) and Esteban (2024), who reported that

Table 1: Growth performance of maize at different growth stages experienced seven days of waterlogging.

Growth stages	PS (%)	VSRL 1	VSRL 2	VSRL 3	NRL	NRN	PH (cm)
No waterlogging	100.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	69.01^{a}	33.04^{ab}	166.47^{a}
VGS (16-23 DAP)	91.22^{b}	5.94^{b}	2.89^{b}	0.88^{ab}	58.51^{b}	23.04^{d}	157.53^{ab}
VGS (28-35 DAP)	89.67^{b}	7.02^{c}	3.40^{b}	1.01^{b}	46.57^{c}	31.22^{c}	147.91^{c}
Tasseling stage	60.22^{d}	9.05^{d}	7.22^{c}	4.42^{c}	37.31^{d}	36.33^{ab}	157.13^{b}
Silking sage	73.89^{c}	9.36^{d}	7.82^{c}	5.20^{c}	42.64^{cd}	37.71^{a}	160.19^{ab}
F-test	**	**	**	**	**	**	**
CV (%)	8.90	8.00	15.97	28.24	14.30	12.45	5.51

PS: Percentage survival; VSR: Visual score rating leaf; NRL: Nodal root length; NRN: Nodal root number; PH: Plant height; DAP: Days after planting; CV: Coefficient of variation. **: indicates statistical differences at P≤0.01. Means that the same letter in a column is not significantly different.

waterlogging at the early V2 stage resulted in an 80% yield loss, while later stages showed a lesser, but still considerable, yield reduction. This significant yield loss due to waterlogging stress will also imply a monetary loss or income of the farmers.

Furthermore, the analysis revealed that waterlogged maize plants exhibited a reduction in plant height, ear height and leaf area index, which collectively contributed to lower yields. These physiological changes are in line with the work of Ren *et al*. (2014), who observed a decrease in dry matter accumulation and distribution under waterlogged conditions. The implications of these findings are significant for maize cultivation in areas prone to waterlogging, as they underscore the importance of selecting waterlogging-tolerant hybrids and adjusting planting schedules to mitigate yield losses, providing actionable solutions for the audience. Farmers can minimize yield losses by improving drainage, adjusting planting schedule to avaoid tasseling during heavy rainfall and selecting maize hybrids with longer nodal roots.

The study confirms that waterlogging at any growth stage significantly impairs maize growth and yield performance, with reproductive stages being the most susceptible. The urgency of the situation is underscored by the critical need for adaptive agricultural practices, including using waterlogging-tolerant maize varieties and optimized agronomic management, to cope with the increasing threat of waterlogging due to climate change. This stress on the importance of the study's findings invokes a sense of urgency in the audience, reinforcing the need for immediate action.

Inter-phenotypic correlation of maize traits as influenced by waterlogging

The summary Table of significantly correlated maize traits as influenced by seven days of waterlogging is presented in Table 3. The results demonstrate that specific phenotypic traits in maize, particularly leaf greenness and nodal root length, correlate strongly and positively with survival rates under waterlogging stress. This suggests that greener leaves (leaves 2 and 3) and longer nodal roots are indicators of enhanced waterlogging tolerance. As shown in Table 3, leaf visual scores 2 and 3 exhibit significant positive correlations with percentage survival, indicating that greener leaves contributes to higher survival rates. In addition, the negative correlation between leaf visual score 1 (lower greenness) and nodal root length underscores that reduced greenness in younger leaves is associated with shorter root lengths, which may hinder survival in waterlogged conditions. Therefore, maintaining greener leaves and longer nodal roots is a viable criterion for identifying waterlogging-tolerant lines.

Nodal root length is another critical trait positively correlated with percentage survival under waterlogged conditions. This correlation suggests that maize plants with longer nodal roots are better equipped to withstand waterlogging, possibly due to an enhanced capacity for oxygen absorption or improved resilience to water saturation. These findings align with previous studies of Esteban and Baldo (2024) and Esteban and Solilap (2016), which identified leaf greenness as a reliable selection criterion for waterlogging tolerance. These results indicate that leaf greenness and nodal root length are integral phenotypic indicators of maize tolerance to waterlogging stress, supporting their use in breeding programs targeting climate resilience.

Furthermore, maize yield components, including ear diameter, length and weight, number of kernels per row and kernel rows per ear, show significant correlations, highlighting that maize yield under stress is governed by multiple traits rather than a single phenotype. This finding emphasizes the complexity of improving yield under adverse conditions like waterlogging. Notably, a strong negative correlation between 1000-seed weight and percentage yield reduction indicates that heavier seeds are associated with lower yield losses, suggesting that seed weight is vital in maintaining yield under stress. The correlations among yield components imply that breeding for waterlogging tolerance must consider multiple traits simultaneously to mitigate yield loss effectively.

The results emphasize the importance of selecting traits such as leaf greenness, nodal root length and key yield components to improve waterlogging tolerance in maize. The strong correlations observed across these traits suggest they are reliable indicators of waterlogging tolerance and crucial for sustaining yield under stress.

Table 2: Yield components and total chlorophyll of maize at different growth stages exposed to seven days of waterlogging.

Growth stages	EL (cm)	1000 SW (g)	ED (cm)	NKPE	NKRPE	EW (cm)	PYR (%)	TC
No waterlogging	12.90^{a}	300.79^{a}	4.05^{a}	286.88^{a}	13.36^{a}	116.55^{a}	0.00^{c}	1.19^{a}
VGS (16-23 DAP)	11.21^{bc}	240.20^{b}	3.66^{b}	193.36^{c}	11.57^{c}	75.72^{b}	20.14^{b}	0.87^{bc}
VGS (28-35 DAP)	11.07^{bc}	233.20^{b}	3.56^{b}	196.97^{bc}	12.31^{bc}	77.45^{b}	22.47^{b}	1.26^{a}
Tasseling stage	10.26^{c}	125.43^{c}	2.83^{c}	139.56^{d}	8.53^{d}	47.28^{c}	58.30^{a}	0.96^{b}
Silking stage	11.87^{ab}	221.99^{b}	3.69^{c}	228.55^{b}	12.67^{ab}	86.23^{b}	26.20^{b}	0.75^{c}
F-test	**	**	**	**	**	**	**	**
CV (%)	9.34	10.37	6.54	15.51	7.39	26.11	12.34	16.63

EL: Ear length; SW: Seed weight; ED: Ear diameter: NKPE: Number of kernels per Ear; NKRPE: Number of kernel rows per Ear: Ear weight; PYR: Percentage yield loss; TC: Total chlorophyll; DAP: Days after planting. **: indicates statistical differences at P≤0.01. Means that the same letter in a column is not significantly different.

Table 3: Summary table of significantly correlated maize traits as influenced by seven days waterlogging.

Correlated traits		Correlation coefficient (R)	Strength of relationship	Pr>F
Leaf visual score 1	Nodal root length	-0.9411	Strong relationship	0.0170
Leaf visual score 2	Nodal root length	-0.9214	Strong relationship	0.0261
	Percentage survival	-0.9200	Strong relationship	0.0268
	Leaf visual score 1	0.9306	Strong relationship	0.0217
Leaf visual score 3	Leaf visual score 2	0.9694	Strong relationship	0.0064
	Percentage survival	-0.9053	Strong relationship	0.0345
Nodal root length	Percentage survival	0.8945	Strong relationship	0.0405
Ear diameter	Ear weight	0.9494	Strong relationship	0.0136
	Number of kernels per row	0.9302	Strong relationship	0.0219
	Number of kernel rows per ear	0.9638	Strong relationship	0.0082
	1000 seed weight	0.9818	Strong relationship	0.0029
	Percentage yield reduction	-0.9818	Strong relationship	0.0029
Ear length	Ear weight	0.9842	Strong relationship	0.0024
	Number of kernels per row	0.9951	Strong relationship	0.0004
	1000 seed weight	0.8837	Strong relationship	0.0468
	Percentage yield reduction	-0.8837	Strong relationship	0.0468
Ear weight	Number of kernels per row	0.9951	Strong relationship	0.0004
	Number of kernel rows per ear	0.9074	Strong relationship	0.0333
	1000 seed weight	0.9440	Strong relationship	0.0158
	Percentage yield reduction	-0.9440	Strong relationship	0.0158
Number of kernels per row	Number of kernel rows per ear	0.8944	Strong relationship	0.0405
	1000 seed weight	0.9105	Strong relationship	0.0317
	Percentage yield reduction	-0.9105	Strong relationship	0.0317
Number of kernel rows per ear	1000 seed weight	-0.9295	Strong relationship	0.0222
	Percentage yield reduction	0.9295	Strong relationship	0.0222
1000 seed weight	Percentage yield reduction	-1.000	Perfect relationship	0.0000
Percentage survival	1000 seed weight	0.9406	Strong relationship	0.0172
	Percentage yield reduction	-0.9406	Strong relationship	0.0172

p<0.01 or ** - highly significant; p<0.05 or * - significant.

By integrating these traits into breeding strategies, there is potential to develop maize varieties with enhanced resilience, contributing to more sustainable and climate-adaptive agricultural systems.

CONCLUSION

These research findings highlight the practical implications of waterlogging on maize growth and yield performance. Researchers found that seven days of waterlogging at any maize growth stage can significantly reduce growth and yield. The tasseling stage is the most sensitive to waterlogging, showing up to 58.30% yield reduction. In addition, the nodal root length and leaf greenness can serve as selection criteria for breeding waterlogging-tolerant maize varieties. These findings indicate that reproductive stages are more sensitive to waterlogging stress than vegetative stages, providing further guidance for agricultural practices. Future studies should explore genetic markers associated with waterlogging tolerance and validate findings under field conditions.

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Conflict of interest

The authors declare that there is no conflict of interest.

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