ASSESSING THE TOLERANCE OF MAIZE GENOTYPE FROM NORTH WEST NIGERIA TO WATERLOGGING STRESS AT FIVE LEAF STAGE

BY

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FACULTY OF AGRICULTURE
UNIVERSITY OF BENIN
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A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF CROP SCIENCE, FACULTY OF AGRICULTURE, UNIVERSITY OF BENIN, BENIN CITY IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF AGRICULTURE DEGREE B. AGRIC (CROP SCIENCE)

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CERTIFICATION

This is to certify that this research was carried out by **Oluwatoyin Joy ADABA (Miss)** of the Department of Crop Science, Faculty of Agriculture, University of Benin, Edo State. Nigeria.

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DEDICATION

This project is dedicated to God Almighty, whose wisdom and grace have brightened my journey throughout my time at the university of Benin.

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ABSTRACT

This study was conducted to assess the tolerance of maize genotypes from northwest, Nigeria in order to screen for the genotypes that could withstand waterlogging stress. The experiment was carried out in a screen house of the Department of Crop Science, Faculty of Agriculture, University of Benin, Nigeria. There were 6 genotypes from (Kaduna, Kano, Katsina, Kebbi, Jigawa, Sokoto) states tested for waterlogging stress at 4 weeks after planting. There were three replications

The experiment was laid out in a completely randomized design (CRD). Data were collected from 2 weeks after planting till 10 weeks. Key parameters measured included plant height, left length, leaf breath, number of leaves, chlorotic leaves and number of dead leaves.

At the end of the experiment, few replications of Sokoto accession survived the waterlogging stress but due to the high temperature of the screen at the time, the replications could not set seed. Overall, this study provided valuable insights into maize responses to waterlogging stress, which would aid breeding programme where genotypes that can be used for developing resilient maize varieties with improved tolerance to waterlogging were identified.

CHAPTER ONE

INTRODUCTION

In the past few decades, climate change has increased the probability of extreme weather events such as drought and floods (Bailey *et al*., 2012). Global climate change is leading to unexpected and extreme weather events like flooding which is becoming more frequent world-wide and is among the most serious abiotic stresses for plants (Kun Liang et al., 2020) Based on statistical data, excessive rainfall can easily lead to waterlogging, which affects 12% of the world's crop hectare and can result in up to 20% crop losses (Ren *et al.,* 2016, Shabala, 2011).

Maize occupies a prestigious place in the world of agriculture. It is a miracle crop in view of widespread usage as food and non-food items (Ajax A lone *et al* 2016) Maize is increasingly used as a staple food (Grote *et al.,* 2021), feed for poultry, fish (Erenstein, 2010), and dairy cows (Khan *et al*., 2015), and raw materials for the food industries including oil, flour, and snacks (Zhang *et al*., 2021). After wheat and rice, maize is the third most cultivated crops globally (David and Adams, 1985). There are different varieties of maize based on their kernel type which include popcorn, dent maize; based on hybrid and improved varieties in Nigeria they include the Sammaz series by (IAR, Zaria) and Tzee by (IITA) and based on kernel colour which includes white and yellow maize. Maize is widely cultivated in Nigeria with the highest production in northern region of the country. In Nigeria, the white and yellow maize are predominantly cultivated. Maize grain produced in Nigeria are sold as a commercial crop for industrial, agro-based, medical, pharmaceutical and other related uses (David and Adams, 2015). Waterlogging limits the availability of oxygen from the soil to the plants resulting in a condition of soil hypoxia (Barrett-Lennard, 2003; Liu et al., 2020).

This anaerobic condition leads to the unbalanced transport of both nutrients and water to the leaf tissue (Sachs *et al*., 1996), reduced leaf water potential, stomatal closure, leaf curling (Sairam *et al*., 2008), and yield reduction (Ren *et al*., 2014b). Maize yield reduces due to waterlogging, this can vary from 7 to 80% depending on cultivar, crop growth stage (Ren *et al*., 2016a, 2017), and the duration of imposed stress (Tian *et al*., 2019). Waterlogging initially disrupts the root activity in the crop, subsequently affecting the growth of above ground plants (Gao *et al*., 2022). These adverse effects are evident not only during prolonged waterlogging lasting weeks but also in short-term waterlogging events lasting just hours or days (Malik *et al*., 2001; Arduini *et al.,* 2016).

During waterlogging, maize roots are fully submerged, and the resulting lack of intracellular oxygen for energy production (Mano and Omori 2007). The slow dispersion of oxygen and various gases in the soil limits accessibility of oxygen to plant roots and soil microorganism (Balakhnina *et al*. 2015). But when exposed to prolonged periods of excess moisture (more than three days), maize roots may suffer from hypoxia (low oxygen) followed by anoxia (no oxygen), which results in a decline in oxygen availability to the roots (Zaidi *et al.,* 2002). In barley, waterlogging decreases the number of spikelets and kernels per spike, leading to lower yields (Zhang *et al*., 2009). Similarly, maize yields are significantly reduced under waterlogging by decreasing ear length and width and an increase in bald tip length (Tian *et al.,* 2019).

Global warming has increased the frequency of extreme weather events worldwide, worsening the effects of waterlogging on maize (Pan *et al*., 2021). Because of this global climate changes, extreme in water availability such as flooding are predicted to become a major abiotic stresses threatening crop production (Bailey-Serres *et al*.2012). Therefore, further breeding for flooding tolerance in maize will be increasingly important to prepare the plant to adapt to waterlogging. It is essential to identify genetic factors related to the response and tolerance to waterlogging (Kun Liang *et al*.). Limited information is available on the combined effects of waterlogging at multiple growth stages and varying durations on maize growth and yield. Identifying waterlogging-responsive genotypes is crucial for creating new maize varieties that can better withstand waterlogging stress.

1.1 Objectives of the Study

The objectives of the study were to;

1. Evaluate the growth performance of maize genotypes from North West Nigeria under waterlogging conditions

2. Identify promising resilient genotypes that could survive prolonged excess soil water condition

CHAPTER TWO

LITERATURE REVIEW

2.1 Maize

Maize is an important cereal crop after wheat and rice in the world and It is the first in sub Saharan Africa where over 80% of the population depend on it as a source of food, income, livelihood (Pandey *et al*., 2016; ASARECA 2014; Ranum *et al*., 2014; Sharma *et al*.,(2018)). Maize is increasingly used as a staple food *(*feed for poultry, fish (Erenstein*,* 2010), and dairy cows (Khan *et al.,* 2015), and raw materials for the food industries including oil, flour, and snacks *(*Zhang *et al.,* 2021). It has been adapted to various cultivation areas, resulting in different subspecies that are classified based on their starch content (Piperno *et al*., 2019). Maize grain produced in Nigeria are sold as a commercial crop for industrial, agro-based, medical, pharmaceutical and other related uses (David and Adams, 2015).

In Nigeria, maize is produced across all agro-ecological zones, with the northern part of the country being the largest producer. It utilizes the C_4 photosynthetic pathway, making it more efficient in photosynthesis and capable of higher yield production. Maize is adaptable to various agro-climatic zones. It is a staple food for many people and serves as a nutritional supplement for livestock feed. Furthermore, maize plays a significant role in providing raw materials for a variety of agro-industrial products. In developing countries, maize accounts for about 9% of all cereal production, making it the third most consumed food grain after wheat (38%) and rice (42%) (Ren *et al.,* 2014).

Waterlogging is a major abiotic stress that impacts crop productivity, affecting approximately 10% of the world's land area (Shabala, 2011). Waterlogging can occur due to heavy and frequent rainfall, poor soil drainage, soil texture, and high water tables. It significantly reduces maize yields by hindering crop growth and development under waterlogged conditions (Ren et al., 2014).

Waterlogging limits the availability of oxygen from the soil to the plants resulting in a condition of soil hypoxia (Barrett-Lennard, 2003; Liu *et al.,* 2020). This anaerobic condition leads to the unbalanced transport of both nutrients and water to the leaf tissue (Sachs *et al.,* 1996), reduced leaf water potential, stomatal closure, leaf curling (Sairam *et al., 2008*), and yield reduction (Ren *et al.,* 2014). While maize is nutrient-intensive and responds well to frequent irrigation, it is highly vulnerable to waterlogging. Unlike rice, maize plants lack air spaces in their roots, making them more susceptible to the effects of waterlogging. When exposed to prolonged periods of excess moisture (more than three days), maize roots may suffer from hypoxia (low oxygen) followed by anoxia (no oxygen), which results in a decline in oxygen availability to the roots (Zaidi et al., 2002). Maize yield reduces due to waterlogging, this can vary from 7 to 80% depending upon cultivar, crop growth stage (Ren *et al.,* 2016*,* 2017), and the duration of imposed stress *(*Tian *et al.,* 2019*)*.

2.2 Varieties of maize

Maize is a globally significant cereal crop, serving as a staple food, animal feed, and industrial raw material. Its cultivation spans diverse agro-ecological zones, leading to the development of various varieties tailored to specific environmental conditions and uses. There are different varieties of maize based on their kernel type it includes popcorn, dent maize; based on hybrid and improved varieties in Nigeria they include the Sammaz series by (IAR, Zaria) and Tzee by (IITA) and based on kernel colour which include white and yellow maize.

In Nigeria, maize is cultivated across multiple ecological zones, including the rainforest and derived savannah. Efforts to enhance maize production have led to the development of landraces, improved high-yielding varieties, and pest- and disease-resistant strains. Iken and Amusa (2004) highlighted these advancements in their review of maize research and production in Nigeria.

Globally, maize breeding has focused on developing high-yielding varieties with enhanced resistance to biotic and abiotic stresses. The Green Revolution introduced semi-dwarf, high-yielding varieties that significantly boosted maize production worldwide.

These varieties were developed through conventional breeding techniques, emphasizing traits such as disease resistance and adaptability to various climatic conditions.

In recent years, the focus has shifted towards developing maize varieties that can withstand climate-induced stresses. Studies have examined the simultaneous adoption of drought-tolerant maize varieties and other climate-smart agricultural practices, highlighting their importance in ensuring food security under changing climatic conditions (Oyetunde-usman *et al*., (2023)

2.3 The Effect of Climate Change on Agrosystem

Climate change poses significant challenges to maize production in Nigeria. According to Coster and Adeoti (2015) who utilized the Ricardian approach to assess the economic effects of climate change on maize production, finding that maize net revenue is sensitive to climatic variables such as temperature and rainfall. Their study predicts that future climate scenarios may negatively impact maize revenue, emphasizing the need for effective adaptation measures.

Ajiere and Weli (2018) investigated the impact of climate change on maize and cassava yields in Rivers State, Nigeria. They observed a steady increase in annual temperatures and a decrease in rainfall over a 30-year period, concluding that these climatic changes significantly affect crop yields. The study advocates for improved agricultural techniques and alternative water sources to mitigate these effects.

A systematic review by Anabaraonye et al. (2021) analyzed climate change impact research in Nigeria, highlighting that agriculture is the most studied sector concerning climate impacts. The review identifies research gaps, including a lack of studies on the aquatic environment and limited attention to the northern regions of Nigeria, suggesting areas for future investigation.

Collectively, these studies underscore the vulnerability of maize production in Nigeria to climate change and the importance of developing and implementing effective adaptation strategies to ensure food security.

2.4 The Effects of Climatic Change on Maize Production

In Nigeria, over 80% of crop production relies on rainfall, making it highly susceptible to climatic variations. The country has experienced a notable increase in extreme weather events, such as intense rainfall leading to severe flooding. These floods have devastated large areas of agricultural land, including maize fields, leading to significant yield reductions. For instance, the 2022 floods affected 33 of Nigeria's 36 states, displacing over 1.4 million people and destroying more than 332,000 hectares of farmland.(Reliefweb (2022, November 1).

The North West region of Nigeria is particularly vulnerable due to its geographical and climatic conditions. The area has witnessed recurrent flooding events, which have led to the destruction of maize crops and other staples. In 2024, for example, the release of water from Cameroon's Lagdo Dam, combined with heavy rainfall, resulted in extensive flooding in several Nigerian states along the Benue River, including those in the North West. This event led to substantial agricultural losses and exacerbated food insecurity in the region.(United Nations office for the coordination of humanitarian affairs(2022, December 14).

The impact of these climatic events on maize production is multifaceted. Flooding leads to waterlogged soils, which can cause root rot and hinder maize growth. Moreover, the loss of arable land due to erosion and sediment deposition reduces the available area for cultivation. Economic factors also play a role in exacerbating the challenges faced by maize farmers. The aftermath of flooding often leads to increased food prices due to reduced supply. In October 2024, Nigeria's inflation rate rose for the second consecutive month, reaching 33.88% annually, primarily driven by higher food prices. Staple foods, including maize, saw significant price hikes, making it difficult for consumers and affecting the livelihoods of farmers. National bureau of statistics (2024).

Studies indicate that rising temperatures and altered precipitation patterns significantly affect maize yields worldwide. Maize thrives in climates ranging from temperate to tropical, where average daily temperatures exceed 15°C and frost is absent. Its adaptability to various climates can vary widely, making the selection of the appropriate variety crucial for successful cultivation. This ensures the growing period aligns with the length of the season and the crop's intended use. To determine the most suitable varieties for specific areas, variety trials are often conducted. A NASA study projects that under a high greenhouse gas emissions scenario, maize yields could decline by approximately 24% as early as 2030. This decline is attributed to increased temperatures, shifts in rainfall patterns, and elevated surface carbon dioxide concentrations, which collectively create unfavorable conditions for maize cultivation (NASA, 2021). Further research highlights that for every degree Celsius increase in global mean temperature, maize yields are projected to decrease by an average of 7.4%, underscoring the vulnerability of maize to even modest climatic changes (Lobell et al., 2011).

Nigeria's agriculture is predominantly rain-fed, making it highly vulnerable to climate variability. The country has experienced fluctuations in rainfall and temperature patterns, adversely affecting maize yields. A study focusing on Rivers State observed that decreased rainfall and increased temperatures have led to significant reductions in maize output. The regression analysis from this study revealed that temperature increases have a more pronounced negative effect on maize yields than rainfall variations (Eze and Maduka, 2017). Additionally, climate change has been linked to increased incidences of droughts and floods in Nigeria, further disrupting maize production. The 2022 floods, described as the most severe since 2012, devastated over 500,000 hectares of farmland, significantly impacting maize and other staple crops (NEMA, 2022).

2.5 The Influence of Temperature Variations on Maize yield

Temperature variations significantly impact maize yields both globally and in Nigeria. Globally, climate variability accounts for approximately 32–39% of observed yield fluctuations, with temperature changes being a primary factor (Ray *et al*., 2015). This indicates that for each degree Celsius increase in global mean temperature, maize yields may decline by about 7.4% (Zhao *et al*., 2017) Projections suggest that by 2030, under high greenhouse gas emission scenarios, maize yields could decrease by up to 24% due to rising temperatures and altered rainfall patterns (Jägermeyr *et al*., 2021).

In Nigeria, climate variability, particularly temperature fluctuations, significantly affects maize production. For instance, in Southern Nigeria, increased climate variability has led to less reliable maize yields (Ajetomobi and Abiodun, 2010). In Rivers State, between 1987 and 2016, a steady increase in annual temperatures was observed, correlating with a decrease in maize yields. Regression analyses from this period revealed that temperature and rainfall variations could explain 28% of the chang loles in maize yields, with temperature having a more pronounced effect (Ajiere and Weli, 2018). Similarly, in Wukari Local Government Area of Taraba State, between 1999 and 2018, an increasing trend in average annual maximum temperature was noted, which significantly influenced maize yields (Fyinbu *et al*., 2024).

Adaptation strategies, such as the adoption of drought-tolerant maize varieties, have been explored to mitigate these impacts. Model simulations indicate that while drought-tolerant varieties may reduce yield losses under future climate scenarios, significant reductions (ranging from 13% to 43% by the end of the century) are still anticipated. This underscores the need for breeding programs to develop maize varieties resilient to both drought and heat stresses (Shehu *et al*., 2021).

2.6 Irrigation Needs for Maize Production

Maize (Zea mays) is a staple crop cultivated globally, with water requirements varying based on climate, soil type, and growth stages. According to the Food and Agriculture Organization (FAO), a medium-maturity maize crop necessitates between 500 and 800 mm of water throughout its growth cycle, depending on climatic conditions. The crop is particularly sensitive to water stress during the flowering and grain-filling stages, where adequate moisture is crucial for optimal yield. In Nigeria, maize production spans diverse agro-ecological zones, leading to varying water needs. A study by Nwa (1979) in western Nigeria indicated that approximately 330 mm of water, sourced from either well-distributed rainfall or irrigation, is sufficient to produce a good maize crop when utilizing a 7-day irrigation frequency. Similarly, research by Ankidawa and Vanke (2018) in the Lake Geriyo Irrigation Scheme, Yola, Adamawa State, determined that the net seasonal water requirement for maize ranged between 539 to 692 mm, with an optimal net water requirement of 582 mm and peak evapotranspiration of 14.0 mm/day. These findings underscore the importance of region-specific water management strategies to ensure sustainable maize production. Globally, maize accounts for a significant portion of agricultural water consumption. A study by Brauman *et al.* (2020) reported that maize contributes to 12% and 26% of global green and blue water consumption, respectively. Efficient water management practices, such as the adoption of drought-tolerant maize varieties and optimized irrigation scheduling, are essential to enhance water use efficiency and ensure food security in the face of climate variability**.**

2.7 Impacts of waterlogging on growth and development of maize

Waterlogging significantly impairs maize growth and development worldwide, including in Nigeria. In a study by Ren *et al.* (2014), it was observed that waterlogging can delay maize growth and development, leading to delayed pollen shedding and reduced yields.

Similarly, research by Wang *et al.* (2023) in Northeast China highlighted that waterlogging during critical growth stages adversely affects maize, with the flowering to silking stages being particularly sensitive.

In Nigeria, Vwioko *et al*. (2017) investigated the effects of prolonged waterlogging on maize and found that waterlogged conditions induced early production of adventitious roots in maize, which may have assisted in trapping oxygen required for survival. Waterlogging also negatively affects maize biomass yield and harvest index, with the impact varying by genotype and growth stage. In some maize varieties, waterlogging can lead to a 55.29% reduction in biomass yield (Balakhnina *et al*., 2010). During the early growth stage, waterlogging for 4 days can severely limit seedling growth (Azahar *et al*., 2020), decrease plant height, ear and internode length, and stem diameter, and lower the leaf area index (LAI) and chlorophyll content index (CCI) of maize leaves (Ren et al., 2020, Ren *et al*., 2016). Additionally, waterlogging tends to rapidly reduce photosynthesis rates in many plant species (Kozlowski, 1997).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of the experimental study

The experiment was conducted at the Department of Crop Science, Faculty of Agriculture, University of Benin Screen House 2 Located in Benin City, Edo State, Nigeria. The experimental site falls within the humid tropical climate.

3.2 Accession used

The genotypes selected for the study were accessions sourced from the states of Jigawa, Kaduna, Kano, Katsina, Kebbi and Sokoto

3.3 Source of experimental material

Topsoil for the experiment was collected from a farmland in Ovia North East. The buckets (15 litres capacity) used for the study were purchased from the market.

3.4 Experimental design of treatments

A Completely Randomized Design (CRD) employed for the experiment, with three replications and one control. The distance between each plot (bucket) was 30cm with 30cm between blocks (treatment) and 50cm between replications. A total of 24 buckets were used in the study, with each replication consisting of 6 buckets.

3.5 Cultural practices

The screen house was cleared with cutlass, hoe and spade. A total of 6 seeds were planted per bucket and later thinned to 2 per bucket after emergence. Weeding was done when appropriate. NPK 15:15:15 fertilizer and Urea fertilizer was used. The neem leaves (*Azadirachta indica*) and garlic soaked in water and applied to prevent Army worm infestation. Waterlogging treatment was carried out at Five leaf stage (5LS) corresponding to treatment at 4 weeks after planting

3.6 Data collection

The following plant characters were measured and recorded during the experiment:

3.6.1 Plant height

The plant height was measured from the soil surface to the point where the last leaf terminates, using a measuring tape. This measurement was taken from the plants in the buckets

3.6.2 Leaf length

The length of the leaf was measured from where the leaf blade attaches to the leaf sheath to the tip of the leaf blade. Leaf lengths were measured for plants in the buckets

3.6.3 Leaf breadth

The leaf breadth was measured across the widest part of the leaf. This measurement was taken from plants in the buckets

3.6.4 Chlorotic leaves

Leaves showing signs of chlorosis were identified and counted through visual observation.

3.6.5 Dead plants

The number of dead plants was recorded and counted.

3.6.6 Dead leaves

The number of dead leaves were recorded and counted

3.6.7 Adventitious roots

Adventitious roots were observed visually, and the results were noted.

CHAPTER FOUR

RESULT

4.1 Mean square value due to the effect of genotype and waterlogging on growth of maize seedling at five leaf stage

The mean square values due to the effect of waterlogging stress at the five-leaf stage on maize genotypes from North-West Nigeria are presented in Table 1. There were significant ($p < 0.05$) differences among the genotypes for leaf area, leaf breadth, and leaf length, indicating genotypic variation in response to waterlogging stress. Waterlogging, which was imposed at four weeks after planting (WAP 5), showed highly significant ($p < 0.01$) effects on all growth parameters observed—leaf number, leaf area, leaf breadth, leaf length, and plant height—demonstrating its substantial impact on maize seedling development. However, the interaction between genotype and waterlogging was not significant ($p > 0.05$) for all the growth traits studied.

4.2 Mean values of growth parameters of maize as influenced by genotype and waterlogging treatment at five leaf stage

The mean value of growth characteristics of maize seedlings as influenced by accession and waterlogging treatment are presented in Table 2. Leaf number did not significantly differ among genotypes, with the highest value recorded in Sokoto (6.250) and Kano (6.175), while the lowest was in Kebbi (4.787). Leaf area was largest in Kano (147.9 cm^2) and Kaduna (147.0 cm^2), which did not significantly differ from Jigawa (119.0 cm^2), Katsina (125.9 cm^2), and Sokoto (123.4 cm^2) but were significantly higher than Kebbi (83.3 cm^2), which had the lowest leaf area.

Table 1: Means square value due to the effect of genotype and waterlogging (WAP) of the growth characters of maize seedling at five leaf stage

Source of variation	**d.f**	**Leaf number**	**Leaf area**	**Leaf breath**	**Leaf length**	**Plant height**
Genotype(G)	5	18.584^{ns}	22303*	6.533*	1855.3*	3392^{ns}
Waterlogging (WAP)	9	19.763*	77100**	15.790**	5815.5**	8179**
Genotype (G) x Waterlogging (WAP)	45	1.359^{ns}	2209^{ns}	0.661^{ns}	133.1^{ns}	296^{ns}
Residual	180	8.982	9656	2.327	476.5	1645

*** - Significant**

**** - Highly significant**

NS - Non significant

Table 2: Mean values of growth characters of maize seedlings as influenced by genotype and waterlogging (WAP) at five leaf stage

Genotype (G)	Leaf number	Leaf area	Plant height	Leaf width	Leaf length
Jigawa	4.900^{a}	119.0^{ab}	65.25^{a}	2.781^{abcd}	43.80^{a}
Kaduna	4.850^{a}	147.0^{a}	74.39^{a}	3.011^{abc}	50.33^{a}
Kano	6.175^{a}	147.9^{a}	77.51^{a}	3.284^{a}	51.19^{a}
Kastina	5.688^{a}	125.9^{ab}	75.25^{a}	3.046^{abc}	45.90^{a}
Kebbi	4.787^{a}	83.3^{b}	53.88^{a}	2.128^{bd}	32.52^{b}
Sokoto	6.250^{a}	123.4^{ab}	76.29^{a}	3.016^{ab}	47.759^{a}
Sed	0.670	21.97	9.07	0.6731	4.88
Waterlogging(WAP)					
WAP 2	4.375^{b}	34.5^{g}	37.99^{c}	1.519^{e}	29.33^{ef}
WAP 3	5.396^{ab}	67.8^{efg}	55.47^{bc}	2.158^{cde}	40.70^{cde}
WAP 4	7.167^{a}	138.3^{abcde}	80.91^{ab}	3.058^{abcd}	59.18^{ab}
WAP 5	6.417^{ab}	195.1^{a}	93.67^{a}	3.773^{ab}	67.96^{a}
WAP 6	5.000^{ab}	183.0^{ab}	91.83^{a}	3.600^{ab}	62.42^{ab}
WAP 7	5.792^{ab}	182.3^{abc}	86.69^{ab}	3.979^{a}	55.21^{abc}
WAP 8	6.000^{ab}	152.4^{abcd}	75.75^{ab}	3.296^{abc}	46.71^{bcd}
WAP 9	5.188^{ab}	129.3^{abcdef}	68.58^{abc}	2.823^{abcd}	38.33^{def}
WAP 10	4.667^{ab}	103.6^{bdefg}	58.92^{abc}	2.635^{bcde}	30.61^{def}
WAP 11	4.417^{b}	58.0^{fg}	54.48^{bc}	2.010^{de}	22.04^{f}
Sed	0.865	28.37	11.71	0.8689	12.43
G x WAP interaction	S	S	S	S	S
Sed	2.119	69.48	28.68	1.0786	30.46
Cv	55.1	79.0	57.6	52.9	48.2

However, Kebbi's leaf area was not significantly different from Jigawa, Katsina, and Sokoto. Plant height was highest in Kano (77.51 cm) and lowest in Kebbi (53.88 cm), though differences among other genotypes were not significant. Leaf width was highest in Kano (3.284 cm) and lowest in Kebbi (2.128 cm), while leaf length was significantly higher in Kano (51.19 cm) and Kaduna (50.33 cm) but lowest in Kebbi (32.52 cm).

Waterlogging duration significantly affected growth parameters. Leaf number was highest at 4 WAP (7.167) and progressively decreased as waterlogging continued, reaching the lowest at 11 WAP (4.417). Leaf area was highest at 5 WAP (195.1 cm^2) and declined significantly afterward, with the lowest value recorded at 11 WAP (58.0 cm^2). Plant height peaked at 5 WAP (93.67 cm) but progressively declined, reaching the lowest at 11 WAP (54.48 cm). Leaf width was highest at 5 WAP (3.773 cm) and lowest at 11 WAP (2.010 cm), while leaf length followed a similar trend, peaking at 5 WAP (67.96 cm) and dropping drastically to the lowest at 11 WAP (22.04 cm). The genotype × waterlogging interaction was not significant for all traits, indicating that different genotypes responded similarly to waterlogging stress. The high coefficient of values obtained suggests variability in responses. In general, maize growth was optimal between 4 to 6 WAP but declined under prolonged waterlogging, with Kano and Kaduna accessions performing better and Kebbi accession showing the least growth.

4.3 Mean square value due to the effect of genotype and waterlogging on development of maize seedling at five leaf stage

The mean square values due to the effect of genotype and waterlogging (WAP) on maize seedlings development at the five-leaf stage are presented in Table 3. There were significant ($p < 0.05$) differences among genotypes for dead leaves, while chlorotic leaves showed highly significant ($p < 0.01$) differences. However, the effect of genotype on alive leaves was not significant ($p > 0.05$). The effect of waterlogging duration (WAP) was not significant ($p > 0.05$) for all the traits studied. Similarly, the interaction between genotype and WAP was also not significant ($p > 0.05$) for all traits measured.

4.4 Mean values of growth parameters of maize as influenced by genotype and waterlogging treatment at five leaf stage

The mean value of growth characteristics of maize seedlings as influenced by accession and waterlogging treatment are presented in Table 4. The mean of dead plants was significantly higher in the Katsina genotype (3.571), followed by Sokoto (2.625) and Kaduna (2.554). The Kebbi genotype recorded the mean value for dead plants (1.500). Chlorotic leaf mean were significantly highest in the Sokoto genotype (1.0714), while other genotypes had lower and similar values. The number of alive leaves did not show significant variation among genotypes, as all values were statistically similar.

The number of dead plants increased progressively from WAP 4 to WAP 11, with the highest recorded at WAP 11 (3.292).

Table 3: Means square value due to the effect of Genotype and Waterlogging (WAP) of maize seedling at five leaf stage

Source of variation	d.f	Dead leaf	Chlorotic leaf	Alive leaf
Genotype(G)	5	13.963*	2.5429**	21.66^{ns}
Weeks after planting (WAP)	6	7.721^{ns}	1.1587^{ns}	12.97^{ns}
Genotype(G) x Weeks after planting (WAP)	30	2.116^{ns}	0.0706^{ns}	1.23^{ns}
Residual	126	4.392	0.6032	12.61

*** - Significant**

**** - Highly significant**

NS - Non significant

Table 4: Mean values of growth characteristics of maize seedlings as influenced by Genotype and Waterlogging (WAP) at five leaf stage

Genotype (G)	Dead plant	Chlorotic leaf	Alive leaf
Jigawa	1.911^{b}	0.5714^{b}	4.607^{a}
Kaduna	2.554^{ab}	0.2500^{b}	4.643^{a}
Kano	2.375^{ab}	0.5174^{b}	6.357^{a}
Kastina	3.571^{a}	0.5000^{b}	5.554^{a}
Kebbi	1.500^{b}	0.2500^{b}	4.554^{a}
Sokoto	2.625^{ab}	1.0714^{a}	6.411^{a}
Sed	0.560	0.2076	0.949
Weeks after planting(WAP)			
WAP 2	-	-	-
WAP 3	-	-	-
WAP 4	-	-	-
WAP 5	1.771^{a}	0.2083^{a}	6.417^{a}
WAP 6	1.812^{a}	0.2917^{a}	5.000^{a}
WAP 7	2.312^{a}	0.5833^{a}	5.792^{a}
WAP 8	2.208^{a}	0.5833^{a}	6.000^{a}
WAP 9	2.604^{a}	0.5417^{a}	5.188^{a}
WAP 10	2.958^{a}	0.7083^{a}	4.667^{a}
WAP 11	3.292^{a}	0.8333^{a}	4.417^{a}
Sed	0.605	0.2242	1.025
G x WAP interaction	Ns	Ns	Ns
Sed	1.482	0.5492	2.511
Cv	86.5	145.0	66.3

Chlorotic leaf numbers fluctuated but generally increased with time, reaching the highest value at WAP 11 (0.8333). The number of alive leaves varied over time, peaking at WAP 4 (6.417) and gradually decreasing by WAP 11 (4.417). This suggests that as waterlogging persisted, maize seedlings lost more leaves

The interaction effect (Genotype × WAP) was not significant for all measured characteristics, meaning that genotype responses to waterlogging did not vary significantly over time. A high coefficient of variation was observed in dead plants (86.5%), chlorotic leaves (145%), and alive leaves (66.3%), indicating a high degree of variability among replicate due to waterlogging treatment effects

Maize seedlings exhibited different responses to waterlogging depending on genotype. The Katsina genotype had the highest mortality, whereas Kebbi showed the least. Chlorotic leaf formation was highest in Sokoto. Over time, waterlogging stress increased plant mortality and leaf chlorosis while reducing the number of alive leaves. However, genotype responses to waterlogging were generally similar, as indicated by the non-significant interaction effect.

4.5 Mean square value due to the effect of genotype and waterlogging on reproductive character of maize seedling at five leaf stage

The mean square values due to the effect of genotype on maize seedlings at the five-leaf stage are presented in Table 5. There were no significant ($p > 0.05$) differences among genotypes for ear height, tasseling, shedding, and silking. This indicates that the genotypes responded similarly for these reproductive traits under waterlogging stress, as the effect of genotype was not significant for all the parameters studied.

4.6 Mean values of reproductive characters of maize as influenced by genotype and waterlogging treatment at five leaf stage

The mean value of reproductive characters of maize seedlings as influenced by accession and waterlogging treatment are presented in Table 6. There was no significant difference among genotypes, as indicated by the same letter (a) assigned to all values. However, Katsina (17.25 cm) and Sokoto (17.5 cm) recorded the highest values, while Kaduna, Kano, and Kebbi recorded the lowest (0.00 cm).

The highest mean value was observed in Kano (48.25), followed by Katsina (43.00) and Sokoto (40.25), while Kaduna recorded the lowest (0.00). Despite differences in numerical values, all genotypes share the same letter (a), indicating no statistically significant differences.

Katsina (55.75) and Sokoto (53.50) had the highest shedding values, while Kaduna and Kebbi recorded the lowest (0.00). The statistical notation suggests no significant differences among genotypes. The values for silking were generally low, with Sokoto being the only genotype with a measurable value (17.5). Other genotypes recorded zero silking.

Table 5: Means square value due to the effect of genotype of maize seedling at five leaf stage of waterlogging

Source of variation	d.f	Ear height	Tasseling	Shedding	Silking
Genotype(G)	5	333.0^{ns}	1188.2^{ns}	2552^{ns}	204.2^{ns}
Residual	18	419.2	853.5	1051	204.2

Table 6: Mean values of reproductive characters of maize seedlings as influenced by Genotype and Waterlogging (WAP) At five leaf stage

	Ear height	Tasseling	Shedding	Silking
Genotype (G)				
Jigawa	15.000^a	29.25^a	19.00^a	0.000^a
Kaduna	0.000^a	0.00^a	0.00^a	0.000^a
Kano	0.000^a	48.25^a	39.00^a	0.000^a
Kastina	17.250^a	43.00^a	55.75^a	0.000^a
Kebbi	0.000^a	31.25^a	0.00^a	0.000^a
Sokoto	17.500^a	40.25^a	53.50^a	17.500^a
Sed	14.48	20.66	22.92	10.10

CHAPTER FIVE

Discussion and conclusion

All genotype from north west Nigeria were vulnerable to waterlogging. The result from the study agrees with the findings of (Zaidi *et al*., 2015), that the delay or disruption of reproductive development under waterlogging has also been observed with traits like tasseling, silking and ear formation being adversely affected.

Waterlogging significantly affected maize growth, leading to reduction in photosynthetic activity and plant height. Studies have shown that at five leaf stage waterlogging can cause severe physiological stress, limiting plant development and reducing grain yield(Zaidi *et al*., 2015; Ren *et al*., 2014). Prolonged waterlogging leads to more pronounced stress symptoms, including increased leaf chlorosis and plant mortality. Studies indicated that extended exposure to waterlogging condition can result in reduced plant height, leaf area with severe effects in susceptible genotypes (Ren et al., 2014). Research has also identified specific maize inbred lines with waterlogging tolerance making them more resilient under flooded conditions (Zaidi *et al*., 2020). Breeding for improved waterlogging tolerance can mitigate the adverse effects of flooding on maize productivity (Zhang *et al*., 2021). Data from the present experiment confirmed that waterlogging at five-leaf stage resulted in a significant decrease in maize growth parameters in the various genotypes.

Conclusion

This study demonstrated that waterlogging has a significant impact on maize growth. The result highlighted notable responses with sokoto genotype exhibiting greater tolerance, while kano, kaduna kebbi and katsina genotypes were more adversely affected. Key traits such as leaf area, leaf breath, and leaf length, showed significant reductions under waterlogging stress, As waterlogging duration increased, visible stress symptoms, including leaf chlorosis and plant mortality became more pronounced. Although few replications of sokoto accession survived the waterlogging stress but could not set seed due to non synchrony of pollination. Overall, this study provides valuable insights into maize responses to waterlogging stress, which aids breeding programmme by identifying genotypes that can be used for developing resilient maize varieties with improved tolerance to waterlogging

Plate 1: The w
sign of stress(
growth)

Plate 2: The plant showing a survival mechanism to waterlogging which is the production of adventitious roots

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