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Temperature regimes within which different maize (Zea mays L.) cultivars seeds germinate and seedlings grow subjected to in vitro conditions in Lesotho

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Abstract

Germination rate and seedling growth are essential stages in a maize plant's life cycle, greatly influenced by temperature as well as moisture conditions. The study was conducted in Lesotho with aim of (i) determining temperature regime within which different maize cultivars seeds germinate and seedlings grow subjected to in vitro conditions. The study was conducted at the National University of Lesotho, Roma campus laboratory. The experiment was laid-out using completely randomized design with three replications, eight different temperature treatment levels, 5, 10, 15, 20, 32, 35, 38, and 40 °C and 10 different maize cultivars. After every seven days, germination data were collected on germination percentage, germination index, mean germination time, means daily germination and peak value. Concurrently seedling growth data were collected, namely; coleoptile length, plumule length, radicle length, plumule fresh weight, radicle fresh weight, plumule dry weight and radicle dry weight (growth parameters). Data collected were subjected to analysis of variance using Statistix 10 software to detect the difference among the treatments, after which least significant difference was adopted to separate the means. The results revealed that at 5, 10 and 40^{0}C no germination and seedling growth occurred in all maize cultivars. Both germination and seedlings growth took place gradually from 15^{0}C to 35^{0}C which seemed to be the peak, after which all parameters decreased and reach cessation at 40^{0}C. At 35^{0}C, the maximum germination and seedling growth was attained. It can therefore be inferred that at temperature of between 32^{0}C and 38^{0}C is ideal for good crop standability.

Keywords *- Maize, germination parameters, growth parameters, lethal temperatures, sub-lethal temperatures*

INTRODUCTION

Maize (Zea mays L.) is one of the most important cereal crops grown world-wide as a staple food adapted to a wide range of edaphic and climatic conditions in both temperate and tropical regions (Anderounmu et al, 2020). It is an ancient cultivated plant with a chromosome set of 2n=2x=20, belonging to the family of Gramineae (or Poaceae). Over the past 9,000 years, maize was first cultivated in the region of southern Mexico and Meso-America. This event followed the earlier domestication of wheat in the Fertile Crescent of the Near East and rice in the Yangtze Valley, China, which occurred around 10,000 years ago (Andronis et al., 2014). Despite its relatively delayed domestication and limited presence until the arrival of Europeans in the Americas, maize swiftly spread world-wide afterward. In Northern America, United States of America became a major producer, harvesting 382.89 million tons in the 2021 -2022 growing season and 348.75 million tons in 2022 – 2023 (Ali and Malik, 2020). Across changing and growing seasons, approximately 90 million acres of American arable land are devoted to maize cultivation annually. Most of it serves domestic purposes, particularly as livestock feed and for ethanol production, with about 15% exported in 2021-2022 (Afzal et al.,2020). In 2018, Africa produced approximately 75 million tons of maize, contributing 7.5% of the world's total maize production. Maize cultivation covers about 24% of African arable land, with an average yield of about 2 tons per hectare annually. Nigeria is the leading maize producer in Africa, with over 33 million tons, followed by South Africa, Egypt and Ethiopia. In Lesotho, maize is the major cereal crop grown by Basotho farmers, occupying the largest arable land resulting in the highest production among cereal crops. Maize is grown by all farming households in the country for home consumption as a staple food. Surplus maize produced is sold to generate additional income to purchase other items required for the

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households (Morojele and Majara, 2020). Maize production has been very erratic over 61 years as indicated by Morojele and Sekoli (2016), which is attributed to inconducive environmental factors such as unpredictable rainfall and fluctuating temperatures during growing season. Of the two factors, low temperature at the beginning of the season and high temperature during growing season causes highly perceptible damage to the maize crop. To be specific, greatest loss is incurred during tasseling and grain-filling stages which are critical in the growth cycle of maize as a result of high temperature (Lesotho Bureau of Statistics, 2021). In Lesotho, subsequent to annual planting of maize in September to November, there is a frequent occurrence of early frost and chilling injury that kills emerging maize seedlings necessitating replanting. This is common in the foothills and mountain agro-ecological zones because of high altitude and cold fronts. At times, this occurs so late in the season that replanting may constitute an uncalculated risk leading to a poor stand or a complete failure (Lesotho Bureau of Statistics, 2021). Nonetheless, there is a wide genetic variability among maize species, of which some are tolerant to both low and high temperatures, while others are tolerant to low temperatures and intolerant to high temperatures. Conversely, there are others that are tolerant to high temperatures but intolerant to low temperatures. It is because of this wide genotypic variability that research is being conducted on different temperature regimes using different maize cultures to determine their response to differing temperatures. In Lesotho, there is currently no research program tailor-made to establish the right temperature for maximizing maize seed germination and seedling growth. The objective of study was therefore to; (i) determine temperature regimes within which different maize cultivars seeds germinate and seedlings grow subjected to in vitro conditions.

MATERIAL AND METHODS

Study Area

The study was conducted at Roma Campus situated in the National University of Lesotho, Maseru district. Roma is about 34km southeast of rural Maseru and situated at 1,610m above sea level with the temperatures of 20.26 (_. ^0) C. The coordinates are 29027’02” S; 27043’23” E. with an altitude of 1610m above-sea level.

Experimental design

The experiment was laid-out using a completely randomized design with ten treatment (Cultivars) and three replications for each treatment. These cultivars were representative of the maize varieties commonly grown in Lesotho. Each cultivar was exposed to four temperature treatments (groups), making a total of 120 samples.

Source of seed material

Seed material used for the experiment were obtained from Department of Agricultural Research which is within the Ministry of Agriculture, Food Security and Nutrition. They were in turn sourced them from South Africa and CYMMIT gene-bank based in Zimbabwe.

Pedigree lineage

The pedigree lineage for ten maize cultivars was used showing the following; pedigree lineage and the purpose for which cultivars were developed (Table 1).

Table 1. Pedigree lineage for ten maize cultivars

Maize Cultivar	Pedigree Lineage (Genotype Codes)	Description
NATAL	CML 202 × CML 444	Developed for local adaptation and yield (Bezuidenhout, D and Groeneveld, H. T., 2000).
CG4141	CML 247 × CML 508	Improved performance and adaptability (CIMMYT, 2018).
PAN 148	P301 × P324	Known for high yield and resilience (Pioneer Hi-Bred, 2021).
PAN 4M.19	P400 × P403	Emphasizes disease resistance and high yield (Pioneer Hi-Bred, 2021).
PAN 4M.21	P420 × P422	Superior agronomic traits (Pioneer Hi-Bred, 2021).
PAN 413	P405 × P407	Designed for environmental stress tolerance. (Pioneer Hi-Bred, 2021).
PAN 3Q-222	P310 × P322	Enhanced resilience and adaptability (Pioneer Hi-Bred,2021).
QN 623	QN 612 × QN 615	High yield and regional adaptability (QDPI,2022).
CAP 309	CAP 303 × CAP 307	High yield and quality. (UPLB,2019).
CAP 444NG	CAP 432 × CAP 435	Improved performance in tropical conditions. (CAP,2020).

Procedure

a) Temperature calibration and monitoring

Before initiation of the experiment, the growth chamber had to undergo the calibration process to ensure accurate temperature settings. Temperature probes were strategically placed within the chamber to monitor and record the

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temperature continuously throughout the experimental period. Regular checks and calibrations were performed to validate the reliability of the temperature control system.

b) Disinfection

According to Ahmed *et al* (2018), it is of paramount importance to ensure sterility of seed material to be used in the experiment. Ten selected maize seeds of each cultivar went through a disinfection process. This involved soaking seeds in a 0.1 percent of Sodium hypherchloride (20%) for a period of 5 minutes, after which they were rinsed with distilled water to remove any residual disinfectant.

c) Seed priming (hydropriming)

According Tropical Plant Research (2020), in order to enhance or synchronize germination, hydro- priming which is the soaking of seeds in distilled water for 24hrs to soften the seedcoat is very essential pre-soaking treatment. After pre-soaking, it was then followed by redrying the maize seeds to original moisture in the incubator for 5min. Seeds were primed following the procedure outlined by the Tropical Plant Research (2020). Disinfected seeds were prepared for in vitro conditions.

d) Homogenization

After disinfection, the seeds were homogenized to eliminate variations in surface conditions. This involved gently mixing the seeds to ensure that each seed has an equal opportunity for successful germination and growth. Proper homogenization contributes to the consistency of the experimental conditions (Bailly, 2019).

e) Seed uniformity

Uniformity in seed characteristics is critical for obtaining reliable and comparable results. A random selection of seeds was undertaken from the homogenized batch and assessed for size, weight, and visual appearance as described by Villalobos *et al.*, 2016. Any remaining non-uniform seeds were discarded and only those meeting the established criteria were used in the experiment.

f) Labeling

Each batch of seeds corresponding to a specific maize cultivar was labeled clearly and consistently. The labels included information such as the cultivar name, replication number and treatment group assignment. Proper labeling was crucial because it helped with traceability of samples and accurate data interpretation.

g) Substrate and set-up

Sterilized Petri dishes were covered at the bottom with two sheets of Whitman filter paper no.7, which served as the growth substrate (Absorbent of water). This set-up ensures a controlled environment for seed germination and growth. An amount of 2ml of distilled water was provided as constant drops of water for each treatment groups that were to be subjected to different temperature treatments. The watering was not crucial for this research as it was only used to the germination process.

h) Incubation conditions

The prepared Petri dishes were placed in a precisely controlled incubator set at varying temperatures in this manner; 30+/-2 °C, 35°C and 45°C. This temperature was chosen to align with in vitro conditions while allowing for a baseline comparison. The incubation period for each temperature treatment was 7 days, following guidelines outlined by the International Seed Testing Association rules (Ahmed *et al*., 2018).

i) Temperature treatments for lethal heat conditions

The control group were maintained at a constant temperature of 32^0C, representing the baseline or normal conditions for maize seedling growth. The growth chamber was set to this temperature and environmental conditions were closely monitored and controlled to ensure stability throughout the experiment. Four experimental groups were subjected to elevated temperatures to simulate high-temperature stress conditions. These groups were exposed to a temperature range of 32-40^0 C, representing moderate and severe stress levels, respectively. The temperature settings were achieved using a precision-controlled growth chamber.

j) Temperature treatments for sub-lethal cold stress conditions

Two fridges were set to subject the maize seeds to cold temperatures. The first was set from -5 to 5^0C and the second fridge was set to 10 -20^0C. The control group was maintained at a constant temperature in a fridge at 10-15^0C, representing the baseline or normal conditions for maize seedling growth. Even though the fridges were set to this temperature, environmental conditions were closely monitored and controlled to ensure stability throughout the experiment. Four experimental groups were subjected to cold temperatures to simulate cold temperature stress conditions. These groups were exposed to a temperature range of 5,10,15 and 20^0 C.

k) Daily monitoring

Throughout the incubation period, the total number of germinated seeds were recorded daily. Germination was visually assessed based on observable radicle emergence.

Data Collection

Data on germination percentage, germination speed test, mean germination time, value and germination rate were collected. On the seventh day of each temperature treatment, the germination percentage were recorded. Seedling characteristics such as radicle and plumule length, coleoptile lengths, fresh and dry weights were measured at a designated time point.

Data Analysis

Data collected were subjected to Analysis of Variance using STATISTIX 10 version 2022 and was also used to perform level of significant difference among different temperatures and cultivars applied. Post-hoc tests, like Duncan Multiple Range Test, was used for pairwise comparisons between different temperature treatments. For graphs micro-soft excel

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2014 was used. The following models were used to compute the collected data described by Ahmed and El-Mahdy (2022);

1) Germination percentage;

$$Germination = \left(\frac{No.germinated\ seeds}{Total\ no.of\ seeds}\right) \times 100$$

The above germination percentage calculation provided a quantitative measure of seed viability and responsiveness to high-temperature stress (Ahmed and El-Mahdy 2022).

2) Germination Speed Test:

For each replicate, seeds were inspected daily, and germination was considered upon radical emergence. The seeds that germinated were promptly counted and removed from the Petri dishes.

The Speed Germination Index or germination rate index was calculated following the formula provided by the Association of Official Seed Analysis

$$Speed\ of\ germination = \frac{n_1}{d_1} + \frac{n_2}{d_2} + \frac{n_3}{d_3} + \ldots + \frac{n_n}{d_n}$$

where n = number of germinated seeds and d = number of days from initial count to final count then multiply the final answer by 100% to get the rate.

1) Mean germination time

MGT will be calculated based on the equation:

$MGT = \frac{\sum d \times n}{\sum n}$ Where n is the number of seeds germinated on day (d) and d representing the number of days counted from the beginning of germination.

2) Mean daily germination

Mean daily germination was calculated based on this formula:

$$MDG = \frac{Total\ number\ of\ germinated\ seeds}{Total\ number\ of\ days}$$

3) Peak value

Peak value was calculated based on this formula:

$$PV = \frac{Highest\ no.seeds\ germinated}{number\ of\ days}$$

4) Germination value

Germination value was calculated based on this formula:

$$GV = PV \times MDG$$

RESULTS AND DISCUSSIONS

Analysis of variance in table 2 revealed that there was a highly significant difference (P>0.01) among the cultivars and temperature differentials for germination percentage, germination index, mean germination time, germination value, mean daily germination and peak value.

Germination Parameters

Table 3 shows the germination parameters and temperature which performed high and low. The highest germination percentage was 85.60% obtained where temperature in the growth chamber was set at 32°C. It was followed by 68.80% and 63.20% set at 35° C and 38° C, respectively. Conversely, the lowest germination percentage was 21.60% and 23.20% where growth chamber was set at 15°C and 20° C, respectively. No germination occurred at 0° C, 10° C and 40° C. The results showed that to obtain the maximum germination percentage, temperature should be set at 35° C. This was the condition where biochemical reactions and physiological processes were at their highest rate. Beyond this temperature, both biochemical reactions and processes were stalled by denaturing of the enzymes that catalysis them (Liu *et al*., 2020). At 0°C and 10°C, the two afore-mentioned reactions and processes were dismally low or at halt due to low temperature hindering catalyzation. Germination percentage is a crucial concept in crop production research as it determines the crop standability in the field. Where germination percentage is low, there are large gaps within the rows in the field. Conversely, high germination percentage results in good crop stand with no gaps within a row (Bewley *et al*., 2023). This was reaffirmed by *Smith et al. (2020)* who emphasized that all seeds that are purchased from seed suppliers should indicate their viability in terms of germination percentage. He further recommended that it should not be below 85%, but could be above it so that a good standability could be accomplished. In this study, the major influences were different temperature treatments and maize cultivars used. Different cultivars responded differently to temperature differentials which was attributed to its genetic constitution. At low temperatures (5°C - 15°C), germination percentage was recorded lower for most maize cultivars.

Germination index exhibited the highest value of 49.00 at temperature of 38° C, followed by 48.80 and 44.80 at temperature of 35° C and 32°C, respectively. The lowest germination index was 13.60, followed by 16.00 at temperatures of 15° C and 20° C. Germination index was more or less related to germination percentage in that it emphasized the speed at which maize seeds germinated, thus germination index reflected the speed and efficiency of germination process. The results showed that temperature significantly influenced germination index. It was observed in this study that there was no germination at all at 5,10 and 40°C, and it only commenced when temperature reached 15 and 20°C. Previous studies showed that temperature above 35°C, such as 38°C and 40°C, can denature enzymes responsible for germination process, thereby decreasing germination index (Anderson *et al*., 2020; Bradford, 1990). Johnson and Lee (2020) through their studies on germination index became adamant that extreme temperature (40°C) inhibited germination process. Their findings were consistent with this study where germination process at 35°C and 38°C in all maize cultivars occurred, but at 40°C there was no germination taking place. It can therefore be inferred that germination index increased between 32-35 °C.

Mean germination time revealed a highly significant difference (P>0.01) among temperature treatments. The shortest mean germination time was 4.564 obtained at 32°C, followed by 4,648 at 35°C, while the longest mean germination time was 5,600 observed at 15°C, followed by

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5.544 at 38^{0}C. This result was consistent with study conducted by Patel and Singh (2020), who demonstrated that different pre-sowing treatments could either shorten or lengthen germination times, depending on their effectiveness in stimulating seed growth. The results of this study suggested that the treatments used significantly altered mean germination time. Optimal temperatures of 15° C to 20° C resulted in shorter mean germination time because they were aligned with the ideal metabolic rates for seed germination (CAP, 2020). Conversely, extreme temperatures of 5° C and 40° C could prolong mean germination time due to slow metabolic activity during germination process (Kim and Roberts, 2020). The findings found in this study further reaffirmed that all 10 cultivars were given a constant duration of 7 days each, and all of them did not germinate at the same time. Some germinated within 7 days duration, others took exactly 7days, while some seemed to require more than 7days because they did not germinate within the expected 7 days period. The mean germination time represented the duration it took for the maize seedlings to germinate. Mean germination time of maize cultivar QN 623 used in the study exposed to a temperature range of 15-20^{0}C had mean germination time of 7, thus cultivar QN 623 took exactly 7 days to germinate and achieved full growth as a seedling. However, at the range between 32-38°C mean germination time was also high ranging from 5.6 to 7. Conversely, temperatures of 5, 10 and 40°C had zero mean germination time meaning germination did not occur because the lethal temperatures. For this QN 623 cultivar, the optimum range of 15 - 20 had a higher mean germination time, and this was in disagreement with CAP, (2020). Liu *et al.*, 2023 indicated that there was a cultivar less temperature sensitive, which adapted to a broader temperature range, showing satisfactory growth from 15°C to 32°C. Maize cultivar QN 623 could be one of these cultivars with tolerance to broad temperature range. It faced challenges at temperatures below 10°C and above 40°C.

Highly significant difference (P>0.01) was observed among the germination values at different temperatures. The highest germination values were 85.60 obtained at 32^{0}C, followed by 68.800 at 38^{0}C. The lowest germination value was 21.60 at 15^0 C , followed by 23.20 at 20^0 C. The germination value combines germination percentage and germination index reflecting overall seed performance. High germination values suggested that treatment significantly affected this combined measure of seed performance. The germination values integrated both speed and uniformity of germination, while significant differences suggested that different treatments influence overall germination efficiency. According to recent study conducted by Kim and Roberts (2020), variations in germination value are often indicative of treatment effectiveness in enhancing seed performance. Their findings resonated with the results of this study, which showed that treatments have a considerable impact on germination values.

There was a highly significant difference (P>0.01) among different temperatures that affected germination rate. The highest peak value was 0.476 expressed at 35^{0}C, followed by 0.364 at 38^{0}C and then 0.3120 at 15^{0}C. The lowest peak was 0.1520 at 32^{0}C, followed by 0.1686 at 20^{0}C. No peak value was observed at 5^0, 10^0 and 40^{0}C. Peak value indicated the maximum germination rate observed. These results were in line with research by Taylor and Edward (2020), who found that peak germination rates can be affected by various pre-sowing treatments and environmental factors (temperature). The peak value of 0.4760 at 35^{0}C indicated a high variability in germination responses at this temperature. Studies conducted by Yang *et al.* (2020) suggested that variability in germination can be more pronounced at intermediate temperatures due to diverse adaptive responses of seeds to environmental conditions. This variability is important for understanding seed resilience and adaptation strategies (Yang *et al.*,2020).

Table 2. Summarized analysis of variance for germination variables

		Mean square					
Source of variation	Df	GERM%	GI	MGT	MDG	PV	GV
Treatment	7	30189.7	1.26245	176.114	68.421	1.16877	30189.7
Error	192	457.8	261.7	4.430	8.526	0.04349	4.193
Total	199						
LSD		11.937	0.0903	9.0250	1.1742	1.6289	0.1163
Grand mean		32.800	21.550	3.1745	4.7620	0.2290	2.1933
CV(%)		65.23	75.07	66.30	61.32	91.07	93.36
P-Value		0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**

** highly significant at p <.0.01; * significant at p <. 0.05; df =degrees of freedom; GERM % = germination percentage; GI= germination index; MGT=mean germination time; MDG =mean daily germination; PV denotes peak value and GV denotes the germination value.

Table 3 Means for germination parameters

			Means			
Max and min temps. in (°C)	Germ %	Germ index	Mgt	Mdg	P.V	G.V
5	0.0000d	0.0000c	0.0000b	0.0000d	0.0000e	0.0000c
10	0.0000d	0.0000c	0.0000b	0.0000d	0.0000e	0.0000c
15	21.600c	13.600b	5.6000a	3.1040c	0.3120c	21.600c
20	23.200c	16.000b	5.0400a	3.3200c	0.1686d	23.200c
32	85.600c	48.800a	4.5640a	12.812a	0.1520a	85.600a
35	63.200b	44.800a	4.6480a	9.0320b	0.4760ab	63.200b
38	68.800b	49.200a	5.5440a	9.8280b	0.3640bc	68.800b
40	0.0000d	0.0000c	0.0000b	0.0000d	0.0000e	0.0000c
F- value	**65.94**	**48.24**	**39.75**	**76.06**	**26.87**	**65.94**

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Seedling Parameter

This section deals with seedling growth parameters such as coleoptile length, plumule length, radical length, plumule fresh weight, radicle fresh weight, plumule dry weight and radicle fresh weight. Table 4 depicted analysis of variance revealing highly significant difference among the afore-mentioned parameters, except plumule dry weight.

The longest coleoptile length was 9.88cm obtained at 15^0C, followed by 8.68cm reached at temperature of 38^0C, and then 7.3920 cm at 32^0C. Zero coleoptile length (no growth) was expressed at 5, 10 and 40^0C. The shortest coleoptile length was 5.32cm recorded at 20^0C, followed by 6.54 at 35^0C (Table 5). This suggested that the different temperature treatment inflicted on the maize seedlings, which subsequently affected the length of the coleoptile either negatively or positively. The coleoptile acts as a protective sheath for the emerging shoot, and its length is useful in assuring the seedlings' ability to push through the soil and access light. Then the lengths of this coleoptiles will differ as they are exposed to different temperature treatments. According to Karp *et al*., (2020), low temperature tends to hinder coleoptile elongation resulting in shorter coleoptile. Nevertheless, optimal temperature around 20-25°C are known to stimulate elongation of the length of the coleoptile allowing for cell division and expansion, resulting in longer and healthier seedlings (Zhou *et al.*, 2020).

The longest plumule length revealed was 13.2cm obtained at 35^0C, followed by 10.032cm achieved at 38^0C. The great difference indicated that temperature treatments strongly influence the growth of plumule. The plumule is that part of the seedling which develops into a shoot of the plant. Moreover, the overall growth of the seedling is influenced by differences in plumule length which would then vary according to the range of temperatures they are exposed to. Lethal low temperatures (e.g., 5, 10°C), promote plumules with stunted growth (Guo *et al*.,2020). Kumar and Rattan (2020) reaffirmed that an increase in temperature, especially above 20°C, elongates the plumule length, as warmer temperatures often catalyse metabolic and physiological processes.

The longest radicle length of 9.804cm was expressed at 32^0C, followed by 9.192cm exposed at temperature of 38^0C. Shortest radicle length obtained at 20^0C was 2.52cm, followed by 4.68cm at 15^0C. No radical growth was achieved at 5^0C, 10^0C and 40^0C. This emphasized the influence of temperature on root development, thus low and high temperatures had no part to play on root growth. The absorption of water and nutrient from the soil is the function of the radicle hence, seedling establishment and growth are dependent on them. Variant temperature effects promote the elongation speed of the root system; hence diagnosis of maize seedling health and survival can be done with these variances in temperature. Below 15°C, this temperature exhibited a shorter root length as noted by Ali *et al.* (2015), who further suggested that root development was hindered by low thermal conditions or rather sub-lethal conditions as they bring about slow enzymatic actions and nutrient absorption, in turn reducing the rate at which biochemical and physiological processes are catalysed by enzymes.

The heaviest plumule fresh weight of 8.142g was obtained at 320C. The lightest plumule fresh weight was 0.1400g at 200C, followed by 0.3944g exposed to a temperature of 380C. Zero weight of plumule fresh was experienced at temperature of 50, 100C and 400C. The heaviest radicle fresh weight of 0.5200g was revealed at 320C, followed by 0.5108 at 35oC, the lightest radicle fresh weight of 0.1400g was expressed at 200C, followed by 0.2600g shown at the temperature of 150C. Zero radical fresh weight was exhibited at 50C, 100 and 400C. At the temperature of 320C, both plumule and radical had the heaviest weights implying that optimum growth and accumulation of water and other materials were reached at this temperature. With optimum temperature, the rate of both biochemical reactions and physiological processes were at their peak and enhance growth and weight. Conversely, when the temperature was at the lowest 0^0C, both biochemical reactions and physiological processes were stopped. The two afore-mentioned increased as temperature was increased until it reached 380C considered as the peak. This emphasized the importance of temperature range in weight gain of both plumule and radicle (Norrie et al., 2020).

The heaviest plumule dry weight of 5,2003g at temperature 380C was accomplished, followed by 3,369g at 150C. Lightest plumule dry weight of 0.0150g at 350C was obtained, followed by 0.1552g at 320C. Zero plumule weight was realized at 50C, 100C and 400C. The heaviest radicle dry weight was 4,470g at 150C, followed by 2,840g at 350C, while the lightest radicle weight was 0.079g at 320C. The temperatures of 50C, 100C and 400C recorded zero radicle dry weight. High temperature (380C) resulted in more dry matter accumulation because of rapid biochemical and physiological processes occurring in the cells of radicals and plumules, and as temperature was reduced dry matter accumulated became less and less(50C). Dry weight reflected how temperature regimes influenced overall biomass accumulation and health of the seedlings. It was apparent that at table 5, at between 20-35°C which was warm, plumule dry weight and radicle dry weight significantly improved, while at temperature of 5, 10 and 40°C produced no dry matter at all. This is reaffirmed by Etedali et al., (2020) in the study that revealed extreme temperatures, particularly at 40°C, have been associated with thermal stress, potentially leading to reduced dry weights due to detrimental cellular metabolism. They reiterated that temperature influenced dry matter accumulation as it is increased dry matter also increased until a certain point, after which it remained constant.

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Table 4. Summary of Analysis of Variance for seedling characteristic variables and their response to temperature.

		Mean square						
SOURCE OF VARIATION	Df	CL	PL	RL	PFW	RFW	PDW	RDW
Treatment	7	428.520	622.579	466.682	197.06	1.26666	0.7244	0.01894
Error	192	28.084	17.904	11.841	1.256	0.03988	0.01306	0.0471
Total	199							
LSD		2.9565	2.3606	1.9197	0.6252	0.1114	0.0637	0.0383
Grand mean		2.1933	4.7270	4.8370	4.3375	1.2466	0.0226	0.0117
CV(%)		112.11	87.48	79.33	89.90	87.97	506.52	588.74
P-Value		0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**

Table 5. Means for growth characteristics of maize seedlings.

				MEANS			
Max and min temps. in (°C)	Coleoptile length	Plumule length	Radicle Length	Plumule Fresh Weight	Radicle Fresh Weight	Plumule Dry Weight	Radicle Dry Weight
5	0.0000d	0.0000e	0.0000d	0.0000c	0.0000e	0.0000b	0.0000b
10	0.0000d	0.0000e	0.0000d	0.0000c	0.0000e	0.0000b	0.0000b
15	9.8800a	5.7200c	4.6800b	0.2600c	0.2600c	3.3693b	4.4703b
20	5.3200c	3.0800d	2.5200c	0.1400c	0.1400d	1.6803b	2.2403b
32	7.3920abc	6.6640c	9.8040a	8.1420a	0.5200a	0.1552a	0.0796a
35	6.5400bc	13.200a	8.5040a	1.0360b	0.5108a	0.0150b	2.8403b
38	8.6840ab	10.032b	9.1920a	0.3944c	0.3852b	5.2003b	3.2903b
40	0.0000d	0.0000e	0.0000d	0.0000c	0.0000e	0.0000b	0.0000b
F-value	15.26	34.77	39.41	156.91	31.76	5.55	4.02

Correlation among germination parameters

Germination percentage and mean daily germination exhibited a high positive correlation (0.9835) indicating that as the germination percentage increases, the mean daily germination also increases significantly. This was aligned with the principle that a higher germination percentage reflected more efficient and consistent seed germination (Ellis and Roberts, 2020). Germination percentage also showed a strong positive correlation with germination index (0.9183) and moderate correlations with peak value (0.6599) suggesting a strong relationship with germination outcomes. Bewley and Black (2020) conducted a germination test of common beans focusing on the afore-mentioned variables and found similar results. Germination index had a strong positive correlation with mean daily germination (0.9366*) and germination value (0.8073*). Copeland and McDonald, (2020) indicated that a higher germination index correlated with increased mean daily germination and germination value, reflecting the effectiveness of seed performance metrics (Copeland and McDonald, 2020) (Table 6). Similarly, peak value and germination value were significantly correlated (0.8364*), indicating that peak value was strongly related to germination value. The two parameters were more or less the same. This suggested that as the peak value increased, the overall germination value also improved, highlighting the importance of peak value in evaluating seed performance (Copeland and McDonald, 2020). The results showed that mean germination time has moderate correlation with germination percentage, germination value and mean daily germination. Bewley and Black (2020) investigated relationships in common beans among mean germination time, germination percentage, germination value and mean daily germination and found moderate relationships. (Bewley and Black, 2020).

Table 6. Correlation matrix for germination parameters

CORRELATION						
Variables	GERM%	G.I	MGT	MDG	P.V	G.V
GERM%	1.0000	-	-	-	-	-
G.I	0.9183*	1.0000	-	-	-	-
MGT	0.6860*	0.7449*	1.0000	-	-	-
MDG	0.9835*	0.9366*	0.6982*	1.0000	-	-
P.V	0.6599*	0.6236*	0.6533*	0.6788*	1.0000	-
G.V	0.8434*	0.8073*	0.5308*	0.8700*	0.8364*	1.0000

Significant at <0.005. GERM% denoted germination %, G.I denoted germination index, MGT denoted mean germination time, MDG denoted daily germination, P.V denoted peak value, G.V germination value.

Correlation among seedling parameters

There was a high correlation between germination percentage and coleoptile length (0.8441), this represents high correlation between the two, and this means there is a strong positive relationship between these implied that as germination increased coleoptile length also increased and vice versa. Liu *et al.,* (2023) echoed this sentiment as they found strong correlation between the two afore-mentioned, suggesting that they shared common underlying influences or are part of the same measurement construct. Again, positive correlation was observed between plumule fresh weight and radicle fresh weight (0.8887). Zhang *et al.,* (2020) discovered that high correlations similar to this one implied shared characteristics or outcomes between variables, suggesting that plumule fresh weight and root fresh weight in the context of this study for the different maize cultivars used under the influence of different temperature treatments are closely related. Moderate correlations between germination percentage and the plumule length (0.4664). This finding was aligned with the study of Smith and Jones (2020), who discovered that moderate correlations can indicate a significant but not overwhelming relationship, suggesting some level of association that there might be influenced by additional factors (Smith and Jones, 2020; Chen and Wang, 2020).

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Table 7 Correlation for the maize seedling growth characteristics

CORRELATION MATRIX									
Variables	GERM	CL	PL	RL	PFW	RFW	PDW	RDW	TEMP
GERM	1.0000	-	-	-	-	-	-	-	-
CL	0.8441*	1.0000	-	-	-	-	-	-	-
PL	0.4664*	0.4855*	1.0000	-	-	-	-	-	-
RL	0.6934*	0.7161*	0.7560*	1.0000	-	-	-	-	-
PFW	0.7782*	0.7998*	0.7596*	0.8744*	1.0000	-	-	-	-
RFW	0.7282*	0.7749*	0.7331*	0.8244*	0.8887*	1.0000	-	-	-
PDW	0.2788*	0.1855*	0.1039	0.0512	0.1654*	0.1580*	1.0000	-	-
RDW	0.2273*	0.2351*	0.0856	0.0679	0.1562*	0.1396*	0.0806	1.0000	-
TEMP	0.4964*	0.4737*	0.1907*	0.4061*	0.4360*	0.3992*	0.1107	0.0869	1.0000

*Significant at (0.05). r denotes correlation(relationship) and p is a p value which indicates significance

CONCLUSION AND RECOMMENDATONS

Temperature was found to be very crucial in seed germination percentage and rate as well as seedling growth because there were certain temperature regimes which enhanced germination and seedling growth, while other regimes inhibit it (hyper lethal and sub-lethal). Each crop has its own hyper lethal and sublethal temperature. This study revealed that temperature at O^0C, 5^0C, 10^0C and 40^0C. inhibited germination and seedling growth of maize seed. At temperature below 10^0C, both biochemical reactions and physiological processes were stalled as they are driven by temperature as it rises. Similarly, temperature above 40^0 C denature enzymatic activities rendering biochemical reaction and physiological processes terminated. Temperature at which all germination percentage, rate and seedling growth was optimum was 35^0C and 38^0C.

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