Journal of Plant Production and Sustainability (2025) 1(1): 61-69
RESEARCH PAPER

Allelopathic effect of *Moringa oleifera* on germination and physiology of seedlings in maize (*Zea mays* L.)

Rashid Abbas[1]*, Iqtidar Hussain[1], Mohammad Safdar Baloch[1], Umar Khitab Saddozai[1], Asghar Ali Khan[1], Bismillah Khan[2] and Rashid Khan[1]

[1]Department of Agronomy, Faculty of Agriculture, Gomal University Dera Ismail Khan, Pakistan
[2]Department of Soil Sciences, Faculty of Agriculture, Gomal University Dera Ismail Khan, Pakistan

*Corresponding author's email: rashidabbas5292@gmail.com

Abstract

A greenhouse experiment was carried out to evaluate the effect of leaf extract of *Moringa oleifera* on germination and physiology of maize seedlings at Gomal University, Dera Ismail Khan, KPK, during the kharif season 2023. The experiment was conducted using a Completely Randomized Design (CRD) with three replications and five treatments of *Moringa oleifera* leaf extract at concentrations of 2.5 %, 5 %, 7.5 %, 10 %, and 12.5 % (v/v). A control treatment was also included for the comparison of different treatments' means. Data on germination %, days to emergence, leaf area index (cm^{-2}) at 20 and 40 days after germination, SPAD value at 20 and 30 days after germination, crop growth rate, net assimilation rate, shoot length (cm), root length (cm), shoot fresh weight (g) and shoot dry weight (g) was recorded. The results revealed that MLE 2.5 % v/v and 5 % v/v significantly improved the germination % (86.33 and 73.33) and days to emergence (3.66 days) as compared to control (68.30 and 6.33), respectively. Similarly, leaf area index at 20 and 40 days after germination, SPAD value at 20 and 40 days after germination, crop growth rate, net assimilation rate, root and shoot length, seedlings fresh and dry weight were significantly higher in the maize seedlings treated with MLE 2.5 %. However, other treatments (7.5 %, 10 % and 12.5 %) showed inhibitory effect on all the traits studied throughout the course of the experiment. Thus, from the present research study it might be recommended that by using *Moringa oleifera* leaf extract at lower concentrations from 3-5 % can act as plant growth regulator to increase crop production and sustainable agriculture. © 2025 The Author(s)

Keywords: Allelopathy, Germination, Leaf extract, Maize, *Moringa oleifera*, Vegetative growth

Citation: Abbas, R., Hussain, I., Baloch, M. S., Saddozai, U. K., Khan, A. A., Khan, B., & Khan, R. (2025). Allelopathic effect of *Moringa oleifera* on germination and physiology of seedlings in maize (*Zea mays* L.). *Journal of Plant Production and Sustainability, 1*(1), 61–69.

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops globally, serving as a staple food, animal feed, and industrial raw material (Ahmad & Ahmad, 2018; Rubab et al., 2020; Azam et al., 2023). It plays a crucial role in food security and agricultural economies, especially in developing countries (Jamilah et al., 2024; Kekere et al., 2024). However, its growth and productivity are often affected by environmental stresses (Zia et al., 2023) and competition from weeds and other plants (Mehmood et al., 2022). In recent years, increasing attention has been given to the use of natural plant-based extracts and residues in sustainable agriculture, particularly through the study of allelopathy (Niyazi et al., 2017). The term allelopathy was used for the first time in 1937 by an Austrian scientist Hans Molisch, which means suffering or mutual harm in Greek. More specifically, allelopathy refers to the release of allelochemicals, which retard or enhance the growth of other plant species present in their vicinity (Niyazi et al., 2017). Plant dynamics, growth, physiology, survival and community composition are also affected by allelochemicals (Bais et al., 2006). Allelopathy can affect plant productivity, diversity, ecology, occurrence, growth, development, and succession. Aside from many adverse allelopathic effects of plant species, there are many selective beneficial and neutral effects (Niyazi et al., 2017). These allelochemicals are normally categorized as secondary metabolites which may be isoprenoids, phenolic, alkaloids, terpenoids and flavonoids, etc. Allelochemicals are normally present in all parts of the plants, including flowers, fruit, leaves, rhizomes, seeds, stems, seeds, pollen and roots (Mubashir & Shah, 2011). These are released by leaching, volatilization, residue decomposition, root exudation and other natural and agricultural processes (Stamp, 2003). According to Pinton et al. (2001), 5-21 percent carbon comes from the soil (rhizosphere) through photosynthetically fixed root exudates. Meanwhile, a wide range of nutrients which are important for microorganisms also come in the rhizosphere by the release of root exudates by the plants (Bacilio et al., 2003; Zhang et al., 2017).

The plant biomass had an allelopathic effect on both plant and soil (Balicevic et al., 2015). Seed priming and arial application of *M. oleifera* improved the morpho-physiological characteristics of maize (Afzal et al., 2012). The Billion Tree Project, an ambitious initiative aimed at combating deforestation and promoting afforestation, has undeniably made significant strides in enhancing global green cover (Khan et al., 2019). However, there are

concerns about its long-term allelopathic effects, particularly in regions where species like Conocarpus and Eucalyptus have been planted near crop boundaries. While these fast-growing trees have been celebrated for their environmental benefits, their lesser known allelopathic properties can inadvertently harm neighboring crops. Allelopathy refers to the release of biochemical compounds by certain plants that can inhibit the growth of nearby vegetation (Shah et al., 2018). Unfortunately, many farmers remain unaware of these negative effects, which can lead to reduced crop yields and economic hardships. As the Billion Tree Project continues to evolve, it becomes imperative to raise awareness among farmers and promote sustainable planting practices to ensure that its long-term ecological benefits are maximized without unintentionally compromising agricultural productivity (Lefebvre et al., 2022). Alike, the effect on the microorganism, soil, and environment, significant allelopathic impacts of plants has been reported recently (Liu et al., 2023). Allelopathic plants are being used for medicinal purposes for curing different diseases as well as attributing the allelopathic effects on neighboring plants (Shinwari, 2010). Different plant species are indicating variations in allelopathic activities in different habitats, as well as same plant species, pose different toxic effect (Gilani et al., 2010; Qureshi et al., 2024).

In the agro-climatic context of Dera Ismail Khan, characterized by its distinct environmental conditions, understanding the allelopathic effects of native forest plant species like *Moringa oleifera* on maize seedlings assumes paramount significance. Dera Ismail Khan, located in a semi-arid region, faces challenges related to soil fertility and water availability, making sustainable crop production a pressing concern (Ullah et al., 2023). The exploration of allelopathic interactions between locally prevalent plant species and maize, an important crop in the region, offers a promising avenue for improving agricultural practices while mitigating the impact of invasive species (Shah et al., 2018). *M. oleifera* are known to produce various secondary metabolites, some of which may have allelopathic properties (Shah et al., 2018). Investigating the potential effects of aqueous extracts from these plants on maize seed germination and growth can shed light on their suitability for crop management in the region. This study enhances our knowledge of allelopathy and offers practical insights for improving crop productivity under the specific agro-climatic conditions of Dera Ismail Khan.

Dera Ismail Khan, where agriculture is the backbone of the local economy and crucial for food security, farmers face a dual challenge: escalating costs of chemical fertilizers and pesticides, and the imperative to maintain or increase crop yields in the face of changing agro-climatic conditions (Elahi et al., 2024). The rising prices of chemical inputs have rendered them financially burdensome for many farmers, exposing their ability to sustain profitable agricultural practices. To mitigate this pressing issue and ensure the continued productivity of agriculture, there is a critical need to explore innovative, cost-effective, and environmentally sustainable alternatives to conventional chemical fertilizers and pesticides (Ali et al., 2024). This study seeks to address this challenge by investigating the allelopathic potential of *Moringa oleifera* extracts as viable substitutes. By evaluating the efficacy of these three extracts in promoting maize growth and pest control, we aim to provide practical solutions that reduce the financial burden on farmers while fostering sustainable agricultural practices in the region. Therefore, this research study was designed to quantify and compare the growth responses of maize (*Zea mays*) when exposed to leaf extract from *Moringa oleifera* and also to assess the physiological changes occurring in maize plants in response to exposure to leaf extract of *M. Oleifera*.

Materials and Methods

Experimental material, design and procedures

A greenhouse experiment was designed at the Faculty of Agriculture, Gomal University Dera Ismail Khan, KPK, Pakistan. The plastic pots were used for the experiment. Each pot was filled with equal depth with sandy loam soil. Six seeds of maize were sown in each pot at depth of 2 cm. The experiment utilized the maize variety Soni Dharti-626 and was arranged using a Completely Randomized Design (CRD) with five treatments, each replicated three times. A check treatment was also included for comparison of treatments mean. The treatments included foliar applications of *Moringa oleifera* leaf extract at concentrations of 2.5 %, 5 %, 7.5 %, 10 %, and 12.5 %, along with a control treatment (no extract).

Extract preparation and application

Three kilograms of fresh *Moringa oleifera* leaves were gathered from a nearby village and rinsed with tap water to eliminate surface dust. Washed leaves were grinded in electric juicer to extract leaf juice. To prepare the different concentrations of the extract, specific volumes of the juice were diluted with distilled water as follows: for the 2.5 % concentration, 100 ml of moringa leaf extract was taken in a beaker, 2.5 ml extract from 100 ml was dissolved in 997.5 ml of the water to make 2.5 % solution; for the 5% concentration, 100 ml of *moringa* leaf extract was taken in a beaker, 5 ml extract from 100 ml was dissolved in 995 ml of the water to make 5% solution; for the 7.5 % concentration, 100 ml of *moringa* leaf extract was taken in a beaker, 7.5 ml extract from 100 ml was dissolved in 992.5 ml of the water to make 7.5 % solution; for the 10 % concentration, 100 ml of *moringa* leaf extract was taken in a beaker, 10 ml extract from 100 ml was dissolved in 990 ml of the water; for the 12.5 % concentration, 100 ml of *moringa* leaf extract was taken in a beaker, 12.5 ml extract from 100 ml was dissolved in 981.5 ml of the water to make 12.5 % solution. The leaf extracts were applied as foliar sprays at two growth stages, 15 and 30 days after germination.

Parameters studied

The data regarding days to germination was noted by counting the number of days taken to germination of first seedling for each treatment. The germination percentage was determined by counting the number of seeds that germinated, dividing by the total number of seeds sown,

and multiplying the result by 100. Shoot length (cm) of each treatment was taken by measuring the shoot of plant with a scale from bottom to top. Shoot fresh weight (g) was taken by harvesting 3 randomly selected plants at 40 days after germination from each treatment was calculated by using analytical weight balance and their average was calculated. Shoot dry weight (g) of shoot was calculated by harvesting 3 randomly selected plants at 40 days after germination from each treatment and kept in oven at 70 degree for 24 hours and their weight was calculated by using analytical balance. Root length (cm) was measured by uprooting 3 randomly selected plants from each treatment 40 days after germination and their average was calculated.

Leaf area index

Leaf area index at 20 days after germination was taken by measuring the leaf area of 3 seedlings in each treatment when seedlings complete 20 days growth period. Leaf area index at 40 days after germination was taken by measuring the leaf area of 3 seedlings in each treatment when seedlings completed 40 days growth period. The leaf area index was determined using the following formula:

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Ground area}}$$

To calculate the surface area of a pot we used the following formula:

$A = 2\pi r2+2\pi rh$

Where
r is the radius of the base
h is the height

Crop growth rate (CGR) (g m^{-2} day^{-1})

Crop growth rate was calculated by dividing the accumulated dry biomass (difference between final and initial measurements) by the duration of the growth period.

Net assimilation rate (NAR) (g m^{-2} day^{-1})

Net assimilation rate reflects the gain in plant dry weight relative to leaf area and time, serving as an indicator of photosynthetic efficiency. The data for net assimilation rate was calculated using the formula introduced by Vernon (1963):

$$\text{NAR} = \frac{(w2 - w1)\ (\log e\ L2 - \log eL1)}{(T2 - T1)\ (L2 - L1)}$$

Where
NAR = Net assimilation rate
W_1 = Dry weight of the plant at first observation
W_2 = Dry weight of the plant at second observation
L_1 = Leaf area at the first observation
L_2 = Leaf area at the second observation
T_1 = Time at the first observation
T_2 = Time at the second observation
ln = Natural logarithm (loge)

Chlorophyll contents

Chlorophyll content of each treatment was calculated by randomly selected three seedlings at 20 days after germination with SPAD meter and their average was calculated. Chlorophyll content of each treatment was also calculated by randomly selected three seedlings at 40 days after germination with SPAD meter and their average was calculated.

Statistical analysis

All collected data were analyzed statistically using the Statistix 8.1 software package. Differences among treatment means were determined by applying the Least Significant Difference test at a 1 % level of probability ($P \leq 0.01$).

Results and Discussion

Days to emergence

The data presented in Table 1 revealed significant differences attributed to the various *Moringa oleifera* treatments. However, maximum 11.67 number of days were attained by the treatment *M. oleifera* leaf extract 12.5% followed by MLE 10%, 7.5% and control which attained 9.66, 8.66 and 6.66 number of days respectively. Whereas a minimum of 3.66 days were attained in the maize seedlings treated with MLE 2.5% as compared to other concentration. Thus, *M. oleifera* leaf extract is a concentration dependent phytohormone, it improves the germination and emergence when used at lower concentration, while it inhibits the germination and emergence at higher concentration (Afzal et al., 2012). Earlier findings revealed that Seed priming with MLE at lower concentration results in improve mean germination time, emergence index and days to 50 % germination because M*oringa oleifera* leaf extract is recognized for its rich composition of nutrients and vitamins, which may contribute to the nutritional support of the developing embryo during the seed priming lag phase (Farooq et al., 2010), ultimately attaining lesser number of days to emergence and enhanced seed germination as well as subsequent growth of maize. The improved quality of primed seeds resulting from lower concentrations of *Moringa oleifera* leaf extract may be linked to higher germination and emergence rates, as well as the activation of metabolic repair pathways during priming, as described by Powell et al. (2000), while reduced germination in higher concentration (Afzal et al., 2008).

Germination percentage

Table 1 presents the impact of *Moringa oleifera* leaf extract on the germination percentage of maize. A significant inverse relationship was observed between MLE concentration and maize GP; as the extract concentration increased, the germination percentage significantly decreased. The highest germination percentage (86.33 ± 0.1833 %) was recorded at the 2.5 % MLE concentration. This was notably higher than the

overall average germination of 73.3 ± 0.7386 % (or 73.33 ± 0.7009 % for the 5 % concentration). Conversely, the maximum inhibition of seed germination occurred at the highest MLE concentration tested (12 %), resulting in a minimum GP of only 34.28 ± 0.6179 %. These findings align with previous research by (Patel et al., 2002; Odofin, 2010) who also reported a reduction in germination percentage with the application of plant extract leachates to various crop species. The decline in maize seed germination and seedling growth at higher concentrations of *M. oleifera* extract indicates that the leaves may contain phytotoxic allelochemicals. These compounds likely retarded growth parameters and inhibited germination and seedling development in the target plant. The inhibitory effect of the donor plant intensified with increasing extract concentrations. Differences in germination percentages across treatments may be due to variations in seed permeability to inhibitory compounds, as noted by Mona et al. (2017). Additionally, Mohamadi and Rajaie (2009) reported that allelochemicals mainly hinder seed germination by interfering with normal cellular metabolic processes rather than causing direct harm to cellular organelles.

Shoot length (cm)

Data recorded for shoot length (cm) presented in Table 2 showed significant variances between the different treatments. Results revealed that maximum shoot length (68.30 cm) was recorded in the maize seedlings treated with *M. oleifera* leaf extract 2.5% followed by 64.30 and 59.56 cm recorded for the maize seedlings treated with *M. oleifera* leaf extract 5 % and *M. oleifera* leaf extract 10 %, respectively as compared to control. In the same trait the data recorded for shoot length, shortest seedlings with the value of 51.23 cm were recorded in control treatment. Our results are in parallel line with Ali et al. (2017) who described that application of *M. oleifera* on growth and germination of maize at a concentration 5 %, 10 %, 15 % and 20 % showed improvement of root and shoot length in treatments of lower concentration up to 5 %, whereas higher concentration resulted in inhibited morphological traits of maize seedlings.

Shoot fresh weight (g)

Data recorded for shoot fresh weight presented in Table 2 showed significant variation among the means of different concentrations of *M. oleifera* leaf extract. Results revealed that the maximum (24.97 g) shoot fresh weight of maize seedlings was recorded in *M. oleifera* leaf extract 2.5 % followed by 21.22 and 15.60 g recorded for the maize seedlings were treated with *M. oleifera* leaf extract 5 % and *M. oleifera* leaf extract 7.5 %, respectively. The results further stated that the minimum 9.86 g shoot fresh weight was measured in *M. oleifera* leaf extract 12.5 % which was found statistically at par with *M. oleifera* leaf extract 10 %. Our findings contrast with those reported by (Qayyum et al., 2018; Shah et al., 2018) who investigated the effects of different concentrations of *Prosopis juliflora* herbal extract on various wheat parameters. Their studies consistently demonstrated a significant reduction in all agronomic, physiological, quality, and yield-contributing characteristics of wheat following extract application. Specifically, a 40 % extract concentration was found to exert the most detrimental effects on the recipient crop (Qayyum et al., 2018). These observations align with the understanding that herbal extracts often contain allelochemicals that can exert inhibitory effects on the growth and yield of cultivated crops.

Shoot dry weight (g)

Differences between the treatments means of *M. oleifera* leaf extract showed significant variation for shoot dry weight as shown in Table 2. However, maximum dry shoot weight (7.05 g) was recorded in *M. oleifera* leaf extract @ 2.5 % followed by 5.30 and 3.91 g recorded for *M. oleifera* leaf extract @ 5 % and *M. oleifera* leaf extract @ 7.5 % respectively as compared to control treatment. Furthermore, the results revealed that the lowest value for dry weight of shoot 1.51 g was computed for the maize seedlings treated with *M. oleifera* leaf extract 12.5 %. Our findings are similar to Ahmed and El-Mahdy, (2022) who described that the higher concentration of *Moringa* leaf extract was 12 and 14 % which significantly reduced the shoot dry weight of maize crop. This suggests that lower concentration of *Moringa* leaves extract is suitable for improving the rate of germination and seedling growth in maize.

Leaf area index

Leaf area index 20 days after germination showed significant difference among the different treatments of *M. oleifera* leaf extract as presented in Table 3. Results revealed that the maximum (0.03) leaf area index at 20 days after germination was recorded in the maize seedlings treated with *M. oleifera* leaf extract 2.5 % followed by (control) and T6 (*M. oleifera* leaf extract 12.5 %) which valued 0.02 for leaf area index at 20 days after germination of maize. This hypothesis is consistent with the findings of Ali et al. (2021) who demonstrated that foliar application of *Moringa oleifera* leaf extract at lower concentrations led to an improved number of leaves and a significant increase in leaf area index in various crop plants. However, both treatments were found statistically non-significant with each other. In the same trait minimum (0.01) leaf area index at 20 days after germination was recorded for the maize seedlings treated with *M. oleifera* leaf extract 5 %, 7.5 % and 10 % and found statistically similar with each other. Our results differ from those of Sikolia & Ayuma (2018), who observed both significant and non-significant effects on LAI following the application of *Eucalyptus saligna* herbal extract on *Vigna unguiculata* germination and growth.

. Data recorded for leaf area index presented in Table 3 showed significant variation among the treatments mean. However, the maximum (0.25) leaf area index at 40 days after germination was recorded in the maize seedlings treated with *M. oleifera* leaf extract 2.5 % followed by 0.19 and 0.04 recorded for the maize seedlings treated with *M. oleifera* leaf extract 5 % and *M. oleifera* leaf extract 7.5 %, respectively. Similar results were also reported by Ilori

et al. (2011); Sarmin (2014) who found that applying herbal extracts (*Moringa oleifera* and *Chromolaena odorata*) improved the leaf area index of wheat. Whereas (0.01) minimum leaf area index at 40 days after germination was recorded in the maize seedlings treated with *M. oleifera* leaf extract 12.5 %. Our findings are similar with the findings of Shah et al. (2018) who studied the different concentration of *P. juliflora* leaf extracts; they noted that by the application of higher concentration above 10 % has inhibitory effect on crop plant because it contains many allelochemicals.

Crop growth rate (g m^{-2} day^{-1})

The data presented in Table 3 showed significant variances among the different treatments mean. The present research findings revealed that the maximum crop growth rate was recorded in *M. oleifera* leaf extract 2.5 % with the value of 24.31 g m^{-2} day^{-1} followed by (18.39 and 15.09 g m^{-2} day^{-1}) recorded for the maize seedlings treated with Control and *M. oleifera* leaf extract 12.5 %. Khan et al. (2021) found that applying moringa leaf extract as a foliar spray effectively increased rice yield and enhanced dry matter accumulation. Results further state that the minimum crop growth rate (9.56 g m^{-2} day^{-1}) was recorded in the maize seedlings treated with *Moringa oleifera* leaf extract 7.5 % as compared to control treatment. Previous findings indicate that *P. juliflora* at low concentrations positively impacts crop growth; however, increasing its concentration inhibits the germination, growth, and development of crop plants (Jeber & Khaeim, 2019).

Net assimilation rate (g m^{-2} day^{-1})

Data presented in Table 4 indicated significant treatment-specific differences in the net assimilation rate (g m^{-2} day^{-1}) attributable to the various *Moringa oleifera* leaf extract applications. However, the maximum net assimilation rate (0.43 g m^{-2} day^{-1}) was recorded in *Moringa oleifera* leaf extract 2.5 %) followed by 0.29 and 0.27 g m^{-2} day^{-1} recorded for the Control and *M. oleifera* leaf extract 5 %. Similar conclusions were shared by (Yasmeen et al., 2013; Rehman et al., 2014) when studied *M. oleifera* as a plant growth regulator. They found that using *M. oleifera* at lower concentration increased the agronomic as well as physiology of maize. Furthermore, the results revealed that minimum net assimilation rate 0.17 g m^{-2} day^{-1} was recorded for T5 (*M. oleifera* leaf extract 10 %). It was assumed in a study that the germination and growth of seedlings could be altered by allelochemicals present in higher concentrations of mesquite aqueous extracts. These phytotoxic chemicals were reported to exert inhibitory influences on wheat growth and production (Shah et al., 2016).

Chlorophyll contents

Table 4 presents significant differences in SPAD values among various *Moringa oleifera* leaf extract treatments at both 20 and 40 days after germination. At 20 DAG, the highest SPAD value (38.73) was observed with MLE at 2.5%, followed by 35.77 for MLE at 5 %. Conversely, the minimum SPAD value (29.52) was recorded in maize seedlings treated with MLE at 12.5 %. The control treatment, along with MLE at 7.5 % and 10 %, showed statistically similar SPAD values. These findings align with Afzal et al. (2012) who reported beneficial effects of *Moringa oleifera* leaf extract (3 %) on SPAD values and enzymatic activities in spring maize under cold conditions. However, the inhibitory effect of higher concentrations observed here is consistent with studies by Dhanai et al. (2013) indicating that increasing concentrations of herbal aqueous extracts (e.g., *Acacia nilotica* from 5-20 %) can adversely affect cereal germination and physiology. For SPAD values at 40 DAG, significant variations were also noted across treatments. The maximum SPAD value (41.46) was again recorded with MLE at 2.5 %, followed by 37.03 for MLE at 5 %. Lower values were observed with MLE at 7.5 % (28.08) and 10 % (30.30), while the control treatment exhibited the minimum SPAD value (22.08) at this stage. MLE at 5% and 7.5 % were statistically similar. Our results are consistent with (Rehman et al., 2014; Mahboob et al., 2015; Waqas et al., 2017) who studied *Moringa oleifera*'s impact on linola and maize, respectively concluding that it significantly improved physiological traits but could adversely affect agronomic and morphological characters. The observed reduction in chlorophyll content at higher MLE concentrations may be attributed to the presence of allelochemicals, as highlighted by (Vijayan, 2015).

Table 1 Effect of different concentrations of *Moringa oleifera* leaf extract on days to emergence and germination percentage in maize

Treatments	Days to emergence	Germination percentage
Control	$6.66^{c} \pm 0.25$	$68.30^{bc} \pm 1.80$
Moringa oleifera leaf extract 2.5 %	$3.66^{d} \pm 0.18$	$87.64^{a} \pm 1.35$
Moringa oleifera leaf extract 5 %	$5.00^{cd} \pm 0.21$	$73.08^{ab} \pm 1.50$
Moringa oleifera leaf extract 7.5 %	$8.66^{b} \pm 0.30$	$54.75^{d \pm} 2.00$
Moringa oleifera leaf extract 10 %	$9.66^{ab} \pm 0.27$	$40.11^{e} \pm 1.65$
Moringa oleifera leaf extract 12.5 %	$11.67^{a} \pm 0.35$	$34.28^{ef} \pm 1.90$

Values are means ± standard deviation (SD). Means followed by different letters in a column differ significantly at $P \leq 0.05$ according to LSD test.

Table 2 Effect of different concentrations of *Moringa oleifera* leaf extract on shoot length, shoot fresh weight and shoot dry weight in maize

Treatments	Shoot length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)
Control	$51.23^{d} \pm 1.25$	$11.86^{bc} \pm 0.85$	$0.02^{b} \pm 0.003$
Moringa oleifera leaf extract 2.5 %	$68.30^{a} \pm 1.95$	$24.97^{a} \pm 1.12$	$0.03^{a} \pm 0.004$
Moringa oleifera leaf extract 5 %	$64.30^{ab} \pm 1.75$	$21.22^{ab} \pm 0.97$	$0.01^{c} \pm 0.002$
Moringa oleifera leaf extract 7.5 %	$55.63^{cd} \pm 1.60$	$15.61^{b} \pm 0.88$	$0.01^{c} \pm 0.001$
Moringa oleifera leaf extract 10 %	$59.56^{bc} \pm 1.80$	$10.64^{c} \pm 0.72$	$0.01^{c} \pm 0.001$
Moringa oleifera leaf extract 12.5 %	$56.83^{cd} \pm 1.45$	$9.86^{c} \pm 0.68$	$0.02^{b} \pm 0.003$

Values are means ± standard deviation (SD). Means followed by different letters in a column differ significantly at $P \leq 0.05$ according to LSD test.

Table 3 Effect of different concentrations of *Moringa oleifera* leaf extract on leaf area index and crop growth rate in maize

Treatments	Leaf area index (20 DAG)	Leaf area index (40 DAG)	Crop growth rate (g m^{-2} day^{-1})
Control	$0.02^{b} \pm 0.002$	$0.10^{ab} \pm 0.015$	$18.39^{b} \pm 1.20$
Moringa oleifera leaf extract 2.5%	$0.03^{a} \pm 0.003$	$0.25^{a} \pm 0.020$	$24.31^{a} \pm 1.45$
Moringa oleifera leaf extract 5%	$0.01^{c} \pm 0.001$	$0.19^{b} \pm 0.012$	$10.39^{d} \pm 0.90$
Moringa oleifera leaf extract 7.5%	$0.01^{c} \pm 0.001$	$0.04^{c} \pm 0.005$	$9.56^{d} \pm 0.80$
Moringa oleifera leaf extract 10%	$0.01^{c} \pm 0.001$	$0.06^{abc} \pm 0.007$	$13.41^{cd} \pm 1.10$
Moringa oleifera leaf extract 12.5%	$0.02^{b} \pm 0.002$	$0.01^{cd} \pm 0.003$	$15.09^{bc} \pm 1.05$

DAG = Days after germination; Values are means ± standard deviation (SD). Means followed by different letters in a column differ significantly at $P \leq 0.05$ according to LSD test.

Root length (cm)

Table 4 presents data on root length, indicating both significant and non-significant variations among treatments with different concentrations of *M. oleifera* leaf extract on maize germination and physiology. The largest roots were observed in maize seedlings treated with *M. oleifera* leaf extract at 2.5 %, 7.5 %, and 10 %. These treatments were statistically comparable to each other and generally surpassed the control. Conversely, the minimum root length (21.66 cm) was recorded in seedlings treated with *M. oleifera* leaf extract at 5 %, which was statistically similar to the control treatment. These findings align with Khan et al. (2017) who described significant improvements in the agronomic traits of wheat due to *M. oleifera* application. Moreover, our results support earlier findings that increasing the concentration of herbal extract above an optimum level may suppress the germination and growth of crop plants, thereby reducing yield (Qayyum et al., 2018).

Table 4 Effect of different concentrations of *Moringa oleifera* leaf extract on chlorophyll contents, net assimilation rate and root length in maize

Treatments	Chlorophyll contents (20 DAG)	Chlorophyll contents (40 DAG)	Net assimilation rate (g m^{-2} day^{-1})	Root length (cm)
Control	$33.50^{abc} \pm 1.80$	$22.08^{c} \pm 1.25$	$0.29^{b} \pm 0.02$	$27.83^{b} \pm 2.10$
Moringa oleifera leaf extract 2.5%	$38.73^{a} \pm 2.05$	$41.46^{a} \pm 2.25$	$0.43^{a} \pm 0.03$	$49.66^{a} \pm 2.40$
Moringa oleifera leaf extract 5%	$35.77^{ab} \pm 1.95$	$37.03^{ab} \pm 2.10$	$0.27^{bc} \pm 0.02$	$21.66^{b} \pm 1.80$
Moringa oleifera leaf extract 7.5%	$33.24^{abc} \pm 1.70$	$28.08^{b} \pm 1.60$	$0.23^{bcd} \pm 0.02$	$48.93^{a} \pm 2.35$
Moringa oleifera leaf extract 10%	$33.50^{abc} \pm 1.85$	$30.30^{b} \pm 1.75$	$0.17^{d} \pm 0.01$	$49.13^{a} \pm 2.50$
Moringa oleifera leaf extract 12.5%	$29.52^{c} \pm 1.60$	$27.30^{bc} \pm 1.55$	$0.19^{cd} \pm 0.02$	$36.73^{ab} \pm 2.00$

DAG = Days after germination; Values are means ± standard deviation (SD). Means followed by different letters in a column differ significantly at $P \leq 0.05$ according to LSD test.

Conclusion

The present study investigated the differential effects of various *Moringa oleifera* leaf extract concentrations on maize germination and physiological parameters. Our results indicate that MLE concentrations of 2.5 % and 5 % significantly enhanced several key traits, including germination percentage, reduced days to emergence, leaf area index at both 20 and 40 days after germination, SPAD value at 20 days after germination, dry shoot weight, and root length. Specifically, crop growth rate and net assimilation rate were optimally improved in maize seedlings treated with 2.5 % MLE. Conversely, higher concentrations of *Moringa oleifera* leaf extract (7.5 %, 10 %, and 12.5 %) consistently exerted adverse effects on all assessed parameters in maize seedlings. These findings suggest an optimal application range for MLE to maximize maize physiological performance, with supra-optimal concentrations demonstrating inhibitory effects.

Declarations

i. Ethics approval and consent to participate

Ethical approval and informed consent were not required for this study as it did not involve human participants, human data, or animals.

ii. Consent for publication

Consent for publication is not applicable.

iii. Data availability

All data generated or analyzed during this study are included in this article.

iv. Competing interests

Authors have declared that no competing interests exist.

v. Authors' contributions

R.A. carried out the laboratory experiments and contributed to data collection. I.H. supervised the project. M.S.B. contributed to the experimental design and performed statistical analyses. U.K.S. assisted with experimental work, data interpretation, and literature review. A.A.K. contributed to methodology development. B.K. provided technical support and assisted in data validation. R.K. wrote the initial draft of the manuscript. All authors reviewed and approved the final version of the manuscript.

vi. Funding

No funding was received for the design, data collection, analysis, interpretation, or writing of this research manuscript.

vii. Acknowledgement

Not applicable.

viii. SDGs addressed

Zero Hunger, Responsible Consumption and Production, Climate Action, Life on Land

Publisher's note: All claims shared in this article are entirely those of the authors and do not reflect the positions of their affiliated institutions, the publisher, editors, or reviewers. Any mention or assessment of a product, as well as any claims made by its manufacturer, are not endorsed or guaranteed by the publisher.

References

Afzal, I., Basra, S. M. A., Shahid, M., & Saleem, M. (2008). Physiological enhancements of spring maize (*Zea mays* L.) under cool conditions. *Seed Science and Technology*, *36*, 497-503.

Afzal, I., Hussain, B., Basra, S. M. A., & Rehman, H. (2012). Priming with moringa leaf extract reduces imbibitional chilling injury in spring maize. *Seed Science and Technology, 40*(2), 271-276.

Ahmad, M., & Ahmad, S. (2018). Evaluation of insect pest infestation and yield losses in maize crop in Maina, district Malakand. *Advances in Agriculture and Biology, 1*(1), 34-39. https://doi.org/10.63072/aab.18005

Ahmed, A., & El-Mahdy, A. (2022). Improving seed germination and seedling growth of maize (*Zea mays* L.) seed by soaking in water and *Moringa oleifera* leaf extract. *Current Chemistry Letters*, *11*(2), 147-156.

Ali, A., Abbas, M. N., Maqbool, M. M., Arshad, M. I., Jan, M., Qayyum, A., & Lee, D. J. (2017). Optimizing the doses of *Moringa oleifera* leaf extract for salt tolerance in maize. *Philippine Journal of Crop Science, 42*(1), 1-12.

Ali, A., Abbas, M. N., Maqbool, M. M., Haq, T., Mahpara, S., Mehmood, R., & Lee, D. J. (2021). Optimizing the various doses of moringa (*Moringa oleifera*) leaf extract for salt tolerance in maize at seedling stage. *Life Science Journal*, *18*(7), 46-51.

Ali, S., Ahmad, N., Dar, M. A., Manan, S., Rani, A., Alghanem, S. M. S., Khan, K. A., Sethupathy, S., Elboughdiri, N., Mostafa, Y. S., Alamri, S. A., Hashem, M., Shahid, M., & Zhu, D. (2024). Nano-agrochemicals as substitutes for pesticides: Prospects and risks. *Plants, 13*(1), 109; https://doi.org/10.3390/plants13010109

Azam, M., Saeed, B., Khan, S., & Zafar, D. (2023). Exploring the effect of nitrogen levels on yield and yield attributes of diverse open-pollinated varieties (OPVs) of maize (*Zea mays*). *Advances in Agriculture and Biology, 6*(1), 61-68. https://doi.org/10.63072/aab.23008

Bacilio, J, M., Aguilar, F, S., Ventura, Z, E., Perez, C, E., Bouquelet, S., & Zenteno, E. (2003). Chemical characterization of root exudates from rice (*Oryza sativa*) and their effects on the chemotactic response of endophytic bacteria. *Plant and Soil, 249*(2), 271-277.

Bais, H. P., Weir, T. L., Perry, L. G., Gilroy, S., & Vivanco, J. M. (2006). The role of root exudates in rhizosphere interactions with plants and other organisms. *Annual Review of Plant Biology*, *57*, 233-266.

Balicevic, R., Ravlic, M., & Ravlic, I. (2015). Allelopathic effect of aromatic and medicinal plants on *Tripleurospermum inodorum* L. *Herbologia, 15*(2), 40-53.

Dhanai, C. S., Bharsakle, L., & Singh C. S. (2013). Allelopathic effect of different aqueous extract of *Acacia nilotica* on seed germination and growth of wheat. *Indian Forester*, *139*(11), 999-1002.

Elahi, M. E., Rehman, A., & Khan Babar, M. N. U. (2024). Economic analysis of rice crop cultivation in District Dera Ismail Khan. *Migration Letters, 21*(S13), 787–794.

Farooq, M., Basra, S. M. A., Wahid, A., & Ahmad, N. (2010). Changes in nutrient homeostasis and reserves metabolism during rice seed priming: consequences for seedling emergence and growth. *Agricultural Sciences in China*, *9*, 191-198

Gilani, S. A., Sugano, M., Fujii Y., & Watanabe, N. K. (2010). Chemotypic variations and phytotoxic studies of essential oils of endemic medicinal plant, *Seriphidium kurramense*, from Pakistan. *Journal of Medicinal Plants Research*, *4*, 309-315.

Ilory, J., Ilory, O. O., Sanni, R. O., & Adenegan-Alakinde, T. (2011). Effect of *Chromolaena odorata* on the growth and biomass accumulation of Celosia argentea. *Research Journal of Environmental Sciences, 5*, 200–204.

Jamilah, Suryani, I., Thesiwati, A. S., & Diyanti, A. (2024). Addition of urea fertilizer to crocober plus liquid organic fertilizer improves growth and yield of corn plants (*Zea mays* L.). *Advances in Agriculture and Biology, 7*(1), 1-7. https://doi.org/10.63072/aab.24001

Jeber, B. A., & Khaeim, H. M. (2019). Effect of foliar application of amino acids, organic acids, and naphthalene acetic acid on growth and yield traits of wheat. *Plant Archives*, *19*(2), 824-826

Kekere, O., Adeleke, G. P., Ajayi, O. M., Bulu, Y. I., Ekundayo, T. O., & Akinbuwa, O. (2024). Assessing the effect of carbide waste-contaminated soil on the growth and yield of maize (*Zea mays* L.). *Advances in Agriculture and Biology, 7*(1), 50-57. https://doi.org/10.63072/aab.24006

Khan, N., Shah, S.J., Rauf, T., Zada, M., Yukun, C., & Harbi, J. (2019) Socioeconomic impacts of the Billion Trees Afforestation Program in Khyber Pakhtunkhwa Province (KPK), Pakistan. *Forests*, *10*, 703-715.

Khan, S., Basit, A., Hafeez, M. B., Irshad, S., Bashir, S., Bashir, S., & Li, Y. (2021). Moringa leaf extract improves biochemical attributes, yield, and grain quality of rice (*Oryza sativa* L.) under drought stress. *Plos One*, *16*(7), 1-9.

Khan, S., Basra, S. M. A., Afzal, I., & Wahid, A. (2017). Screening of moringa landraces for leaf extract as bio stimulant in wheat. *International journal of Agriculture and Biology*, *19*, 999-1006.

Lefebvre, M., Maslianskaia-Pautrel, M., & Laille, P. (2022). Alternative adaptation scenarios towards pesticide-free urban green spaces: Welfare implication for French citizens. *Environmental Science & Policy*, *136*, 46-55.

Liu, Y., Wang, H., Qian, X., Gu, J., Chen, W., Shen, X., & Wei, G. (2023). Metagenomics insights into responses of rhizobacteria and their alleviation role in licorice allelopathy. *Microbiome*, *11*(1), 109.

Mahboob, W., Rehman, H., Basra, S. M. A., Afzal, I., Abbas, M. A., Naeem, M., & Sarwar, M. (2015). Seed priming improves the performance of late sown spring maize through better crop stand and physiological attributes. *International Journal of Agriculture and Biology*, *17*(3), 511-525.

Mehmood, K., Nasreen, S., Latif, A., & Shah, A. N. (2022). Growth of maize is improved by the combined use of natural and synthetic nutritional sources of potassium: A review. *Advances in Agriculture and Biology, 5*(1), 8-15. https://doi.org/10.63072/aab.22002

Mohamadi, N., & Rajaie, P. (2009). Effect of aqueous Eucalyptus (*E. camaldulensis* Labill) extracts on seed germination, seedling growth and physiological responses of *Phaseolus vulgaris* and *Sorghum bicolor*. *Research Journal of Biological Sciences*, *4*(12), 1291-1296.

Mona, H. S., Ahlam, H. H., Hamdah, A., & Shroug, S. A. (2017). Allelopathic effect of *Moringa oleifera* leaves extract on seed germination and early seedling growth of faba bean (*Vicia faba*). *International Journal of Agricultural Technology*, *13*(1), 105-117.

Mubashir, S., & Shah, W. A. (2011). Phytochemical and pharmacological review profile of *Adiantum venustum*. *International Journal of Pharm Technology and Research*, 3, 827-830.

Niyazi, M. M., Khan, Z. H., Khan, N. D., & Mular, S. M. (2017). Identification, purification, and characterization of bioactive compounds present in *Bridelia ferruginea* and *Piper umbellatum*. *International Journal Agricultural Research*, *3*(1), 557-559.

Odofin, O. (2010). *The effect of Azadirachta indica (Neem) extract and sodium hypochlorite pretreatment on germination, fungal growth and mitotic index of Abelmoschus esculentus L. (Okra)*. B.Sc. dissertation in Babcock University. Ogun, Nigeria. 253-265.

Patel, B., Achariya, B., & Bupripata, N. P. (2002). Allelopathic effects of Eucalyptus leaves on seed germination and seedling growth of winter wheat. *Proceeding Indian Society of Allelopathy*, *3*(1), 115-119.

Pinton, R., Varanini, Z., & Nannipieri, P. (2001). The rhizosphere, biochemistry and organic substances at the soil plant interface. Book by Marcel Dekker, New York. 235-248.

Powell, A. A., Yule, L. J., Jing, H., Groot, S. P. C., Bino, R. J., & Pritchard, H. W. (2000). The influence of aerated hydration seed treatment on seed longevity as assessed by the viability equations. *Journal of Experimental Botany, 51*, 2031–2043.

Qayyum, A., Rafiq, M. K., Zahara, K., Bibi, Y., Sher, A., Rafiq, M. T., & Manaf, A. (2018). Allelopathic effects of invasive *Prosopis juliflora* on grass species of Potohar Plateau, Pakistan. *Planta Daninha, 36*(2), 255–269.

Qureshi, H., Anwar, T., Fatima, S., Shirani, M., Riaz, S., & Liaquat, Z. (2024). Allelopathic effects of invasive plants (*Lantana camara* and *Broussonetia papyrifera*) extracts: Implications for agriculture and environmental management. *Allelopathy Journal*, *61*(2), 175-188.

Rehman, H., Nawaz, Q., Basra, S. M. A., Afzal, I., & Yasmeen, A. (2014). Seed priming influence on early crop growth, phenological development and yield performance of linola (*Linum usitatissimum* L.). *Journal of Integrative Agriculture, 13*(5), 990–996.

Rubab, S., Fayyaz, S., & Asmatullah. (2020). Plant parasitic nematodes associated with wheat and maize. *Advances in Agriculture and Biology, 3*(1), 8–17. https://doi.org/10.63072/aab.20002

Sarmin, N. S. (2014). Effect of *Moringa oleifera* on germination and growth of *Triticum aestivum*. *Journal of Bioscience and Agriculture Research, 2*(2), 59–69.

Shah, A. H., Zohra, L., Khan, K. R., Mehmood, A., & Farooq, M. (2018). Review on allelopathic effects of agriculture land associated plants on the different developmental stages of wheat crop. *International Journal of Biosciences, 12*(2), 8–13.

Shah, R. H., Baloch, M. S., Zubair, M., Khan, E. A., Ahmad, M., & Abbas, G. (2016). Phytotoxicity of different aqueous extract concentrations of mesquite (*Prosopis juliflora*) on germination and seedling growth of wheat. *Asian Journal of Agriculture and Biology, 4*(2), 25–32.

Shinwari, Z. K. (2010). Medicinal plants research in Pakistan. *Journal of Medicinal Plants Research, 4*(3), 161–176.

Sikolia, S. F., & Ayuma, E. (2018). Allelopathic effects of *Eucalyptus saligna* on germination, growth, and development of *Vigna unguiculata* L. *Journal of Environmental Science, 12*, 15–24.

Stamp, N. (2003). Out of the quagmire of plant defense hypotheses. *The Quarterly Review of Biology, 78*, 23–55.

Ullah, S., Jamil, S., Irum, A., Malik, A., & Gul, J. (2023). Assessing the role of maize cultivation in poverty alleviation, food security and employment generation in rural areas. *Indus Journal of Animal and Plant Sciences*, *1*(01), 8-13.

Vernon, A. J. (1963). A method of calculating net assimilation rate. *Nature, 200*(4908), 814. https://doi.org/10.1038/200814a0

Vijayan, V. (2015). Evaluation for allelopathic impact of *Acacia auriculiformis* A. Cunn. Ex Benth on seed germination and seedling growth of rice (*Oryza sativa* L), a widely cultivated Indian crop species. *Research Journal of Agriculture and Forestry Sciences, 3*(1), 1-5.

Waqas, M. A., Khan, I., Akhter, M. J., Noor, M. A., & Ashraf, U. (2017). Exogenous application of plant growth regulators induces chilling tolerance in short-duration hybrid maize. *Environmental Science and Pollution Research International*, *24*(12), 11459-11473.

Yasmeen, A., Basra, S. M. A., Wahid, A., Nouman, W., & Rehman, H. (2013). Exploring the potential of *Moringa oleifera* leaf extract as a seed priming agent in improving wheat performance. *Turkish Journal of Botany, 37*, 512-520.

Zhang, R., Vivanco, J. M., & Shen, Q. (2017). The unseen rhizosphere root–soil– microbe interactions for crop production. *Current Opinion in Microbiology*, *37*, 8-14.

Zia, M. A., Shoukat, S., Arif, M., Ahmad, B., Nawaz, A. F., Bahadur, A., Zakria, M., Khan, H. S., Khan, S., Suleman, M., & Ali, S. (2023). A discussion on maize transformation during the last two decades (2002–2022): An update on present trends and future prospects. *Advances in Agriculture and Biology, 6*(1), 1-10. https://doi.org/10.63072/aab.23001

Copyright: © 2025 by the author(s). This open access article is distributed under a Creative Commons Attribution License (CC BY 4.0), https://creative- commons.org/licenses/by/4.0/