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Effects of Gibberellic Acid (Ga) Concentration and Soaking Duration on Seed Physiological Quality and Agronomic 3 Attributes of Maize Inbred Line (Zea Mays L.) Under Irrigation Condition in Bahir Dar, North Western Ethiopia

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BAHIR DAR UNIVERSITY
COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES
DEPARTMENT OF PLANT SCIENCES
EFFECTS OF GIBBERELIC ACID (GA_3) CONCENTRATION AND SOAKING
DURATION ON SEED PHYSIOLOGICAL QUALITY AND AGRONOMIC
ATTRIBUTES OF MAIZE INBRED LINE (*Zea mays* L.) UNDER IRRIGATION
CONDITION IN BAHIR DAR, NORTH WESTERN ETHIOPIA

M.Sc. Thesis

By

Yemataw Chanie Haile

March 2025

Bahir Dar, Ethiopia



BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

GRADUATE PROGRAM IN SEED SCIENCE AND TECHNOLOGY

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By

Yemataw Chanie Haile

**SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE (MSc.) IN SEED SCIENCE AND
TECHNOLOGY**

Mach 2025

Bahir Dar, Ethiopia

THESIS APPROVAL SHEET

As a member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by Mr. Yemataw Chanie Haile entitled "Effects of Gibberellic Acid (GA₃) Concentration and Soaking Duration on Seed Physiological Quality and Agronomic Attributes of Maize Inbred Line (*Zea mays* L.) Under Irrigation Condition in Bahir Dar, North Western Ethiopia". We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Science (M.Sc.) in Seed Science and Technology.

Board of Examiners

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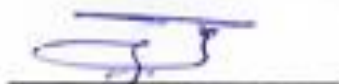
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The research presented in this thesis results from independent investigation and experimentation conducted by Mr. Yemataw Chanie. It has not been previously submitted for the award of any other degree or diploma, and the findings are original to this study. The methodology, analysis, and conclusions drawn are the candidate's work, and the thesis represents an independent contribution to Seed Science and Technology.

Date _____

Date _____

Date _____

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DEDICATION

This work is dedicated to my beloved daughter, Hana Yemataw. You are the light of my life and my greatest inspiration. Your presence fills me with the strength and motivation to strive for success every day. I hope this achievement serves as a reminder that with determination, hard work, and belief in oneself, anything is possible. Everything I do is for your future, and I am endlessly proud to be your father.

ABBREVIATIONS AND ACRONYMS

AARC	Adet Agricultural Research Center
ABA	Absciscic Acid
ANOVA	Analysis of Variance
AOSA	Association of Official Seed Analysis
BH	Bako Hybrid
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CML	CIMMYT Line
CSA	Central Statics Agency
EGS	Early Generation Seed
EIAR	Ethiopian Institute of Agricultural Research
GA ₃	Gibberellic Acid
IAA	Indole Acetic Acid
ISSSE	Institutional Support for Seed System in Ethiopia
ISTA	International Seed Testing Association
OPVs	Open-Pollinated Varieties
PCA	Principal Component Analysis
PEG	Poly Ethylene Glycol
PGRs	Plant Growth Regulators

Effects of Gibberellic Acid Concentration and Soaking Duration on Seed Physiological Quality and Agronomic Attributes of Maize Inbred Line (*Zea Mays L.*) Under Irrigation Condition in Bahir Dar, North Western Ethiopia

By: Yemataw Chanie

Major advisor: Dr. Dereje Ayalew

ABSTRACT

The seed yield of hybrid maize varieties relies on the traits of their parental inbred lines. However, inbred lines are susceptible to environmental factors due to inbreeding challenges in field establishment, stand uniformity, and yield. To address these challenges, the laboratory experiment was conducted at Adet, and the field experiment was conducted at Bahirdar under irrigation conditions to evaluate the effects of GA₃ concentrations and soaking durations on seed physiological quality and agronomic attributes of maize inbred line. Treatments comprised a factorial combination of four GA₃ concentrations (0 ppm, 75 ppm, 150 ppm, and 225 ppm) and three soaking durations (12, 18, and 24 hours). The laboratory experiment was laid out in a completely randomized design with four replications, while the field experiment was laid out in a randomized complete block design with three replications. Results indicated that the main effect of GA₃ concentrations and soaking durations significantly influenced seed physiological quality, yield, and yield components; however, their interaction was non significant. The highest germination (95.25%, 94.31%), seedling vigor index (2842.30, 2499.63), and seed yield (4.22 t/ha, 3.44 t/ha) were achieved with 225 ppm GA₃ and 24-hour soaking, respectively, while reducing 50% maturity time (132.33, 134.83 days). The combined effect of 225 ppm GA₃ + 24 hours gave the highest emergence index (3.71) and shortest mean emergence time (6.12 days). The partial budget analysis confirmed the feasibility of treating seeds with 225 ppm GA₃, yielding a net benefit of 510,293.16 ETB/ha and a marginal rate of return of 1,420.06%. Similarly, a 24-hour soaking duration resulted in the highest net benefit (427,705.44 ETB/ha) and marginal rate of return (11,524.76%). In conclusion, 225 ppm GA₃ concentration and 24-hour soaking duration enhanced seed quality, field emergence, yield, and yield components. These findings recommend adopting these treatments for sustainable inbred line seed production; however, further research is needed to confirm consistency and applicability by repeating field experiments across multiple years and locations.

Keywords:- field emergence, yield, yield components, partial budget analysis.

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Chapter 1. INTRODUCTION

1.1. Background and Justification

Maize (*Zea mays L.*) is a critical food crop in Ethiopia, playing a pivotal role in the country's agricultural sector. It serves as a primary source of livelihood for a significant portion of the population and contributes substantially to the national economy (Yirga Chilot *et al.*, 2020). During the 2021/22 main cropping season, maize production covered approximately 2.56 million hectares, yielding nearly 10.75 million tons and involving 11.17 million farmers. Cereals accounted for 88.69% of Ethiopia's total grain production, with maize contributing 32.79% of cereal production, followed by wheat, teff, and sorghum (CSA, 2022).

In the Amhara region, maize production spanned approximately 0.6 million hectares during the same season, producing around 2.64 million metric tons. Specifically, the West Gojam Zone cultivated maize on 0.24 million hectares, yielding 1.11 million metric tons (CSA, 2022). Despite its importance, maize productivity in Ethiopia remains below its potential (8 t/ha) due to factors such as poor seed quality, suboptimal agronomic practices, and environmental stresses like drought and soil fertility depletion (Sisay Debebe *et al.*, 2022; Dagmawe Menelek *et al.*, 2024).

Hybrid maize production relies on the systematic cross-pollination of parental inbred lines, which is critical for achieving high yields and performance in hybrid varieties (Pinnisch *et al.*, 2012; MacRobert *et al.*, 2014). However, maize inbred lines are highly susceptible to environmental stresses due to the negative effects of inbreeding, resulting in poor field establishment, stunted growth, reduced vigor, and lower yields (Achrem *et al.*, 2023; Merrick *et al.*, 2023). Additionally, the maturity period of inbred lines produced under irrigation often coincides with the rainy season, leading to potential seed quality issues (Personal observation).

To address these challenges, seed priming with gibberellic acid (GA₃) has emerged as a promising technique to enhance germination, crop establishment, and seed yield under both normal and stressful conditions (Ghodrat *et al.*, 2012; Berhanu Abraha and Melkamu Andargie, 2018; Getahun Bekele *et al.*, 2024). Gibberellic acid (GA₃), a plant growth regulator, plays a significant role in seed germination, stem elongation, and flowering

(Camara *et al.*, 2018). Gibberellic acid (GA₃) seed priming has been shown to enhance seed physiological quality by promoting germination, breaking seed dormancy, and improving seedling vigor (Khan *et al.*, 2017). Gibberellic acid (GA₃) seed priming has been shown to accelerate germination, promote uniformity, and enhance seedling vigor, even under variable environmental conditions (Nada and Hamza, 2018). Additionally, GA₃ priming improves yield components such as cob number, cob length, and kernel weight, leading to increased overall yield (Ma *et al.*, 2018). It also optimizes water use efficiency, enabling superior water uptake and utilization by plants (Kaya C *et al.*, 2006; Arun *et al.*, 2017; El-Sanatawy *et al.*, 2021). Gibberellic acid (GA₃) promotes balanced hormonal activity, ensuring uniform cell division and elongation, which contributes to synchronized growth stages and consistent maturity across the field (Castro-Camba *et al.*, 2022). Additionally, GA₃ enhances photosynthetic efficiency by increasing leaf expansion and chlorophyll synthesis while also improving reproductive development, resulting in higher kernel numbers and weight (Hakla *et al.*, 2021). Abebe Chindi and Tekalign Tsegaw (2019) reported that gibberellic acid (GA₃) application increased sprout number and vigor, leading to better vegetative growth.

While gibberellic acid (GA₃) has demonstrated the potential to improve seed physiological quality, field emergence, and yield, its efficacy depends on factors such as concentration, soaking duration, seed quality, and plant species (Kaya M.D. *et al.*, 2024). Studies have demonstrated that optimal concentrations of GA₃ can significantly enhance germination percentage, vigor, and speed, which are critical for successful crop establishment and yield performance (Hussien *et al.*, 2019).

Furthermore, optimal soaking period enhances water absorption, activating metabolic processes that break seed dormancy and accelerate germination (Nadeem *et al.*, 2017). This early hydration boosts root and shoot development, allowing seedlings to establish more quickly and efficiently absorb nutrients and water from the soil (Mosavian and Esmaeilzade, 2016). Optimal durations allow seeds to absorb sufficient GA₃, enhancing water uptake, enzyme activity, and germination rates under both normal and stress conditions (Ayaz *et al.*, 2019). Properly managed soaking durations ensure better crop establishment, uniformity, and yield improvements (Adhikari *et al.*, 2021).

The growing demand for hybrid maize seed in Ethiopia, particularly in the Amhara region, has prompted regional and national seed enterprises, cooperatives, unions, and private

seed producers to engage actively in hybrid maize seed production. This has, in turn, increased the demand of maize inbred lines (Anteneh Mekuria *et al.*, 2024). To meet this demand, enhancing the physiological quality of maize seeds through GA₃ treatment could provide a viable solution to increase the productivity of maize inbred line (Getahun Bekele *et al.*, 2024). Therefore, optimizing GA₃ concentration and soaking duration is critical for enhancing seed quality, field emergence, and yield in maize inbred line.

1.2. Statement of the Problem

Maize inbred lines are essential for hybrid seed production; however, due to the deleterious effects of inbreeding, they often exhibit stunted growth, reduced vigor, thinner stalks, smaller tassels and ears, and lower yields (Yao *et al.*, 2020; Han *et al.*, 2021). These physiological limitations result in poor field establishment, uneven stand uniformity, and ultimately, reduced yields. It also significantly hinders maize inbred line seed production (Getahun Bekele *et al.*, 2024).

To address these challenges, an effective and practical solution is needed to enhance seedling vigor, improve stand uniformity, optimize yield potential, and reduce the maturity period under irrigation conditions. Gibberellic acid (GA₃) priming has shown promise in promoting seed germination, stimulating seedling growth, and enhancing overall plant development. Previous studies have demonstrated its potential benefits across various crop species, including maize. For instance, Berhanu Abraha and Melkamu Andargie (2018) reported that seed priming with gibberellic acid (GA₃) significantly improved the germination percentage, reduced mean germination time, and increased shoot and root length, thereby alleviating the negative impacts of salinity on *Zea mays* L., *Pisum sativum* Var. *abyssinicum* A. Braun, and *Lathyrus sativus* L.. Similarly, Getahun Bekele *et al.* (2024) found that priming maize inbred line seeds with GA₃ at 200 ppm for 36 hours significantly improved the germination index and vigor index I while also reducing mean germination time. Under field conditions, Sarwar *et al.* (2017) reported that 150 mg/L GA₃ was most effective in enhancing maize growth parameters when applied at key developmental stages. Additionally, Shahzad *et al.* (2021) demonstrated that GA₃ priming at 100 ppm, combined with foliar application, enhanced maize growth and mitigated oxidative stress in salt-contaminated soils. Despite these advancements, most studies have been conducted under laboratory conditions or through foliar applications, with limited focus on field conditions. Specifically, there is insufficient empirical evidence on the

optimal GA₃ concentrations and soaking durations required to improve seed quality and yield components of maize inbred lines under the agroecological conditions of Bahir Dar, North Western Ethiopia. Addressing this knowledge gap is critical for improving maize productivity and ensuring a sustainable supply of high-quality early-generation seeds of maize inbred lines in the region.

1.3. Objectives of the Study

1.3.1. General objective

To investigate the effects of gibberellic acid (GA₃) concentration and seed soaking duration on seed physiological quality and agronomic performance of maize inbred line (*Zea mays L.*) under irrigated conditions in Bahir Dar, North Western Ethiopia.

1.3.2. Specific Objectives

- ✚ To evaluate the impact of varying concentrations of GA₃ on seed physiological quality, field emergence, yield, and yield components.
- ✚ To evaluate the impact of different soaking durations on seed physiological quality field emergence, yield, and yield components.
- ✚ To evaluate the interaction effect of GA₃ concentration and soaking duration on seed physiological quality, field emergence, yield, and yield components
- ✚ To determine the economic feasibility of GA₃ application and soaking duration in maize inbred line seed production.

Chapter 2. LITERATURE REVIEW

2.1. Origin, Distribution, and Economic Importance of Maize

Maize, believed to have originated in the Americas, was introduced to Ethiopia and Africa during the colonial era. Its presence in Ethiopia traces back several centuries, likely brought by Portuguese traders during the early 16th century. The crop gradually spread across the country, adapting to various agroecological zones due to its versatility and ability to thrive in diverse climates (Tsedeke Abate *et al.*, 2015). While the timing and mode of maize introduction to tropical Africa cannot be definitively established, it is widely accepted that maize arrived in Ethiopia slightly later, around the late 17th century. This historical context underscores the enduring significance of maize in Ethiopia's agricultural landscape and its pivotal role in food security and production systems (Tsedeke Abate *et al.*, 2015).

Ethiopia boasts a wide distribution of maize cultivation, spanning various regions with distinct agroecological conditions. It is grown extensively in highland areas, mid-altitude regions, and some lowland zones, demonstrating its adaptability to diverse environments. The crop's cultivation spans from the northern highlands of Tigray to the southern areas of Oromia and the Rift Valley, showcasing its importance and widespread adoption among Ethiopian farmers (Tsedeke Abate *et al.*, 2015; Rashid *et al.*, 2019; Mesay Yami *et al.*, 2020).

The Amhara region of Ethiopia significantly contributes to the nation's total annual maize production. According to a report on the maize value chain analysis for Mecha District, the Amhara region contributes 25% of the total national maize production, with Mecha Woreda alone contributing 26.7% to West Gojam, 13% to Amhara, and 3% to national maize production. Maize is an important cereal crop in Ethiopia, and about 82% of maize production is produced in Ethiopia's Amhara and Oromia regions (Mesay Yami *et al.*, 2020).

Maize is a staple food crop in Ethiopia, providing a substantial portion of the daily caloric intake for millions of Ethiopians. In the Amhara region, maize is a primary food source for many households, forming the base of their diets. Its cultivation and consumption

significantly contribute to food security in both rural and urban areas(Mesay Yami *et al.*, 2020).

Maize production serves as a vital component of the agricultural economy in Ethiopia, including the Amhara region. It's a major cash crop for many smallholder farmers, providing income through sales in local markets and beyond. Additionally, it supports livelihoods and creates employment opportunities along the maize value chain, from farming and harvesting to transportation and trade(Rashid *et al.*, 2019). Maize provides essential nutrients like carbohydrates, fiber, vitamins, and minerals, contributing significantly to the nutrition of Ethiopians. It plays a crucial role in addressing malnutrition and ensuring a balanced diet for many households (MasreshaTessema *et al.*, 2016; Rashid *et al.*, 2019; Marennya *et al.*, 2022).

Cereal production in Ethiopia plays a critical role in the agricultural sector, with cereals occupying 69.1% of the total area coverage in 2022, which equates to approximately 9.9 million hectares (CSA, 2022). In the same year, cereals contributed 71.2% of the total grain production, amounting to 21.5 million tons. Among cereals, maize stands out as the leading crop in terms of production. It accounted for 32.79% of the total cereal production, producing approximately 10.2 million tons from an area of about 2.55 million hectares, with an average yield of 4 tons per hectare (CSA, 2022).

In the Amhara region, maize production plays a significant role in the agricultural landscape. During the same season, maize was cultivated on approximately 600,000 hectares, yielding around 2,640,000 metric tons (CSA, 2022). Notably, the West Gojam Zone emerged as a key contributor to maize production in the region, with cultivation spanning 240,000 hectares and producing an impressive 1,110,000 metric tons.

2.2. Hybrid Maize Production and Challenges in Ethiopia

Hybrid maize varieties have shown remarkable potential in significantly increasing yields compared to traditional varieties. These hybrids are bred to exhibit desirable traits such as high yield potential, disease resistance, and adaptability to local agro-climatic conditions. As a result, farmers in the Amhara region have experienced increased productivity per hectare of land cultivated with hybrid maize (Krishna *et al.*, 2021; Marennya *et al.*, 2022).

In Ethiopia, maize hybrid production has been a significant focus, with the Ethiopian Institute of Agricultural Research (EIAR) and the International Maize and Wheat Improvement Center (CIMMYT) collaborating to develop and release more than 40 improved varieties of maize, including hybrids and open-pollinated varieties (OPVs), since the mid-1990s. These improved varieties have contributed to substantial increases in productivity and incomes of adopting farmers in Ethiopia (Krishna *et al.*, 2021). The maize breeding system in Ethiopia, organized around four major agro-ecological zones, has led to the development of a total of 61 different maize varieties, including hybrids and composites, with more than 68 different maize varieties released in more recent years (Marenja *et al.*, 2022). BH661, BH546, and BH549 are prevalent hybrid maize varieties in the Amhara region, designed to tackle the hurdles confronting farmers, such as boosting yields, navigating environmental pressures, and securing food sources. Widely distributed via agricultural extension initiatives, seed dispersal schemes, and partnerships involving research bodies, seed corporations, and governmental entities, these hybrids play a pivotal role in fortifying maize farming's productivity and resilience within the region (Mosisa Worku *et al.*, 2009; Marenja *et al.*, 2022).

Maize production in Ethiopia faces several significant challenges that impact its efficiency and effectiveness in meeting the growing demand for hybrid maize. A primary issue is the shortage of basic seeds, which are essential for producing certified hybrid seeds; this shortage stems from both public and private sector constraints, with the public sector accounting for about 60% of hybrid seed production but struggling with inconsistent planning and financial limitations (Dawit Alemu and Tripp, 2010). Additionally, the profitability of inbred line seed production is relatively low compared to certified hybrid seed production, discouraging investment and participation from seed producers (Megersa Debele and Belay Taressa, 2023). Concerns over genetic purity and quality also arise, as many seed producers cannot maintain the necessary standards, leading to the multiplication of poor-quality seeds (CIMMYT, 1999). Furthermore, the seed production system is characterized by inefficiencies, high costs, and limited competition, with a market dominated by a few varieties, which restricts farmers' access to diverse and high-quality seeds (Dawit Alemu and Tripp, 2010; Worku Mosisa *et al.*, 2011). In types of hybrid seed production where one or both parents are inbred lines, extra care needs to be taken with those lines, which tend to be weak and more susceptible to environmental stresses (MacRobert *et al.*, 2014).

The maize seed market in Ethiopia is characterized by limited competition and a narrow selection of available varieties. This situation results in excessively high production costs for maize seeds, further limiting farmers' access to improved varieties. Despite the existence of improved seeds developed for specific agroecologies, their dissemination remains inadequate due to these market limitations (Worku Mosisa *et al.*, 2011).

Environmental conditions play a significant role in yield variability. Factors such as soil fertility, moisture availability, and climatic conditions can adversely affect the growth and development of maize parental lines. Inconsistent rainfall patterns and drought conditions, which are common in many regions of Ethiopia, can lead to reduced germination rates and lower yields (Dawit Alemu and Tripp, 2010; Asefa G *et al.*, 2024).

The synchronization of flowering between male and female parental lines is essential for effective pollination and seed set. In Ethiopia, there are often discrepancies in flowering times between different parental lines, which can lead to poor pollination and lower seed yields. Studies have shown that when female parents flower significantly earlier than male parents, it can result in reduced seed production due to ineffective fertilization (Asefa G *et al.*, 2024).

2.3. Importance of Seed Priming

Seed priming is a pre-sowing treatment that involves partially hydrating seeds until germination processes begin without radical emergence, followed by drying them back to their original moisture content (Devika *et al.*, 2021). This creates a physiological state that enables more efficient germination once the seeds are sown.

There are several methods of seed priming, each with distinct mechanisms. Osmopriming uses osmotic solutions like polyethylene glycol (PEG) or salts to control water uptake, allowing seeds to imbibe water while preventing radicle protrusion. This method enhances metabolic processes and improves germination rates under stress conditions, making it effective for various crops (Lutts *et al.*, 2016; Devika *et al.*, 2021). Hydropriming, on the other hand, simply involves soaking seeds in water for a set duration before drying them back to their original moisture content. This straightforward technique is cost-effective and environmentally friendly, promoting faster and more uniform germination while repairing metabolic damage caused by desiccation (Tanwar *et al.*, 2023). Hormonal priming utilizes plant growth regulators such as gibberellic acid (GA₃) or abscisic acid

(ABA) to stimulate growth and enhance seed performance, particularly under adverse conditions (Ali Adam *et al.*, 2021). Bio priming combines hydration with beneficial microorganisms, which can improve seedling growth and stress tolerance by activating specific signaling pathways that enhance plant defense mechanisms (Devika *et al.*, 2021). Lastly, nutritional priming enriches seeds by soaking them in nutrient-rich solutions, which can lead to improved nutrient uptake and enhanced growth rates once germination occurs (Nciizah *et al.*, 2020).

The importance of seed priming lies in its ability to enhance seed performance and crop establishment. It speeds up germination, leading to faster and more uniform emergence, which is critical for optimal plant growth and yield. Primed seeds often exhibit improved tolerance to environmental stresses like drought, salinity, and temperature fluctuations, enabling them to perform better in suboptimal conditions (Lutts *et al.*, 2016; Devika *et al.*, 2021). Furthermore, seed priming increases seedling vigor, resulting in stronger root and shoot development, while also enhancing disease resistance by activating early plant defense mechanisms. Overall, seed priming significantly boosts agricultural productivity and ensures greater crop resilience (Marthandan *et al.*, 2020; Amir *et al.*, 2024).

Hormonal seed priming is an effective technique that uses plant growth regulators to enhance seed germination, seedling growth, and crop yield, especially under adverse environmental conditions. It activates pre-germinative metabolic processes, leading to faster and more uniform emergence, increased tolerance to abiotic stresses like drought and salinity, and improved nutrient uptake, resulting in more vigorous seedlings and boosting yields by up to 45% in crops like mung bean and wheat under stress (Rhaman *et al.*, 2020). Hormonal priming also enhances antioxidant enzyme activity, decreases oxidative damage, and contributes to sustainable agriculture as a low-cost, simple technique requiring only small amounts of plant growth regulators while reducing the need for pesticides and fertilizers (Lutts *et al.*, 2016; Marthandan *et al.*, 2020).

2.4. Gibberellic Acid (GA₃) and Its Role in Plant Growth and Development

Phytohormones are a chemically diverse set of compounds that regulate plant development at micromolar concentrations. Hormone synthesis, transport, and degradation are tightly controlled because minor variations of their levels in tissues can have a huge impact on plant responses as they play important roles in the regulation of gene expression or the

activity of other hormones (Castro-Camba *et al.*, 2022). Plant growth regulators (PGRs) are small chemical messenger molecules that influence growth, physiological and biochemical features, and plant genotypic functions (Shah *et al.*, 2023).

Gibberellic acid (GA), a plant hormone stimulating plant growth and development, is a tetracyclic di-terpenoid compound. GAs stimulate seed germination, trigger transitions from meristem to shoot growth, juvenile to adult leaf stage, vegetative to flowering, and determine sex expression and grain development along with an interaction of different environmental factors viz., light, temperature, and water (Ramwant and SK, 2013). Gibberellic acid has been found to have profound effects on plant growth, including increased inter-node extension, increased leaf growth, and enhanced apical dominance (Brian, 1959). Gibberellic acid can also induce bolting and flowering in some rosette species and rescue dwarf mutants of maize and peas (Hedden and Sponsel, 2015).

Gibberellic acid (GA) plays a significant role in maize growth and development. The exogenous application of GA₃ has been found to enhance the growth and salinity stress tolerance of maize by modulating morpho-physiological, biochemical, and molecular attributes (Shahzad *et al.*, 2021). Gibberellic acid application has also been found to improve water stress tolerance in maize plants by maintaining membrane permeability, enhancing chlorophyll concentration, leaf relative water content, and some macro-nutrient concentrations in leaves (Kaya C *et al.*, 2006). Gibberellic acid can increase plant height, leaf growth, and apical dominance and rescue dwarf mutants of maize. Furthermore, GA can increase the number and size of seeds, which can lead to increased crop yield. Therefore, the use of GA in maize farming can be an effective tool for improving maize growth and development, reducing oxidative stress, and increasing crop yield (Kaya C *et al.*, 2006; Fu *et al.*, 2023). Gibberellic acid in maize farming under irrigation conditions can be an effective tool for improving maize growth and development, reducing oxidative stress, and increasing crop yield, which can ultimately lead to improved water use efficiency (Sarwar *et al.*, 2017).

2.5. Effects of GA₃ Seed Priming on Seed Physiological Quality

Seed physiological quality refers to the intrinsic attributes of seeds that determine their capacity to germinate and emerge rapidly, producing a uniform stand of vigorous plants under various field conditions (Delouche, 1985). It encompasses attributes like

germination rate, vigor, storability, and uniformity, as well as the seed's ability to perform under stress (Gupta *et al.*, 2022; Reed *et al.*, 2022).

Gibberellic Acid (GA₃) seed priming can improve seed germination and seedling growth. It is a plant growth regulator that can promote seed germination and seedling growth. When seeds are primed with GA₃, it activates the enzymes responsible for breaking down the stored food reserves in the seed, which provides the energy required for germination and early seedling growth (Pallaoro *et al.*, 2016). Gibberellic Acid (GA₃) also promotes the synthesis of proteins and nucleic acids, which are essential for cell division and elongation, leading to faster and more vigorous growth of the seedlings (Ma *et al.*, 2018; Nada and Hamza, 2018). The duration of soaking plays a critical role in determining the effectiveness of GA₃ treatment. Optimal soaking times lead to improved seed vigor, faster germination rates, and higher seedling uniformity (Saeedipour, 2013; Setiawan, 2022). However, prolonged soaking durations beyond the optimal range can have detrimental effects, such as reduced seed viability and increased susceptibility to fungal infections. This is likely due to excessive water absorption and oxygen deprivation in seeds (Setiawan, 2022).

According to Gnawali and Subedi (2021), the mean germination time was significantly decreased with GA₃ treatment. Specifically, seeds treated with 100 ppm GA₃ showed a reduction of 35 hours in mean germination time under the most severe drought condition (1.75 MPa) compared to non-primed. Priming seeds of maize with 0.2 g/L GA₃ significantly improved germination percentage, reduced mean germination time, increased shoot and root length, and total weight of the crops when the salinity level is less than 8 dS/M (Berhanu Abraha and Melkamu Andargie, 2018). A study investigated the effect of seed priming agents (GA₃, PEG, hydropriming) on the early development of maize. The results showed that GA₃ seed priming significantly increased germination percentage, root and shoot lengths, seedling vigor index, and relative water content while decreasing the mean germination time of maize seeds (Supral and Roshan, 2022). Another study evaluated the potential of seed priming treatments in improving the performance of early planted maize. The results showed that GA₃ seed priming significantly improved the early seedling vigor, growth, and productivity of spring maize (ur Rehman *et al.*, 2015). According to Setiawan (2022), a GA₃ concentration of 200 ppm effectively reduced dormancy intensity (12.22%) and significantly enhanced maximum growth potential

(87.78%) in oil palm seeds. Gibberellic Acid (GA₃) priming at a concentration of 0.2 g/L significantly improves seed quality parameters. Specifically, it increases the mean germination rate to 90% and the seedling vigor index to 3082.05 (Venkata *et al.*, 2023).

2.6. Effects of GA₃ Seed Priming Field Emergence

Field emergence refers to the process by which maize seeds sprout and successfully establish seedlings under field conditions. It is a critical factor in maize production, as strong and uniform seedling emergence directly impacts plant population density, which in turn influences overall crop yield (Albarenque *et al.*, 2023). Seed priming in maize offers several benefits for field emergence, ultimately contributing to improved crop performance and yield. Seed priming can result in better seedling emergence, uniform stand establishment, earlier flowering, and ultimately, better crop yields (ur Rehman *et al.*, 2015).

Multiple studies have consistently highlighted the remarkable benefits of GA₃ seed priming across various crops, showcasing significant enhancements in germination percentage, seedling emergence, and early seedling vigor. Treated seeds consistently display augmented root and shoot length, amplified seedling biomass, and notably improved overall plant performance in comparison to untreated controls (Berhanu Abraha and Melkamu Andargie, 2018; Ma *et al.*, 2018; Shahzad *et al.*, 2021; Supral and Roshan, 2022). The application of GA₃ seed priming demonstrates promise in alleviating the detrimental impacts of abiotic stresses on both seed germination and emergence. Extensive research underscores that seeds treated with GA₃ exhibit heightened resilience to adverse conditions such as salinity, drought, low temperatures, and toxicity from heavy metals, consequently resulting in markedly improved field emergence rates when exposed to these stressors (Ma *et al.*, 2018; Nada and Hamza, 2018; Shahzad *et al.*, 2021). Furthermore, investigations suggest that GA₃ seed priming contributes to a reduction in the germination and emergence period of seeds in the field. This accelerated pace of germination proves advantageous, particularly in crops where early establishment plays a pivotal role in optimizing yields. Gibberellic acid seed priming has demonstrated the capability to promote faster and more uniform germination of maize seeds (Berhanu Abraha and Melkamu Andargie, 2018; Shahzad *et al.*, 2021). Treatment with GA triggers the activation of enzymes responsible for breaking dormancy, leading to quicker and more synchronized seedling emergence. This enhancement in germination and field

establishment can contribute to a more uniform stand, reducing the risk of uneven plant growth and ultimately improving crop yield potential (Supral and Roshan, 2022).

One of the notable benefits of GA seed priming is its potential to hasten the maturity time of many plant species, including maize. Primed seeds tend to exhibit earlier flowering and shorter time to maturity compared to non-primed seeds. This acceleration in the growth and reproductive phases can be advantageous, especially in regions with shorter growing seasons or where early maturation is necessary to avoid adverse environmental conditions during the latter stages of crop development (Shahzad *et al.*, 2021; Supral and Roshan, 2022). According to Hamza and Ali (2017) the concentration of 300 ppm GA₃ has shown positive effects on the emergence and seedling growth of maize under salt stress.

2.7. Effect of Soaking Duration on Seed Physiological Quality and Field Emergence

The duration of seed soaking is a critical factor that influences seed physiological quality and field emergence (Nadeem *et al.*, 2017). Soaking seeds in GA₃ solutions enhances water uptake and accelerates metabolic processes, leading to improved seed vigor and uniformity (Kaya C *et al.*, 2006). Research has shown that soaking seeds can enhance germination rates and reduce the time to emergence. For instance, a study on wheat seeds found that soaking duration significantly affected seed weight increase and emergence. Seeds soaked for 12 hours showed the highest germination rate, while longer soaking times resulted in decreased emergence, with only 55% emergence after 24 hours (Murungu, 2011). Ali and Hamza (2017) showed that soaking corn seeds in a 300 ppm concentration of GA₃ for 24 hours significantly improved emergence and seedling growth under salt stress. Specifically, the treatment enhanced attributes such as emergence rate, seedling length, and seedling dry weight. Khan *et al.* (2017) also reported that seeds treated with gibberellic acid (GA₃) PEG-6000 and hydropriming with distilled water for 24 hours gave higher germination percentage.

2.8. The Interaction Effect of GA₃ Concentrations and Soaking Duration on Seed Physiological Quality and Field Emergence Parameters

Thakur *et al.* (2025) found that priming sunflower seeds with 100 ppm GA₃ for 12 hours significantly enhanced seed germination (92.50%), speed of germination (56.54), seedling length (28.20 cm), seedling fresh weight (582.20 mg), seedling dry weight (28.96 mg),

Seed Vigor Index I (2607.72), Seed Vigor Index II (2678.51), and oil content (43.99%). Getahun Bekele *et al.* (2024) showed that priming seeds with 200 ppm GA₃ for 36 hours improved germination index and vigor index while reducing mean germination time. Hamza and Ali (2017) found that soaking corn seeds with GA₃ significantly improved emergence and seedling growth under salt stress conditions. They recommended soaking seeds in 300 ppm GA₃ for 24 hours before planting in salty lands. This treatment enhanced germination rates, reduced the time to emergence, and increased seedling length and dry weight compared to untreated seeds., Berhanu Abraha and Melkamu Andargie (2018) reported similar improvements in root length when seeds were treated with GA₃ at 200 mg/L for a soaking duration of 24 hours in *Zea mays*, *Lathyrus sativus*, and *Pisum sativum*

2.9. Role of GA₃ Seed Priming and Soaking Duration in Enhancing Maize Yield and Yield Components

Seed priming with optimal concentrations of plant growth hormones, such as auxin (IAA), gibberellins (GA), abscisic acid, and ethylene, has proven that germination performance as well as growth and yield of many crop species under both normal and stress conditions could be improved effectively (Tian *et al.*, 2014). Shoot growth and development, major agronomical traits, are of great relevance for plant yield, architecture, and overall performance, and the activity of GA is believed to influence both processes directly (Castro-Camba *et al.*, 2022).

Gibberellic Acid (GA₃) increases grain yield in the salt-intolerant wheat cultivar due to the increased number of fertile tillers per plant and grain weight rather than the number of grains per ear particularly when under salt stress (Tian *et al.*, 2014). In maize, GA₃ application caused a remarkable increase in total chlorophyll contents under salinity. Under salt stress, GA₃ application enhanced the dry matter production and plant growth of wheat because of increased photosynthetic activities (Ashraf *et al.*, 2002). In another study, seed priming with GA₃ significantly improved the plant height, yield, and yield-related traits, Ca²⁺ and K⁺ concentrations, and transpiration rates while decreasing Na⁺ concentrations in wheat under salt stress (Shahzad *et al.*, 2021).

Gibberellic Acid (GA₃) is the most widely used plant growth regulator, which increases stem elongation along with plant height, growth, dry matter accumulation as well as yield in various crops (Emongor, 2007). The relevance of GA in plant performance extends

beyond its influence on growth and biomass yield. They also impact several reproductive-related processes, such as flowering and fruit formation (Castro-Camba *et al.*, 2022). Gibberellic acid can improve plant height, grain yield, and days to flowering in maize, which can indirectly affect stand establishment (Naghashzadeh *et al.*, 2009). Gibberellic acid can have a significant effect on plant height, grain yield, 1000-seed weight, and days to flowering in maize, depending on the planting dates and doses of gibberellic acid. Foliar application of gibberellic acid also can significantly improve grain yield and 1000-seed weight of maize (Naghashzadeh *et al.*, 2009). Dawadi *et al.* (2023) reported that seed priming with GA₃ can lead to higher yield attributes, such as increased cob length, kernel count, and overall grain yield. This is attributed to better nutrient uptake and enhanced physiological responses during critical growth stages. Soaking maize seeds for 18 hours in cow urine or other solutions has been shown to maximize germination rates and yield components, such as the number of kernels per cob and 1000 kernel weight (Budhathoki *et al.*, 2024).

2.10. Role of GA₃ Seed Priming in Maize Parental Line Seed Production Under Irrigation Conditions

Seed priming, a pre-sowing seed treatment, has been shown to improve seedling growth, vigor, and overall crop productivity in various crops, including maize. Priming methods such as hydropriming, osmopriming, and hormonal priming (e.g., with GA₃) have demonstrated promise in enhancing water use efficiency in maize. Primed seeds tend to germinate faster and establish better root systems, allowing plants to access soil moisture more efficiently, especially under limited water conditions. These treatments have been reported to stimulate root growth and development, leading to increased water uptake efficiency. This enhanced root system helps plants access deeper soil moisture, potentially allowing maize plants to maintain growth and productivity even during water stress periods (ur Rehman *et al.*, 2015; Abebe Misganaw *et al.*, 2020; El-Sanatawy *et al.*, 2021; Supral and Roshan, 2022).

Several studies have investigated the effects of seed priming on maize seedling establishment, grain yield, and crop water productivity under different irrigation conditions. The use of GA₃ seed priming contributes to better water productivity in maize cultivation under irrigation. By enhancing early and uniform seedling emergence, primed seeds enable more efficient water use during critical growth stages. Improved

establishment and accelerated growth result in better utilization of available water resources, potentially reducing water consumption per unit of yield and enhancing overall water productivity in maize production systems (El-Sanatawy *et al.*, 2021; Supral and Roshan, 2022).

Siyami R *et al.* (2018) explored the effects of physical seed priming on corn traits and yield under water-deficient circumstances in Iran. Their results showcased a significant improvement in maize yield and its components when seed priming was implemented, underscoring its potential for enhancing crop productivity amid water scarcity. Furthermore, conducted a comprehensive review of the advantages, adoption, and hurdles associated with seed priming in field crops (Farooq M *et al.*, 2015). Their review emphasized the myriad benefits of seed priming, including heightened seedling emergence, early growth, and overall crop productivity, especially in diverse environmental settings such as those characterized by water limitations.

Gibberellic Acid (GA_3) seed priming plays a significant role in expediting the reproductive development of maize parental lines. This acceleration triggers earlier flowering, a crucial phase that heightens the probability of successful pollination occurring before the arrival of rainy seasons or adverse weather conditions. By achieving pollination earlier, the risk of rain damage during this critical phase is substantially reduced (Nada and Hamza, 2018). Moreover, GA_3 seed priming contributes to the reduction of the flowering-to-maturity duration in maize plants. This optimization results in a quicker maturation process, significantly shortening the vulnerability period to rain damage, particularly during the late stages of seed formation. By hastening the overall growth cycle, GA_3 seed priming effectively minimizes the window of susceptibility to detrimental weather elements (Kakar *et al.*, 2023). Additionally, this accelerated maturity facilitated by GA_3 seed priming aids in establishing a more foreseeable harvest period for parental maize lines. This predictability is invaluable as it allows for enhanced planning and management strategies, ensuring a timely harvest before the onset of unfavorable weather conditions. By aligning maturity with a predictable harvest window, GA_3 seed priming enables farmers to mitigate the risks associated with rain damage and optimize their agricultural practices for more successful seed production (Nada and Hamza, 2018; Supral and Roshan, 2022; Kakar *et al.*, 2023).

Chapter 3. MATERIAL AND METHODS

3.1. Description of the Study Area

The laboratory experiment was conducted at the Adet Agricultural Research Center in 2024. Adet is located 42 km southeast of Bahir Dar and 450 km northwest of Addis Ababa, situated at a latitude of 11°16'57.03" N, a longitude of 37°29'2.44" E, and an altitude of 2175 m.a.s.l.. The area receives an average annual rainfall of 1228 mm, with maximum and minimum annual mean temperatures of 27°C and 10°C, respectively (Beamlaku Alemayehu *et al.*, 2023).

The field experiment was carried out in 2024 at the Woramit Horticultural Research and Training Sub-center under irrigation conditions. Woramit is located in northwestern Bahir Dar, along the shore of Lake Tana in Ethiopia, at a latitude of 11°38'N, a longitude of 37°10'E, and an altitude of 1800 meters above sea level (m.a.s.l.). The area receives an average annual rainfall of 800–1,250 mm, with maximum and minimum annual mean temperatures of 29.5°C and 6.2°C, respectively (Habtamu Tegen and Mnuyelet Jembere, 2022).

Table 3.1. Soil physico-chemical properties of Woramit testing site

Parameters	Description
Soil Type	Nitisol
Soil PH	Moderately acidic (pH 6.4)
Soil Texture	13% sand, 33% silt, 54% clay
Organic Matter Content	3.9%
Olson Available Phosphorus	6.3 mg/kg
Total Nitrogen Content	0.16%

Source (Habtamu Tegen and Mnuyelet Jembere, 2022)

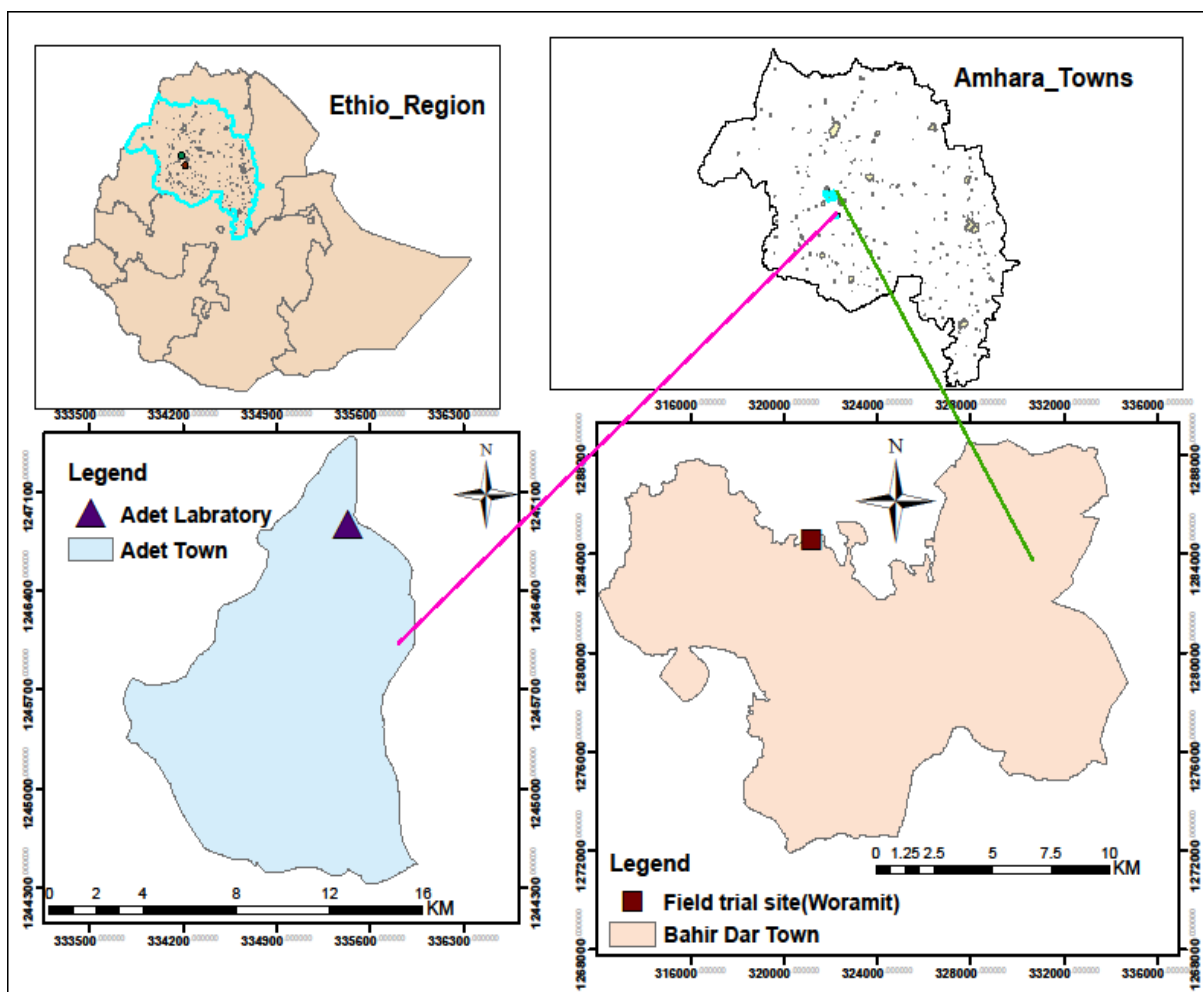


Figure 3.1. Map of the study area.

3.1. Experimental Materials

The CML 395 maize inbred line which was obtained from the Bako National Maize Research Center, was used as the test crop. This line serves as the female parent for the single-cross hybrids BH546 and BH661. CML 395 is well-suited to mid-altitude, sub-humid agroecologies, with a seed yield potential of 3.0–4.0 tons per hectare. It falls under the intermediate maturity group, requiring 155–165 days to reach maturity (Gemechu Asefa *et al.*, 2021). Gibberellic acid (GA_3) 90 % powder was used for seed priming. distilled water used for treatment preparation.

3.2. Experimental Treatments, Design, and Procedures

3.2.1. Laboratory experiment

A laboratory experiment was conducted in 2024 at Adet Seed Science and Technology Directorate, adhering to International Seed Testing Association (ISTA) 2016 guidelines. A factorial experiment was designed using four GA₃ concentrations (0 (Distilled water), 75, 150, and 225 ppm) and three soaking durations (12, 18, and 24 hours) (Table 3.2). A completely randomized design (CRD) with four replications per treatment was employed. Seeds of the maize inbred line CML 395 were primed with the specified GA₃ concentrations and soaking durations. Subsequently, 100 seeds were sown on each experimental unit in plastic germination boxes containing a prepared sand medium. The sand was thoroughly cleaned, sterilized, and moistened before being used. Germination was conducted at room temperature for ten days, with daily observations and recording of the results according to ISTA (2016).

3.2.2. Field experiment

The field experiment consisted of a factorial combination of four gibberellic acid (GA₃) concentrations and three soaking durations (Table 3.2). It was laid out in a randomized complete block design (RCBD) with three replications. Based on the design specifications, a field layout was prepared, and each treatment was randomly assigned to experimental plots within each block. The gross plot size was 3.75 m × 2.5 m (9.375 m²), while the net plot size measured 2.25 m × 2 m (4.5 m²).

Seeds of the CML-395 maize inbred line were planted at a seeding rate of 25 kg/ha, with inter-row and intra-row spacing of 75 cm and 25 cm, respectively. The space between blocks and plots was 1.5 m and 1 m, respectively. Two seeds were sown per stand, and two weeks after emergence, thinning was done by hand to leave one seedling per stand, ensuring the desired plant population per plot.

Nitrogen and phosphorus fertilizers were applied at a rate of 200 kg/ha each, in the form of urea and NPSB, respectively. All NPSB was applied at planting, while urea was applied in two splits: half at planting and the other half at knee height. Irrigation was conducted using the furrow method, with the first irrigation applied one day after sowing, followed by subsequent irrigations at seven-day intervals (Atakltie Abebe *et al.*, 2020). Lambda-

cyhalothrin 5% EC was sprayed twice to control fall armyworm (Addisu Sileshi *et al.*, 2022). Hand weeding was conducted three times at 25 and 45 days after emergence, while weed slashing was executed once during the flowering stage.

Table 3.2. Experimental treatments and combinations (for both lab and field experiments)

Treatment code	Treatment combination
T1	Distilled water + 12 hours
T2	Distilled water + 18 hours
T3	Distilled water + 24 hours
T4	75 ppm GA ₃ + 12 hours
T5	75 ppm GA ₃ + 18 hours
T6	75 ppm GA ₃ + 24 hours
T7	150 ppm GA ₃ + 12 hours
T8	150 ppm GA ₃ + 18 h hours
T9	150 ppm GA ₃ + 24 hours
T10	225 ppm GA ₃ + 12 hours
T11	225 ppm GA ₃ + 18 hours
T12	225 ppm GA ₃ + 24 hours

Note: - GA₃ = Gibberellic Acid, ppm = part per million

3.3. Experimental Treatment Preparation Procedures

Both laboratory and field experiments followed a similar procedure for preparing GA₃ solutions and seed soaking, with a seed-to-solution volume ratio of 1:5 ensuring optimal conditions (Farooq *et al.*, 2006).

For the laboratory experiment, 250 mL of solution was prepared for each concentration to soak 50 grams of CML 395 inbred line seeds. Four GA₃ solutions were prepared: 0 ppm (control, using 250 mL distilled water), 75 ppm (18.75 mg GA₃), 150 ppm (37.5 mg GA₃), and 225 ppm (56.25 mg GA₃). The seeds were placed in containers with 250 mL of the respective solution, fully submerging the seeds. Soaking durations were 12, 18, or 24 hours, depending on the treatment. After soaking, seeds were rinsed three times with distilled water to remove residual GA₃ and dried at room temperature in a shaded area

until they returned to their original moisture content (Afzal *et al.*, 2002; El-Sanatawy *et al.*, 2021).

For the field experiment, a total of 117.5 mL of solution was used for every 23.5 grams of CML 395 inbred line seeds. The GA₃ solutions were prepared in four concentrations: 0 ppm (117.5 mL distilled water), 75 ppm (8.81 mg GA₃), 150 ppm (17.63 mg GA₃), and 225 ppm (26.44 mg GA₃). The seeds were soaked in covered containers for 12, 18, or 24 hours, then rinsed three times with distilled water and dried in a shaded, well-ventilated area until they reached their original moisture content (Afzal *et al.*, 2002; El-Sanatawy *et al.*, 2021).

3.4. Data Collected

3.4.1. Data collected from laboratory experiment

Germination percentage: A germination test was conducted using germination boxes with sand as the medium. After ten days, the germination percentage was evaluated using the following formula (ISTA, 2016).

$$GP(\%) = \frac{\text{Total number of seed germinated}}{\text{Total number of planted seed}} * 100$$

Speed of germination: Daily germination counts were conducted until no further germination was observed. The germination speed index was then calculated using the following formula (Maguire, 1962).

$$SPG = \frac{\text{Normal seedlings}}{\text{No of days to 1st count}} + \dots + \frac{\text{Normal seedlings}}{\text{No.of days to final count}}$$

Mean germination time (MGT): Mean germination time, which represents the average time taken for seeds to germinate, was calculated using the Ellis and Roberts (1981) equation:

$$MGT = \frac{\sum Dn}{\sum n}$$

Where n represents the number of germinated seeds on day D, and the number of days D is calculated when germination was started.

Shoot length: Ten normal seedlings were randomly selected from each replication of the germination test. The shoot lengths were measured from the point of seed attachment to the tip of the shoot using a ruler. The mean shoot length was then expressed in centimeters.

Root length: Ten normal seedlings were randomly selected from each replication of the germination test. The root lengths were measured from the point of seed attachment to the tip of the root using a ruler. The mean root length was then expressed in centimeters.

Root-to-shoot ratio: After the tenth day of the experiment, the root-to-shoot ratio was calculated using the following formula (Supral and Roshan, 2022).

$$RS\ ratio = \frac{(Mean\ of\ root\ dry\ weight)}{(Mean\ of\ shoot\ dry\ weight)}$$

Seedling dry weight: Ten seedlings were randomly selected from each replicate of the germination test. After being cut free from their cotyledons, the seedlings were placed in envelopes and dried in an oven at 80°C for 24 hours. The dried seedlings were then weighed.

Seedling Vigor index I: Seedling vigor index I was calculated after the final count in the standard germination test, following the method described by (Fischer and Maurer, 1978).

$$SVI\ I = GP * \text{Seedling length (root length + shoot length)}$$

Seedling Vigor Index II: Seedling vigor index II was calculated after the final count in the standard germination test, following the method described by (Abdul-Baki and Anderson, 1973).

$$SVI\ II = SDW * GP$$

Where: SVI II - Seedling Vigor Index; SDW –Seedling Dry Weight; GP – Germination Percentage.

3.4.2. Data collected from field experiment

Field emergence parameters

Date to 50% emergence: It was recorded as the time after planting when 50% of the plants had appeared above ground in each net plot.

Mean Emergence Time (MET): Mean emergence time, which is the average time taken for seeds to emerge, was recorded using the Ellis and Roberts (1981) formula.

$$MET = \frac{\sum Dn}{\sum n}$$

Where n represents the number of emerged seeds on day D and the number of days D is calculated when emergence was started.

Field Emergence Index (FEI): The field emergence index was measured according to the Association of Official Seed Analysis (AOSA) (1983) handbook using the following formula.

$$FEI = \frac{\text{Number of germinating seeds}}{\text{Days of the first count}} + \dots + \frac{\text{Number of germinating seeds}}{\text{Days of the final count}}$$

Final emergence percentage (FEP): Final emergence percentage was recorded at the end of the experiment. It represents the ratio of the number of emerged seedlings to the total number of seeds planted, multiplied by 100 (Kakar *et al.*, 2023).

$$FEP = \frac{\text{final no. of seedlings emerged}}{\text{total no. of seeds sown}} * 100$$

Phenological Parameters

Days to 50% tasseling: It was recorded as the number of days from planting until 50% of the plants in each net plot produced tassels.

Days to 50% silking: The number of days from planting to the date when 50% of the plants in a plot have produced 2-3 cm long silks was recorded.

Days to 50 % maturity: The number of days from planting to when 50% of the plants in a plot form a black layer at the tip where the kernel attaches to the cob was recorded.

Yield and yield component parameters

Ear height (cm): Ear height was measured in centimeters by recording the distance from the ground level to the uppermost useful ear-bearing node on ten randomly selected plants. The mean ear height was then calculated and recorded.

Plant height: Plant height was measured in centimeters as the distance from ground level to the point where the tassel begins to branch. Measurements were taken from ten randomly sampled plants from the net plot, and the mean height of these ten plants was recorded.

Ear length: Ear length was recorded as the average length of ten randomly selected ears from each net plot area at harvest, measured in centimeters.

Ear diameter (cm): The average diameter of each ear, using the same samples as for ear length, was measured in centimeters at the midpoint along the length of the ear using a caliper.

Kernel row per ear: The total number of kernel rows on ten randomly selected ears was counted, and the average number of kernel rows per ear was calculated and recorded.

Number of kernels per row: The average number of kernels per row was recorded from ten randomly sampled ears. Additionally, the kernels from ten randomly selected rows of each sampled ear were counted, and the average number of kernels per row was recorded.

Number of ears per plant: This was calculated as the ratio of the total number of ears harvested from a net plot to the total number of plants in that net plot at harvest.

Thousand kernel weight: It was measured in grams by counting 1,000 kernels from a bulk of shelled grains from each net plot area of the treatment, weighing them using a sensitive balance, and adjusting to a 12.5% moisture content.

Seed yield: Grain yield was taken by harvesting, sun drying and threshing the grain from the net plot area. The yield was adjusted to 12.5% moisture content.

$$\text{Adjusted seed yield (t/ha)} = \text{SY(t/ha)} \times \frac{100 - \text{Actual moisture (\%)}}{100 - 12.5}$$

Above-ground biomass: The aboveground dry biomass was determined from plants harvested from the net plot area after sun drying to a constant weight and converted to tons per hectare.

Harvest index: Harvest index was calculated as the ratio of seed yield to above-ground dry biomass yield and expressed as a percentage, following the method described by Yoshida *et al.* (1971).

$$\text{HI} = \frac{\text{Seed yield (t/ha)}}{\text{Above ground biomass(t/ha)}} * 100$$

3.5. Data Analysis

3.5.1. Statistical data analysis

The data collected from both the laboratory and field experiments were analyzed according to the principles of Analysis of Variance (ANOVA) using R software version 4.4.2, with interpretations made following the procedures described by Gomez and Gomez (1984). The least significance difference test (LSD) at a 5% probability level was used to determine the significant differences among means. Before analyzing the collected data, the assumptions of ANOVA were tested. The normality of both laboratory and field data was assessed using the Shapiro-Wilk test and graphical methods, such as Q-Q plots. According to these tests, all laboratory and field parameters met the assumptions of normality.

Correlation analysis was performed to examine the nature and strength of the relationships between seed physiological quality parameters. Correlation coefficients (r) were calculated, and their significance was tested using Pearson's correlation procedure. In contrast, due to a high multicollinearity problem among agronomic measured traits, principal component analysis was conducted to assess the correlations among these traits. Following this, multiple linear regression analysis was performed to explore the relationship between the first two principal components and the seed yield by using R

software. Additionally, simple linear regression analysis was conducted to evaluate the relationship between seed yield and the yield components of the maize inbred line.

3.5.2. Partial budget analysis

The partial budget analysis was conducted following the CIMMYT (1988) procedures to examine the individual economic effects of GA₃ concentration and soaking duration on maize inbred line seed yield. These factors were analyzed separately because their interaction did not significantly influence yield.

This method was used to assess the relative profitability of each treatment by comparing the variable costs and benefits, focusing on changes in GA₃ application costs. Seed yield data were collected from each plot after harvest, and revenue was calculated by multiplying the adjusted seed yield in tone per hectare by the prevailing market price of maize inbred line Prebasic seed. Fixed costs and operational costs, including labor, seed, land preparation, and others, were assumed to be constant across all treatments. According to the CIMMYT (1988) procedures, only the costs that differed between treatments, in this case, the cost of GA₃ and labor for preparation of treatments were considered in the analysis. The net benefit for each treatment was determined by subtracting the total cost from the revenue generated from the seed yield. This net benefit provided an indicator of the profitability of each treatment. To further assess the cost-effectiveness, the marginal rate of return (MRR) was calculated, which represents the percentage return on each additional unit of cost invested. The MRR was obtained by dividing the difference in net benefits between treatments by the difference in costs and multiplying by 100.

Finally, treatments were ranked based on their net benefit and MRR, identifying the most economically viable combination of GA₃ concentration and soaking duration. According to CIMMYT (1988), when all the comparable treatments showed more than 100% MRR value in the experiment, the treatment having the highest NB value can be taken as economically profitable and recommendable to the users.

Chapter 4. RESULT AND DISCUSSION

4.1. Result of Laboratory Experiment

4.1.1. Effect of GA₃ concentration and soaking durations on seed physiological quality parameters

Germination percentage (GP)

The ANOVA results revealed that the main effects of both GA₃ concentration ($P < 0.001$) and soaking duration ($P < 0.05$) significantly influenced germination percentage. However, the interaction effect between GA₃ concentration and soaking duration was not significant ($P > 0.05$) (Appendix Table 1). The results indicated that increasing the GA₃ concentration led to a corresponding increase in germination percentage. As shown in Table 4.1, seeds treated with 225 ppm GA₃ exhibited the highest germination percentage of 95.5%, which was not statistically different from those treated with 150 ppm GA₃ (95.25%). In contrast, seeds treated with distilled water (control) showed the lowest germination percentage of 91.25%.

Regarding soaking duration, seeds soaked for 24 hours exhibited the highest germination percentage (94.31%), which was not statistically different from seeds soaked for 18 hours (93.63%). Conversely, seeds subjected to a 12-hour soaking duration showed the lowest germination percentage of 92.88% (Table 4.1).

The results of this study indicate that seeds treated with 225 ppm GA₃ concentration resulted in a 4.66 % increase in germination percentage compared to the control (distilled water). The observed increase in germination percentage with 225 ppm GA₃ may be attributed to the optimal concentration of GA₃ promoting embryo growth, mobilizing nutrient reserves, and weakening the endosperm layer (Ma *et al.*, 2018). These findings are consistent with Husnain (2014), and Mazed, H. *et al.* (2015), who reported significant improvements in chickpea germination percentages when treated with 225 ppm GA₃ compared to lower concentrations and control groups. Similarly, Berhanu Abraha and Melkamu Andargie (2018) found that a concentration of 200 mg/L GA₃ significantly improved germination rates in *Zea mays* L., *Pisum sativum* Var. *abyssinicum* A. Braun, and *Lathyrus sativus* L. Additionally, Venkata *et al.* (2023) also observed enhanced germination percentages in fodder maize seeds treated with 200 mg/L GA₃. Conversely,

some studies have reported varying optimal concentrations of GA₃ for different plant species. For instance, Salih and Tuncturk (2020) indicated that low concentrations of GA₃ positively influenced germination percentages in wheat cultivars. Additionally, Gnawali and Subedi (2021) found that maize seeds treated with 100 ppm GA₃ achieved higher germination percentages compared to controls and other concentrations tested (50 ppm, 150 ppm, and 200 ppm). Additionally, indicated that low concentrations of GA₃ positively influenced germination percentages in wheat cultivars.

Additionally, seeds soaked for 24 hours achieved the highest germination percentage. This may be due to adequate hydration being crucial for synthesizing hydrolytic enzymes necessary for breaking down stored nutrients, thus providing energy for the developing embryo (Rosental *et al.*, 2014). This result aligns with Nadeem *et al.* (2017), who reported that soaking seeds in water for 24 hours resulted in a significant germination percentage compared to 12 or 36 hours. Khan *et al.* (2017) also reported that seeds treated with gibberellic acid (GA₃) PEG-6000 and hydropriming with distilled water for 24 hours gave higher germination percentage.

Speed of germination (SPG)

The ANOVA showed that the main effect of both GA₃ concentration ($P < 0.001$) and soaking duration ($P < 0.01$) significantly influenced the speed of germination, however, their interaction did not show a significant difference ($P > 0.05$) (Appendix Table 1). As indicated in Table 4.1, seeds treated with a 225 ppm GA₃ concentration resulted in the highest germination speed (21.31), whereas, seeds soaked with distilled water (control) showed the lowest speed of germination (19.47). The result indicated that using 225 ppm GA₃ concentration resulted in an increase of approximately 9.45% compared to the control (distilled water). In terms of soaking duration, seeds that were soaked for 24 hours exhibited the highest germination speed of 20.62, while those soaked for 12 hours showed the lowest speed of germination (20.18) (Table 4.1).

The results of this study indicate that seeds treated with 225 GA₃ significantly enhanced the speed of germination as compared to the control. This improvement is primarily driven by the activation of hydrolytic enzymes, especially α -amylase, which is responsible for breaking down starches into sugars that seeds use for energy during germination (Vieira *et al.*, 2002; Ramwant and SK, 2013). In addition, higher concentrations of GA₃ help lower

abscisic acid (ABA) levels, which function as growth inhibitors, thus facilitating faster germination (Gnawali and Subedi, 2021). These findings aligned with Hussien *et al.* (2019), who reported that seeds soaked at a concentration of 0.58 mM GA₃ enhanced the speed of germination in wheat varieties under saline conditions. Similarly, Venkata *et al.* (2023) found that seeds of fodder maize treated with 200 mg/L GA₃ recorded the highest speed of germination compared to other seed treatments. On the contrary, Salih and Tuncurk (2020) reported that lower concentrations of GA₃ positively impacted the germination speed. In their study, the lowest speed was observed at 200 ppm GA₃, while the highest germination rate occurred at 0 ppm GA₃ in wheat seeds under drought stress.

In terms of soaking duration, a 24-hour soaking duration significantly improved the speed of germination compared to lower durations. This improvement may be due to optimum soaking durations contributing to better nutrient mobilization and increased enzymatic activity, both of which further accelerate germination (Nadeem *et al.*, 2017). These results are in line with Hamza and Ali (2017), who reported that 24-hour soaking duration significantly enhanced the speed of germination compared to lower durations.

Mean germination time (MGT)

The results of this study demonstrated that the main effect of both GA₃ concentration ($P < 0.001$) and soaking duration ($P < 0.01$) significantly influenced mean germination time, while the interaction was not significant ($P > 0.05$) (Appendix Table 1). As presented in Table 4.1, 225 ppm GA₃ concentration resulted in the shortest mean germination time of 3.82 days, while seeds treated solely with distilled water had the longest mean germination time of 4.71 days. This result indicated that 225 ppm GA₃ concentration reduced mean germination time by approximately 18.89% compared to the control (distilled water). Additionally, seeds soaked for 24 hours showed the shortest mean germination time of 4.14 days, while the longest mean germination time was recorded for a 12-hour soaking duration (4.44 days), indicating a percentage advantage of approximately 6.77% for the longer soaking duration (Table 4.1).

These findings indicate that both GA₃ treatment significantly reduced the mean germination time of the maize inbred line. Specifically, the application of GA₃ at a concentration of 225 ppm significantly reduced mean germination time compared to seed soaked only in distilled water (control). This indicates GA₃ increasing overall metabolic

activity within the seed. Specifically, higher concentrations of GA₃ enhance respiration rates and mobilize stored nutrients, which are essential for rapid growth during germination (Vieira *et al.*, 2002; de Mello *et al.*, 2009; Du *et al.*, 2022). These findings align with the result of Kandil *et al.* (2014), who reported that sugar beet seeds treated with GA₃ at 200 ppm reduced mean germination time (4.85 days) as compared to the control (5.53 days). Additionally, Berhanu Abraha and Melkamu Andargie (2018) reported that seed priming with 200 mg/L GA₃ in *Zea mays*, *Lathyrus sativus*, and *Pisum sativum* reduced the MGT value compared to the control (unprimed) treatment. In contrast, Gnawali and Subedi (2021) indicated that maize seed treated with GA₃ at 100 ppm decreased the mean germination time by 35 hours under 1.75 MPa compared to the control, 100, 150, and 200 ppm. Similarly, Supral and Roshan (2022) found that maize seeds treated with GA₃ at 50 ppm had the lowest mean germination time under the non-stress environment compared to seeds treated with 75 ppm and 100 ppm of GA₃ concentrations.

Regarding soaking duration, a 24-hour duration reduced the mean germination time compared to lower concentration. These results align with Hamza and Ali (2017), who reported that a 24-hour soaking duration significantly reduced the mean germination time compared to lower durations.

Table 4.1. The main effect of GA₃ concentration and soaking duration on germination percentage, speed of germination and mean germination time

GA ₃ Conc.	Germination percentage (%)	Speed of germination	Mean germination time (Days)
0 ppm (DW)	91.25 ^c	19.47 ^d	4.71 ^a
75 ppm	92.42 ^b	19.88 ^c	4.60 ^a
150 ppm	95.25 ^a	20.85 ^b	4.16 ^b
225 ppm	95.5 ^a	21.31 ^a	3.82 ^c
SEM (±)	0.362	0.102	0.065
LSD (0.05)	1.0395	0.2918	0.1862
P Value	<.001	<.001	<.001
Soaking durations			
12 hours	92.88 ^b	20.18 ^b	4.44 ^a
18 hours	93.63 ^{ab}	20.33 ^b	4.38 ^a
24 hours	94.31 ^a	20.62 ^a	4.14 ^b
SEM (±)	0.314	0.088	0.056
LSD (0.05)	0.9003	0.2527	0.1612
P value	0.0100	0.004	0.0013
G Mean	93.6	20.38	4.32
CV (%)	1.34	1.73	5.21

Note: - Means with the same letters in each column are not significantly different at $P < 0.05$, GA₃ = Gibberellic Acid, ppm = part per million, DW = Distilled Water, LSD = List Significant Test, SEM = Standard Error of Mean, CV = Coefficient of Variation

Shoot length (SL)

The ANOVA revealed that the main effect of GA₃ concentration very highly significantly influenced shoot length ($P < 0.001$). In contrast, neither the main effect of soaking duration nor the interaction between GA₃ concentration and soaking duration showed non-significant effects ($P > 0.05$) (Appendix Table 1). As shown in Table 4.2. seed treated with 225 ppm GA₃ concentration showed the tallest shoot length of 16.17 cm, while the control (distilled water) resulted in the shortest shoot length of 12.21 cm.

The results indicate that using a 225 ppm GA₃ concentration resulted in an increase of approximately 32.43% in shoot length compared to the control. The significant increase in shoot length observed suggests that gibberellic acid effectively stimulates both cell division and enlargement, leading to the development of larger seedlings (Castro-Camba *et al.*, 2022). These results align with, Berhanu Abraha and Melkamu Andargie (2018), who reported that seed priming with 200 mg/L GA₃ resulted in increased shoot lengths across various species, including *Zea mays*, *Lathyrus sativus*, and *Pisum sativum*, compared to unprimed controls. Similarly, Gnawali and Subedi (2021) reported that maize seeds treated with GA₃ at 200 ppm exhibited a notable increase in shoot length from 2.9 cm in non-primed seeds to 6.4 cm under a water potential of 1.05 MPa. Moreover, corroborating findings from , Setiawan (2022), and Venkata *et al.* (2023) further validate the effectiveness of GA₃ in promoting shoot elongation across different plant species.

Root length (RL)

The results of this study indicated that the main effect of both GA₃ concentrations ($P < 0.001$) and soaking duration ($P < 0.01$) significantly influenced root length, while the interaction effect was not statistically significant ($P > 0.05$) (Appendix Table 1). As shown in Table 4.2, seeds treated with 225 ppm GA₃ concentration showed the longest root length of 13.59 cm, while seeds soaked with distilled water (control) showed the shortest root length of 9.64 cm. This finding demonstrates a notable increase of approximately 40.98% in root length for the GA₃-treated seeds with 225 ppm concentration compared to the control (distilled water). Regarding soaking duration, the seed soaked for 24 hours showed the longest root length of 12.01 cm, which was not statistically significantly different from the 18-hour soaking duration (11.49 cm). In contrast, the seed subjected to 12 hours of soaking duration exhibited the shortest root length of 10.79 cm (Table 4.2).

The result of our study indicates that seeds treated with 225 ppm GA₃ concentration significantly increased root length as compared to the control. This enhancement may be attributed to GA₃-stimulated hydrolytic enzymes that are needed for the degradation of the cells surrounding the radicle (Afzal *et al.*, 2002). Supporting these findings, Berhanu Abraha and Melkamu Andargie (2018) reported similar improvements in root length when seeds were treated with GA₃ at 200 mg/L for a soaking duration of 24 hours in *Zea mays*, *Lathyrus sativus*, and *Pisum sativum*. Studies by Setiawan (2022) and Venkata *et al.* (2023) also corroborate the positive influence of GA₃ concentrations on root growth. On

the contrary, Gnawali and Subedi (2021) reported that the longest root length was recorded at lower GA₃ concentrations compared to higher ones.

Additionally, a 24-hour soaking duration significantly enhanced root length compared to lower durations. This enhancement may be due to prolonged soaking in GA₃ enhances the activity of hydrolase enzymes that convert starch into simple sugars, providing essential energy for root growth (Yayat *et al.*, 2017).

Root to shoot ratio (RSR)

The ANOVA results revealed that the main effect of GA₃ concentration significantly influenced the root-to-shoot ratio ($P < 0.001$). However, soaking duration and the interaction did not show significant effects ($P > 0.05$) (Appendix Table 1). As indicated in Table 4.2. seed soaked with distilled water (control) showed the highest root-to-shoot ratio of 0.79, while seed treated with 225 ppm and 150 ppm GA₃ concentration resulted in the lowest root-to-shoot ratios of 0.53 and 0.56 respectively.

The results indicate that seeds soaked solely in distilled water (control) significantly increased the root-to-shoot ratio compared to higher GA₃ concentrations. This may be due to the increased allocation of resources towards shoot development in response to higher concentrations of GA₃, which enhances shoot elongation while limiting proportional root growth, thereby reducing the root-to-shoot ratio (Arteca *et al.*, 1991; Hakla *et al.*, 2021). This result is partially in agreement with, Gnawali and Subedi (2021) reported that a lower concentration of GA₃ resulted in a more favorable R/S ratio compared to higher concentrations.

Table 4.2. The main effect of GA₃ concentration and soaking duration on shoot length, root length and root-to-shoot ratio

GA ₃ Conc.	Shoot Length (cm)	Root Length (cm)	Root to Shoot Ratio
0 ppm (DW)	12.21 ^d	9.64 ^c	0.79 ^a
75 ppm	13.01 ^c	10.15 ^c	0.65 ^b
150 ppm	14.88 ^b	12.34 ^b	0.56 ^c
225 ppm	16.17 ^a	13.59 ^a	0.53 ^c
SEM (±)	0.239	0.269	0.025
LSD (0.05)	0.6858	0.7724	0.0728
P Value	<.001	<.001	<.001
Soaking durations			
12 hours	13.77	10.79 ^b	0.63
18 hours	13.99	11.49 ^a	0.64
24 hours	14.44	12.01 ^a	0.64
SEM (±)	0.207	0.233	0.022
LSD (0.05)	NS	0.669	NS
P value	0.0789	0.0029	0.9104
G Mean	14.07	11.43	0.63
CV (%)	5.89	8.16	13.89

Note: - Means with the same letters in each column are not significantly different at $P < 0.05$, GA₃ = Gibberellic Acid, ppm = part per million, DW = Distilled Water, LSD = List Significant Test, SEM = Standard Error of Mean, CV = Coefficient of Variation

Seedling dry weight (SDW)

The result of this study indicated that both the main effects of GA₃ concentration ($P < 0.001$) and soaking duration ($P < 0.001$) significantly influenced seedling dry weight, while the interaction effect was not statistically significant ($P > 0.05$) (Appendix Table 1). As shown in Table 4.3, seeds treated with 225 ppm GA₃ concentration showed the highest seedling dry weight of 0.26 g, while seeds soaked solely in distilled water showed the lowest dry weight of 0.14 g. This indicates using 225 GA₃ concentration resulted in an increase in approximately 85.7 % of seedling dry weight compared to the control. In

terms of soaking duration, seeds soaked for 24 hours achieved the highest seedling dry weight of 0.22 g, whereas seeds soaked for 12 hours showed the lowest dry weight of 0.18 g (Table 4.3).

These results indicate that seeds treated with 225 ppm GA₃ showed a significant increase in seedling dry weight. This enhancement can be attributed to the ability of GA₃ and extended soaking durations to promote nutrient mobilization, increase germination rates, improve root development, stimulate cell elongation, and mitigate stress (Chauhan *et al.*, 2019; Castro-Camba *et al.*, 2022). These findings are consistent with, Berhanu Abraha and Melkamu Andargie (2018), who found comparable results in *Zea mays*, *Lathyrus sativus*, and *Pisum sativum*. Erol and Arslanoğlu (2022) reported similar enhancements in seedling growth in soybeans when treated with GA₃. Additionally, Venkata *et al.* (2023) reported that GA₃ priming at 200 mg/L in fodder maize increased seedling dry weight compared to other treatments.

Vigor index I

The ANOVA results revealed that both the main effects of GA₃ concentration and soaking duration showed high significant effect on vigor index I ($P < 0.001$). However, the interaction effect was not statistically significant ($P > 0.05$) (Appendix Table 1). As shown in Table 4.3, seeds treated with 225 ppm GA₃ concentration showed the highest seedling vigor index of 2842.30, while seeds soaked with distilled water (control) exhibited the lowest vigor index I of 1994.35. This indicates an increase of vigor index I approximately 42.5 % compared to the control. In terms of soaking duration, the seed subjected to 24 hours of soaking duration showed the highest seedling vigor index of 2499.63, while the seed soaked for 12 hours exhibited the lowest vigor index of 2286.86 (Table 4.3).

These findings demonstrate that seeds treated with 225 ppm GA₃ concentration significantly improved the Vigor Index I compared to the control. This enhancement can be attributed to several physiological mechanisms, including improved nutrient mobilization, enhanced germination rates, better root and shoot development, and stimulated cell elongation (Ali Adam *et al.*, 2021; Erol and Arslanoğlu, 2022; Setiawan, 2022). The results align with previous studies indicating that optimal GA₃ concentrations and soaking durations significantly enhance seedling vigor. For instance, Husnain (2014)

reported that chickpea seeds treated with 225 ppm GA₃ exhibited significantly enhanced seedling vigor compared to untreated controls. Similarly, Berhanu Abraha and Melkamu Andargie (2018) found that seeds treated with 200 mg/L GA₃ showed marked improvements in seedling vigor in species such as *Zea mays*, *Lathyrus sativus*, and *Pisum sativum*. Further corroborating these findings, Hussien *et al.* (2019) and Venkata *et al.* (2023) observed similar results in wheat and fodder maize. However, in contradicting our results, Gnawali and Subedi (2021) found that maize seeds treated with 50 ppm GA₃ resulted in a higher vigor index compared to treatments at 0, 100, 150, and 200 ppm concentrations.

Vigor Index II

The result of this study showed that both the main effect of GA₃ concentration and soaking duration positively influenced the vigor index II ($P < 0.001$). On the contrary, the interaction effect was not significant ($P > 0.05$) (Appendix Table 1). As illustrated in Table 4.3, seedling dry weight increased when GA₃ concentrations increased. The result indicated that seeds treated with 225 ppm GA₃ concentration showed the highest vigor index II of 24.84, while seeds soaked with solely distilled water showed the lowest vigor index II of 12.62. This indicates an increase of the vigor index II of approximately 96.83 % compared to the control (distilled water). In terms of soaking duration 24 hours of soaking duration showed the highest vigor index of 20.41, while 12 hours of soaking duration recorded the lowest vigor index of 17.07 (Table 4.3).

The results of this study indicate that seeds treated with 225 ppm GA₃ concentration significantly enhanced the seedling vigor index II. This enhancement can be attributed to higher concentrations of GA₃ promoting nutrient mobilization within the seed, stimulating the activity of hydrolyzing enzymes that break down stored carbohydrates and proteins (Ali Adam *et al.*, 2021). The results of our study are supported by various studies. For instance, Venkata *et al.* (2023) demonstrated significant improvements in seedling vigor in fodder maize treated with GA₃, aligning with the findings of this study. Similarly, Tapfumaneyi *et al.* (2023) reported enhanced seedling vigor in Amaranth and *Cleome gynandra* due to GA₃ application, reinforcing the notion that GA₃ effectively stimulates growth across different plant species.

Regarding soaking duration, a 24-hour soaking duration significantly enhanced seedling vigor compared to lower durations. These results align with those of Adhikari *et al.* (2021), who reported that optimum soaking duration enhanced seedling vigor.

Table 4.3. The main effect of GA₃ concentration and soaking duration on seedling dry weight, seedling vigor index I & II

GA ₃ Conc.	Seedling dry weight (g)	Seedling vigor index I	Seedling vigor index II
0 ppm (DW)	0.14 ^d	1994.35 ^c	12.62 ^d
75 ppm	0.18 ^c	2139.84 ^c	16.79 ^c
150 ppm	0.21 ^b	2593.23 ^b	20.40 ^b
225 ppm	0.26 ^a	2842.30 ^a	24.84 ^a
SEM (±)	0.006	34.178	0.537
LSD (0.05)	0.0168	98.027	1.5416
P Value	<.001	<.001	<.001
Soaking durations			
12 hours	0.18 ^b	2286.86 ^c	17.07 ^c
18 hours	0.20 ^b	2390.81 ^b	18.51 ^b
24 hours	0.22 ^a	2499.63 ^a	20.41 ^a
SEM (±)	0.005	29.599	0.465
LSD (0.05)	0.0145	84.894	1.335
P value	0.0003	<.0001	<.0001
G Mean	0.20	2392.43	18.66
CV (%)	10.2	4.95	9.98

Note: Means with the same letters in each column are not significantly different at P < 0.05, GA₃ = Gibberellic Acid, ppm = part per million, DW = Distilled Water, LSD = List Significant Test, SEM = Standard Error of Mean, CV = Coefficient of Variation

4.1.2. Correlation among seed physiological quality parameters

The correlation analysis revealed highly significant relationships among the seed physiological quality traits. As shown in Table 4.4, germination percentage showed a strong positive correlation with the speed of germination ($r = 0.83^{***}$), indicating that

higher germination rates lead to faster germination, as well as with seedling vigor index I ($r = 0.82^{***}$) and seedling vigor index II ($r = 0.77^{***}$), suggesting that seeds with better germination rates produce more vigorous seedlings. In contrast, mean germination time exhibited a strong negative correlation with both germination percentage ($r = -0.78^{***}$) and speed of germination ($r = -0.85^{***}$) (Table 4.4). This indicates that longer germination times are associated with lower germination success and slower sprouting.

Furthermore, shoot length and root length were positively correlated with germination percentage, speed of germination, and both seedling vigor indices. Notably, shoot length had a particularly strong relationship with seedling dry weight ($r = 0.92^{***}$). However, the root-to-shoot ratio was negatively correlated with germination percentage ($r = -0.66^{***}$), shoot length ($r = -0.71^{***}$), and seedling dry weight ($r = -0.73^{***}$) (Table 4.4).

Table 4.4. Pearson's Correlation Coefficient (r) among seed physiological quality traits of maize inbred line

	GP	SPG	MGT	SL	RL	RSR	SDW	SV I	SV II
GP	1								
SPG	0.83 ^{***}	1							
MGT	-0.78 ^{***}	-0.85 ^{***}	1						
SL	0.73 ^{***}	0.83 ^{***}	-0.91 ^{***}	1					
RL	0.73 ^{***}	0.84 ^{***}	-0.79 ^{***}	0.82 ^{***}	1				
RSR	-0.66 ^{***}	-0.61 ^{***}	0.59 ^{***}	-0.71 ^{***}	-0.45 ^{**}	1			
SDW	0.72 ^{***}	0.82 ^{***}	-0.88 ^{***}	0.92 ^{***}	0.76 ^{***}	-0.73 ^{***}	1		
SV I	0.82 ^{***}	0.89 ^{***}	-0.9 ^{***}	0.95 ^{***}	0.95 ^{***}	-0.63 ^{***}	0.88 ^{***}	1	
SV II	0.77 ^{***}	0.84 ^{***}	-0.89 ^{***}	0.92 ^{***}	0.77 ^{***}	-0.73 ^{***}	0.99 ^{***}	0.89 ^{***}	1

*** = $p \leq 0.001$, ** = $p \leq 0.01$, * = $p \leq 0.05$, GP = Germination Percentage, SPG = Speed of Germination, MGT = Mean Germination Time, SL = Shoot Length, RL = Root Length, RSR = Root to Shoot Ratio, SDW = Seedling Dry Weight, VI I = Vigor Index I, VI II = Vigor Index II

4.2.

Results of the Field Experiment

4.2.1. Effect of GA₃ concentration and soaking duration on field emergence parameters

Days to 50 % Emergence (DSE)

The ANOVA results revealed that the main effect of GA₃ concentration, soaking duration, and their interaction effect highly significantly affected days to 50 % emergence ($P < 0.001$) (Appendix Table 2). As illustrated in Figure 4.1, the result indicated seeds treated with 225 ppm GA₃ concentration for 24 and 18 hours showed the shortest emergence time of 5 days, while seeds soaked in distilled water (control) for 12 hours exhibited the longest days to 50% emergence (8 days).

These results indicate that seeds treated with 225 ppm GA₃ concentration for either 24 or 18 hours reduced the time to 50% emergence by approximately 37.5% compared to the control (distilled water). The observed reduction in 50 % emergence time can be attributed to GA₃'s stimulation of hydrolytic enzymes, particularly α -amylase, which breaks down starch into simpler sugars, providing essential energy for the developing embryo (Finch-Savage and Leubner-Metzger, 2006; Iqbal and Ashraf, 2013). These findings are consistent with Husnain (2014) and Mazed, K. *et al.* (2015), who indicated that chickpea seeds treated with 225 ppm GA₃ concentration significantly reduced the time to 50% emergence compared to the control. Furthermore, Aier *et al.* (2015), Shariatmadari *et al.* (2017), and Khan *et al.* (2017) reported the positive effect of GA₃ treatment on reducing the time of emergence.

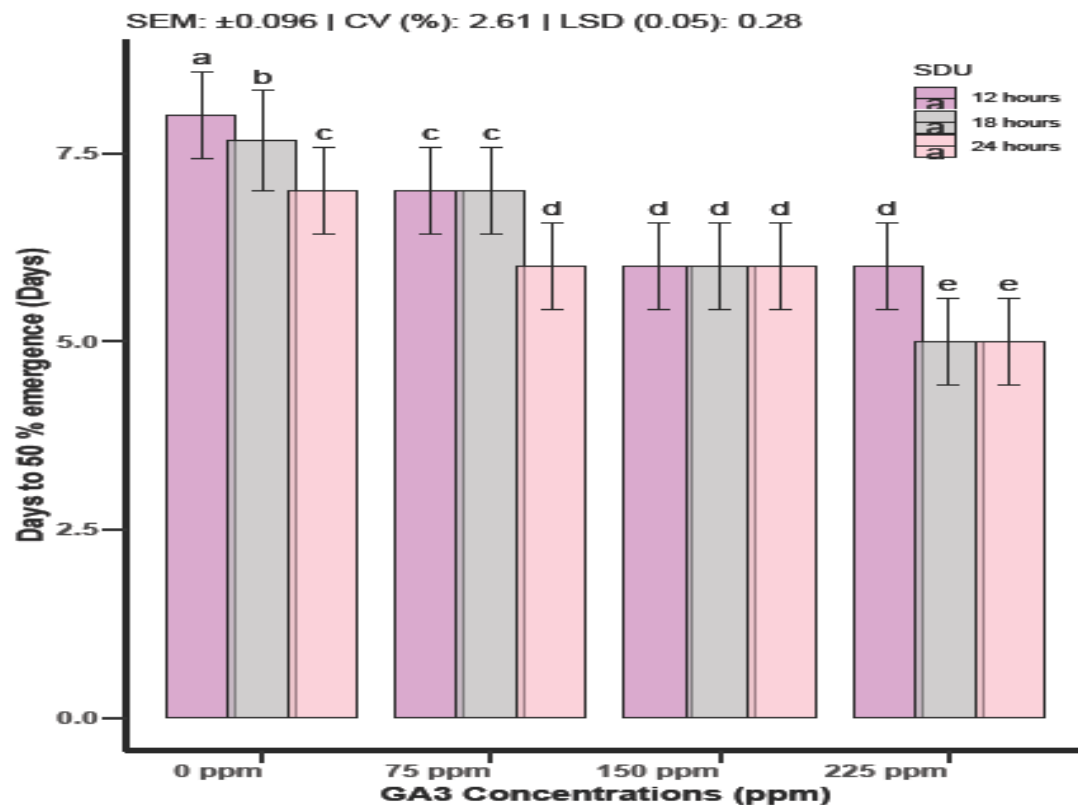


Figure 4.1. The interaction effect of GA₃ concentration and soaking duration on days to 50 % emergence

Mean emergence time (MET)

The ANOVA results indicated that the main effect and their interaction effect of GA₃ concentration and the soaking duration highly significantly influenced mean emergence time ($P < 0.001$) (Appendix Table 2). As illustrated in Figure 4.2, seeds treated with 225 ppm GA₃ concentration for 24 hours resulted in the shortest mean emergence time of 6.12 days, while seeds soaked with solely distilled water for 12 hours showed the longest mean emergence time of 9.1 days.

These findings indicate that the application of GA₃ at 225 ppm concentration for 24 hours resulted in a reduction of approximately 32.74% in emergence time compared to the control. This improvement is attributed to the combined effects of optimal GA₃ concentrations and soaking duration, which enhance water absorption, increase metabolic activity, and promote uniform and synchronized germination (Jamil and Rha, 2007; Ali Adam *et al.*, 2021; Setiawan, 2022). These findings are supported by Kandil *et al.* (2014), who reported that sugar beet seed treated with GA₃ at 200 ppm significantly reduced mean germination time. Furthermore, Khan *et al.* (2017), Arun *et al.* (2017), and

Mohammed (2023) indicated the positive effect of GA₃ seed priming to reduce the mean emergence time of different plant species.

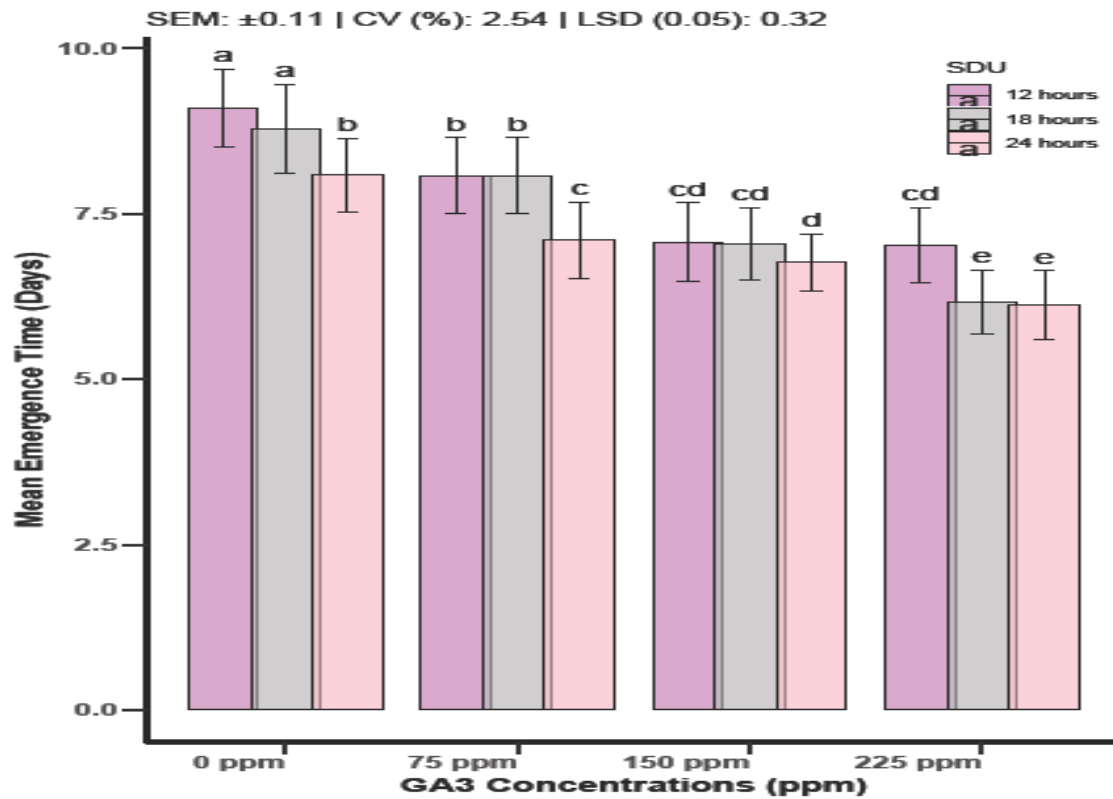


Figure 4.2. The interaction effect of GA₃ concentration and soaking duration on mean emergence time

Field Emergence Index (FEI)

The ANOVA demonstrated that the main effect and the interaction effect of GA₃ concentration and soaking duration significantly affected the field emergence index ($P < 0.001$) (Appendix Table 2). As depicted in Figure 4.3, seeds treated with 225 ppm GA₃ concentration for 24 hours showed the highest field emergence index of 3.71, while seeds soaked in distilled water for 12 hours exhibited the lowest field emergence index of 2.21.

These findings indicate that seeds treated with 225 ppm GA₃ concentration for 24 hours a resulted in remarkable improvement of 67.87% over the control treatment. This might be due to the optimal combination facilitating adequate hormonal stimulation and sufficient water uptake, both essential for activating metabolic pathways within the seeds (Chauhan *et al.*, 2019; Supral and Roshan, 2022). These findings align with previous research by Hamza and Ali (2017), who demonstrated that soaking corn seeds in 300 ppm GA₃

concentration for 24 hours significantly improved emergence rates and seedling growth, particularly under salt stress conditions. Additionally, Shariatmadari *et al.* (2017) reported similar results in chickpeas, where seed priming with GA₃ notably enhanced the field emergence index; specifically, seeds treated with 150 ppm GA₃ showed a marked increase in emergence rates compared to both control and those treated with lower concentrations of GA₃.

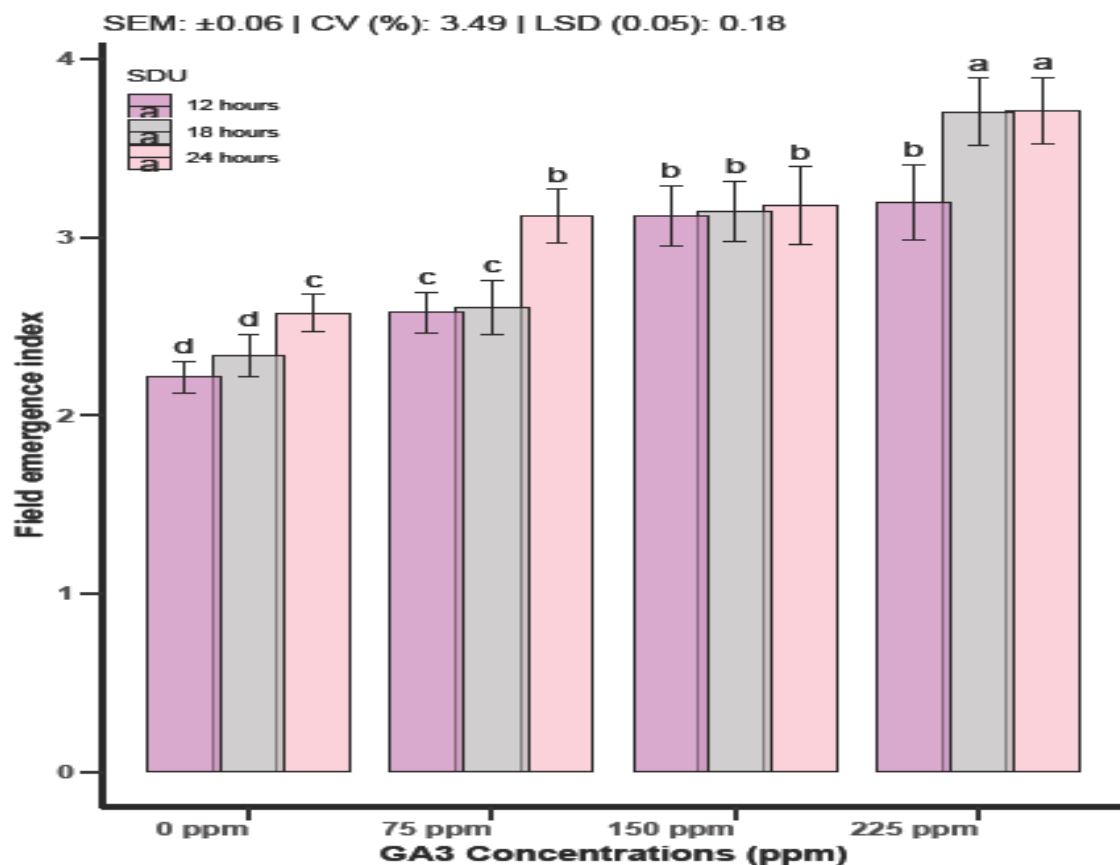


Figure 4.3. The interaction effect of GA₃ concentration and soaking duration on field emergence index

Final emergence percentage (FEP)

The ANOVA results revealed that the main effect of both GA₃ concentration and soaking duration showed high significant influence on the final emergence percentage ($P < 0.001$). However, the interaction effect between these two factors was not statistically significant ($P > 0.05$) (Appendix Table 2). As shown in Figure 4.4, the result indicates that seeds treated with 225 ppm GA₃ concentration showed the highest FEP of 95.37%, while seeds soaked with solely distilled water showed the lowest FEP of 84.72. This indicates an improvement of approximately 12.57% over the control treatment using solely distilled

water. In terms of soaking duration, seeds soaked for 24 hours achieved the highest FEP of 92.36%, while those soaked for only 12 hours recorded the lowest FEP of 89.24% (Figure 4.4).

The results of this study show that a 225 ppm GA₃ concentration significantly enhanced the final field emergence percentage. This enhancement can be attributed to gibberellin's role in improving the synthesis and secretion of hydrolytic enzymes from aleurone cells that mobilize the endosperm storage reserves that are crucial for fueling germination and subsequent growth (Ritchie *et al.*, 1999). Supporting our result, Shariatmadari *et al.* (2017) reported that seed priming with GA₃ at 150 ppm significantly improved emergence rates in chickpeas compared to control and lower concentrations of GA₃. Additionally, studies by Ali Adam *et al.* (2021) and Mohammed (2023) corroborate these findings, indicating increased emergence percentages in various crop species in response to GA₃ application. Regarding soaking duration, Nadeem *et al.* (2017) and Sabongari and Aliero (2004) provide compelling evidence that a soaking duration of around 24 hours is generally optimal for enhancing seed germination across various species.

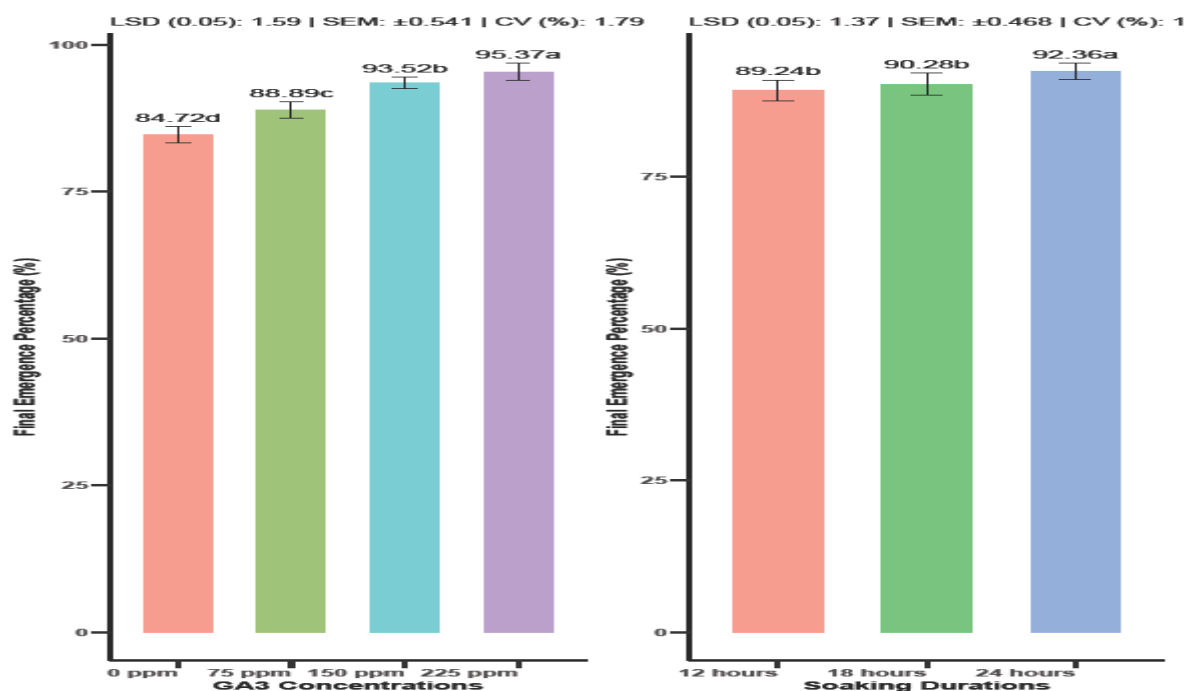


Figure 4.4. The main effect of GA₃ concentrations and Soaking duration on the final emergence percentage

4.2.2. Effect of GA₃ concentration and soaking duration on phenological parameters

The ANOVA indicated that both GA₃ concentration and soaking duration significantly affected all phenological parameters; however, their interaction was not significant ($P > 0.05$) (Appendix Table 3). As shown in Table 4.5, the result indicates that for the days to 50% tasseling, seeds treated with 225 ppm GA₃ resulted in the shortest duration of 62.33 days, while seeds soaked in distilled water (control) recorded the longest duration at 74.78 days. Similarly, in days to 50 % silking, seeds treated with 225 ppm GA₃ concentration showed the shortest days to 50 % silking (66.56 days), while seeds soaked in distilled water (control) showed the longest days to 50% silking of 79.78 days.

In terms of maturity date, seeds treated with GA₃ at 225 ppm concentration showed the shortest 50% maturity date of 132.33 days, whereas seeds soaked with solely distilled water exhibited the longest 50% maturity date of 139.44 days. This indicates that seeds treated with GA₃ at 225 ppm concentration resulted in an impressive reduction of approximately 12.45 days, 13.22 days, and 7.11 days in 50 % tasseling date, 50 % silking date, and 50 % maturity date of maize inbred line compared to the control (distilled water) respectively. In terms of soaking duration, seeds soaked for 24 hours resulted in the shortest days to 50 % tasseling (67.42 days), while seeds soaked for 12 hours showed the longest days to 50% tasseling (70.83 days). A similar trend was observed for days to 50% silking, seeds soaked for 24 hours exhibited the shortest time of 71.67 days, while those soaked for 12 hours showed the longest days to 50% silking (79.78 days). Finally, in 50% maturity date seeds soaked for 24 hours showed the shortest days to 50% maturity (134.83 days), while seeds soaked for 12 hours showed the longest maturity time of 137.75 days (Table 4.5).

The findings indicate that 225 ppm GA₃ concentration and 24 hours soaking duration significantly reduced tasseling, silking, and maturity dates of maize inbred lines. This can be attributed to GA₃'s ability to enhance seed germination and stimulate rapid vegetative growth, thereby facilitating a quicker transition from vegetative to reproductive phase (Mutasa-Göttgens and Hedden, 2009; Shah *et al.*, 2023). Moreover, GA₃ modulates plant hormones that regulate flowering time, shifting the balance toward earlier flowering while improving photosynthetic efficiency and resource allocation to reproductive structures (Evans and Poethig, 1995; Ramwant and SK, 2013; Abbas *et al.*, 2020). These findings are consistent with Husnain (2014), who reported that seeds treated with GA₃ at a concentration of 225 ppm significantly reduced days to 50% flowering and days to pod

maturity in chickpeas compared to the control. Furthermore, Ayaz *et al.* (2019) indicated that seeds treated with GA₃ at 60 mg/L reduced the first flowering date of bitter melon compared to control with lower concentrations of GA₃. In addition, Dawadi *et al.* (2023) and Budhathoki *et al.* (2024) also reported that seed priming shortened the tasseling date and silking date of maize compared to untreated seeds.

The influence of soaking duration on tasseling, silking, and maturity dates indicates that optimal soaking conditions enhance GA₃ absorption, leading to improved physiological responses. Specifically, a soaking period of 24 hours allows seeds sufficient time to absorb an adequate amount of GA₃, optimizing its effects on growth and development (Yayat *et al.*, 2017; Setiawan, 2022). In support of this result, Ayaz *et al.* (2019) reported that bitter melon seeds soaked in GA₃ for an extended time (18 hours) reduced the first flowering date compared to control and seeds soaked for 6 hours and 12 hours.

Table 4.5. The main effect of GA₃ concentration and soaking duration on phenological parameters

GA ₃ Conc.	DT	DS	DM
	(Days)	(Days)	(Days)
0 ppm (DW)	74.78 ^a	79.78 ^a	139.44 ^a
75 ppm	73.33 ^a	78.22 ^a	138.56 ^b
150 ppm	65.33 ^b	70.33 ^b	136.22 ^c
225 ppm	62.33 ^c	66.56 ^c	132.33 ^d
SEM (±)	1.05	1.08	0.27
LSD (0.05)	3.0676	3.1812	0.8058
P Value	< 0.001	< 0.001	< 0.001
Soaking Durations			
12 hours	70.83 ^a	75.42 ^a	137.75 ^a
18 hours	69.33 ^{ab}	74.08 ^{ab}	137.33 ^a
24 hours	67.42 ^b	71.67 ^b	134.83 ^b
SEM(±)	0.91	0.94	0.24
LSD (0.05)	2.6567	2.755	0.6978
P value	< 0.05	< 0.05	< 0.001
G Mean	69.19	73.72	136.64
CV (%)	4.53	4.41	0.6

Note: - GA₃ = Gibberellic Acid, ppm = part per million, DW = Distilled Water, LSD = List Significant Difference Test, SEM = Standard Error of Mean, CV = Coefficient of Variation, DT = Days to 50 % Tasseling, DS= Days to 50% silking, DM = Date of 50 % Maturity.

4.2.3.Effect of GA₃ concentration and soaking duration on yield and yield components maize inbred line

Ear height (EH) and Plant height (PH)

The results of this study indicated that the main effect of GA₃ concentration and soaking duration significantly influenced ear height and plant height, however, the interaction between GA₃ concentration and soaking duration was insignificant ($P > 0.05$) (Appendix Table 4) . As illustrated in Figures 4.5 & 4.6 the result indicates GA₃ concentrations positively influenced both ear height and plant height. Notably, seed treated with 225 ppm GA₃ concentration showed the longest ear height of 95.38 cm and plant height of 180.33 cm, while seed soaked in solely distilled water exhibited the shortest ear height of 76.33 cm and plant height of 153.51 cm. Additionally, soaking duration significantly affected ear height and plant height. Seed soaked for 24 hours resulted in the longest ear height and plant height of 88.61cm and 171.98 cm respectively while soaking durations of 18 hours resulted in the shortest ear height and plant height of 82.68 cm and 162.78 cm respectively (Figure 4.5 &4.6).

The findings of this study show that the application of 225 ppm GA₃ concentration and 24-hour soaking duration resulted in the most substantial improvements in both measured parameters as compared to the control. This might be due to GA₃ facilitates cellular processes such as elongation and division, leading to enhanced vegetative and reproductive growth (Shahzad *et al.*, 2021). Supporting our findings, Husnain (2014) reported that seeds treated with GA₃ at 225 ppm resulted in the tallest plant height in chickpeas compared to the control. Similarly, Shariatmadari *et al.* (2017) indicated that seeds treated with GA₃ at 150 ppm significantly increased plant length in chickpeas compared to the control and lower concentrations of GA₃. Furthermore, Aneela *et al.* (2017) and Arun *et al.* (2017) also reported that seed priming with GA₃ increased plant height in different crop species. In contrast, Atar and Akman (2014) reported that seed priming with gibberellic acid (GA₃) led to a reduction in plant height in wheat when compared to control groups.

Regarding soaking duration, a 24-hour soaking duration resulted in the highest plant height compared to lower durations. These findings are consistent with Ayaz *et al.* (2019), who indicated that a longer soaking duration enhanced plant height compared to the lower durations.

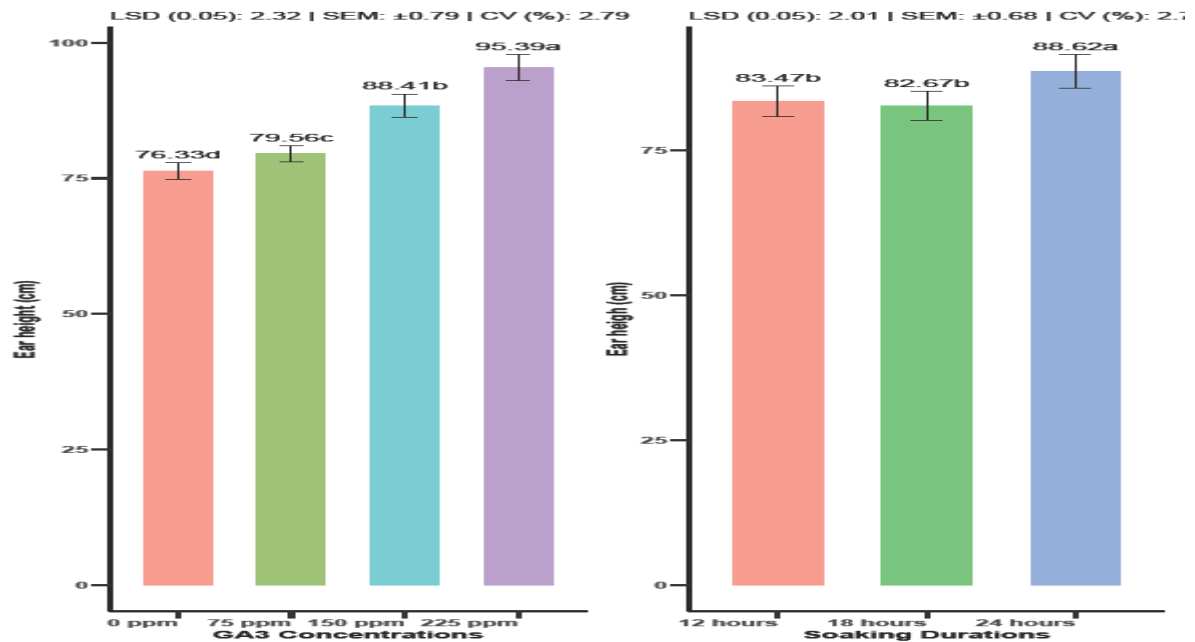


Figure 4.5. The main effect of GA₃ concentrations and soaking duration on ear height

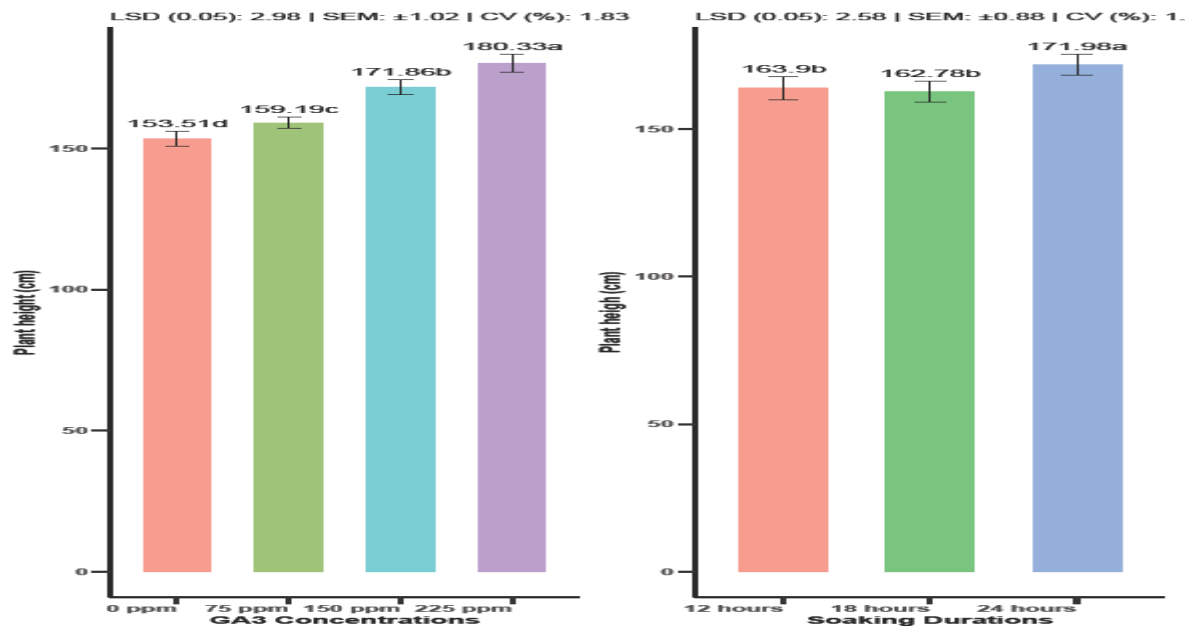


Figure 4.6. The main effect of GA₃ concentrations and soaking duration on plant height

Ear length (EL) and Ear diameter (ED)

The ANOVA results indicated that the main effect of GA₃ concentrations and soaking duration significantly influenced ear length and ear diameters, however, their interaction was not significant ($P > 0.05$) (Appendix Table 4). As shown in Table 4.6, seeds treated with 225 ppm of GA₃ concentration exhibited the longest ear length of 18.06 cm and ear diameter of 4.24 cm, however, both parameters were not statistically significantly different with seeds treated with GA₃ at 150 ppm concentration. In contrast, the control (distilled water) exhibited the shortest ear length of 14.53 cm and ear diameter of 3.46 cm. Regarding soaking duration, seeds soaked for 24 hours showed the longest ear length and diameter of 17.55 cm and 4.06 cm, respectively, while soaking durations of 18 hours resulted in the shortest ear length and ear diameter of 16.03 cm and 3.8 cm, respectively (Table 4.6).

The findings of this study indicate that a 225 ppm GA₃ concentration resulted in the most substantial improvements in both measured parameters. The effectiveness of higher GA₃ concentrations can be attributed to several mechanisms, including enhanced cell elongation and division, improved hormonal balance, and better nutrient uptake (Wang *et al.*, 2020; Xu *et al.*, 2024). This result aligns with previous research by Sopacua *et al.* (2022), who reported that sweet corn treated with 150 ppm GA₃ significantly increased ear length and diameter compared to control groups. Additionally, Ghodrat *et al.* (2012) and Mahender *et al.* (2018) corroborated these findings, highlighting the positive effects of GA₃ on maize ear characteristics. In terms of soaking duration, the optimal results observed with a 24-hour soaking period suggest that extended exposure to GA₃ enhances its absorption and efficacy within the plant system (Yayat *et al.*, 2017).

Kernel row per ear (KRPE) and Number of kernels per row (NKPR)

The ANOVA results indicated that the main effects of both GA₃ concentration and soaking duration significantly affected the kernel rows per ear and the number of kernels per row ($P < 0.001$) (Appendix Table 4). However, the interaction effect between GA₃ concentration and soaking duration was non-significant ($P > 0.05$). As shown in Table 4.6, seeds treated with 225 ppm GA₃ exhibited the highest average kernel rows per ear (14.16) and number of kernels per row (35.61), while seeds soaked in distilled water (control) recorded the lowest averages of 12.3 kernel rows per ear and 26.04 kernels per row,

respectively. Regarding soaking duration, seeds soaked for 24 hours exhibited an average of 13.56 kernel rows per ear and 32.36 kernels per row, while those soaked for 18 hours showed averages of 13.16 kernel rows per ear and 29.95 kernels per row, which were not significantly different from seeds soaked for 12 hours (Table 4.6).

The findings of this study demonstrate that seeds treated with a higher concentration of GA₃ (225 ppm) resulted in the highest kernel rows per ear and number of kernels per row compared to the control (distilled water). This improvement may be attributed to GA₃'s role in promoting the mobilization of reserve food materials to the developing sink through increased activity of hydrolyzing and oxidizing enzymes (Ghodrat *et al.*, 2012). These findings are supported by Sarwar *et al.* (2017) and Singh *et al.* (2018), who reported that foliar application of gibberellic acid significantly increased the number of kernels per row and the number of kernels per ear.

Table 4.6. The main effect of GA₃ concentration and soaking duration on ear characteristics

GA ₃ Conc.	NEPP	EL (cm)	ED (cm)	KRPE	NKPR
0 ppm (DW)	1.23	14.53 ^c	3.46 ^c	12.3 ^d	26.04 ^d
75 ppm	1.21	16.07 ^b	3.85 ^b	13.1 ^c	29.27 ^c
150 ppm	1.22	18.02 ^a	4.13 ^a	13.73 ^b	32.77 ^b
225 ppm	1.24	18.07 ^a	4.24 ^a	14.16 ^a	35.61 ^a
SEM (±)	0.014	0.23	0.05	0.054	0.514
LSD (0.05)	NS	0.66	0.15	0.1571	1.5068
P Value	> 0.05	<.001	<.001	< 0.001	< 0.001
Soaking durations					
12 hours	1.22	16.44 ^b	3.9 ^b	13.24 ^b	30.45 ^b
18 hours	1.21	16.02 ^b	3.8 ^b	13.16 ^b	29.95 ^b
24 hours	1.24	17.55 ^a	4.06 ^a	13.56 ^a	32.36 ^a
SEM (±)	0.012	0.20	0.04	0.046	0.445
LSD (0.05)	NS	0.57	0.13	0.1361	1.305
P value	> 0.05	<.001	< 0.01	< 0.001	< 0.01
G Mean	1.22	16.67	3.92	13.33	30.93
CV (%)	3.61	4.06	3.96	1.21	4.98

Note: - GA₃ = Gibberellic Acid, ppm = part per million, DW = Disilled Water, LSD = List Significant Difference Test, SEM = Standard Error of Mean, CV = Coeficient of Variation NEPP= Number of Ear Per Plant, KRPE = Kernel Row Per Ear, NKPR = Number of Kernel Per Row

Thousand kernel weight (TKW)

The ANOVA results revealed that both the main effects of GA₃ concentration and soaking duration significantly influenced the thousand kernel weight of maize inbred lines ($P < 0.001$). However, the interaction between these two factors was not statistically significant ($P > 0.05$) (Appendix Table 4). The results presented in Table 4.7 showed that seeds treated with 225 ppm GA₃ exhibited the highest thousand kernel weight of 313.27 grams, whereas the control, which was soaked in distilled water, showed the lowest thousand kernel weight of 275.78 grams. In terms of soaking duration, seeds subjected to a 24-hour soaking duration resulted in the highest thousand kernel weight of 300.04 grams, while a 12-hour soaking duration showed the lowest thousand kernel weight of 291.45 grams (Table 4.7).

The findings of this study indicate that seeds treated with 225 ppm GA₃ significantly enhanced thousand kernel weight compared to the control. This suggests that GA₃ at optimal concentrations can improve kernel weight, likely by enhancing germination rates, seedling vigor, and physiological processes that contribute to biomass accumulation. These findings are supported by Husnain (2014) and Mazed, H. *et al.* (2015), who reported that seeds treated with 225 ppm GA₃ significantly improved the thousand seed weight of chickpeas compared to the control. Additionally, Sarwar *et al.* (2017) indicated that foliar application of 150 mg/L GA₃ improved the thousand seed weight of maize.

Seed yield (SY)

The ANOVA results revealed that the main effects of both GA₃ concentrations and soaking duration significantly affected seed yield ($P < 0.001$). However, the interaction between these two factors did not significantly influence seed yield ($P > 0.05$) (Appendix Table 4). As shown in Table 4.7, seeds treated with 225 ppm GA₃ produced the highest seed yield of 4.22 t/ha, whereas seeds soaked solely in distilled water (control) showed the lowest seed yield of 2.40 t/ha. These results indicate that the application of 225 ppm GA₃ increased seed yield by approximately 75.83% compared to the control. Additionally, a

soaking duration of 24 hours resulted in the highest seed yield of 3.44 t/ha, while a 12-hour soaking duration yielded the lowest seed yield of 3.29 t/ha (Table 4.7).

The findings from this study demonstrate that seeds treated with 225 ppm GA₃ concentration significantly increased seed yield compared to the control. This improvement in yield can be attributed to GA₃'s role in stimulating plant growth mechanisms, particularly through the elongation of internodes and the expansion of leaf area. These physiological changes enhance light interception and photosynthesis, which are critical for biomass accumulation and ultimately lead to increased seed yield (Noor *et al.*, 2017). These findings align with those of Mazed, H. *et al.* (2015) and Husnain (2014), who reported that seeds treated with GA₃ at a concentration of 225 ppm significantly increased the seed yield of chickpeas compared to the control. Additionally, Arun *et al.* (2017) and Ayaz *et al.* (2019) found that GA₃ seed priming positively affected the yield of bitter melon and cowpea, respectively. Conversely, Tian *et al.* (2014) and Shariatmadari *et al.* (2017) reported no significant effect on the seed yield of maize and chickpeas, respectively.

Regarding soaking duration, a 24-hour soaking duration significantly enhanced seed yield compared to lower durations. These results align with Ayaz *et al.* (2019), who indicated that higher soaking durations significantly enhanced grain yield compared to lower durations.

Above biomass yield (ABY)

The results of this study demonstrated that both the main effect of GA₃ concentration and soaking duration significantly influenced aboveground biomass yield ($P < 0.001$). However, their interaction effect was not statistically significant ($P > 0.05$) (Appendix Table 4). As shown in Table 4.7, seeds treated with 225 ppm GA₃ concentration showed the highest aboveground biomass yield of 9.63 t/ha. In contrast, seeds treated with distilled water resulted in the lowest aboveground biomass yield of 7.76 t/ha. In terms of soaking duration, seeds subjected to a 24-hour soaking duration exhibited the highest aboveground biomass yield of 8.89 t/ha, while a 12-hour soaking duration resulted in the lowest aboveground biomass yield of 8.65 t/ha (Table 4.7).

The findings from this study show that seeds treated with 225 ppm GA₃ concentration significantly increased the aboveground biomass yield compared to the control group

(distilled water). This might be due to improved germination rates, enhanced photosynthetic activity, and the activation of growth-related enzymes (Sarkar *et al.*, 2018). These findings are consistent with Husnain (2014) and Mazed, H. *et al.* (2015), who reported that seeds treated with GA₃ at a 225 ppm concentration significantly improved the biological yield of chickpeas compared to the control.

Harvest index (HI)

The ANOVA results revealed that the main effect of GA₃ concentration significantly influenced the harvest index of the seeds. However, the main effect of soaking duration and the interaction effect were not statistically significant ($P > 0.05$) (Appendix Table 4). As indicated in Table 4.7, seeds treated with 225 ppm GA₃ showed the highest harvest index of 43.80 %, while seeds that were soaked solely in distilled water (control) exhibited the lowest harvest index of 30.88%.

The results indicate that the application of GA₃, particularly at a concentration of 225 ppm, can effectively enhance the harvest index of seeds. This might be due to the GA₃ application's accelerated photosynthetic activity and translocation of photosynthates to the sink, which leads to a recorded higher harvest index (Ramesh *et al.*, 2019). These results are in line with Mazed, H. *et al.* (2015) and Husnain (2014), who reported that seeds treated with GA₃ at a concentration of 225 ppm showed the highest harvest index of chickpeas compared to control. Additionally, Arun *et al.* (2017) indicated that cowpea seeds treated with GA₃ resulted in the highest harvest index compared to other treatments.

Table 4.7. The main effect of GA₃ concentration and soaking duration on thousand kenel weight, seed yield, above biomas yield and harvest index

GA ₃ Conc.	TKW	SY	ABY	HI
	(g)	(t/ha)	(t/ha)	(%)
0 ppm	275.78 ^d	2.40 ^d	7.76 ^d	30.88 ^d
(DW)				
75 ppm	284.37 ^c	3.18 ^c	8.54 ^c	37.33 ^c
150 ppm	305 ^b	3.58 ^b	9.00 ^b	39.80 ^b
225 ppm	313.27 ^a	4.22 ^a	9.63 ^a	43.80 ^a
SEM (±)	1.323	0.016	0.050	0.243
LSD (0.05)	3.8812	0.0479	0.1463	0.7127
P Value	< 0.001	< 0.001	< 0.001	< 0.001
Soaking durations				
12 hours	291.45 ^b	3.29 ^b	8.65 ^b	37.70
18 hours	292.34 ^b	3.30 ^b	8.67 ^b	37.74
24 hours	300.04 ^a	3.44 ^a	8.89 ^a	38.37
SEM (±)	1.146	0.014	0.043	0.210
LSD (0.05)	3.3612	0.0414	0.1267	NS
P value	< 0.001	< 0.001	< 0.01	> 0.05
G Mean	294.61	3.35	8.73	37.94
CV (%)	1.35	1.46	1.71	1.92

Note: - GA₃ = Gibberellic Acid, ppm = part per million, DW = Distilled Water, LSD = List Significant Difference Test, SEM = Standard Error of Mean, CV = Coefficient of Variation, TKW = Thousand Kernel Weight, SY = Seed Yield, ABY = Above ground Biomas Yield, and HI = Harvest Index

4.2.4. Correlation among agronomic traits

The Principal Component Analysis (PCA) revealed that the first two principal components (PCs) had eigenvalues greater than one, collectively explaining 85.22% of the total variation across the 18 measured traits. Principal Component 1 (PC1) accounted for 66.78% of the variance, while Principal Component 2 (PC2) contributed 18.44% (Figure

4.7). This high cumulative variance indicates that these two components effectively capture the majority of the variability in the dataset (Figure 4.7).

The PC1 was positively influenced by several key agronomic traits, including plant height, seed yield, ear height, biomass yield, harvest index, thousand kernel weight, number of kernels per row, ear length, and ear diameter. Conversely, traits such as days to 50% silking and days to 50% tasseling had a negative influence on PC1. On the other hand, PC2 was primarily influenced by days to 50% maturity, days to 50% emergence, mean emergence time, kernel rows per ear, field emergence index, ear length, and ear diameter. These findings highlight the distinct contributions of different traits to the principal components, with PC1 emphasizing yield-related traits and PC2 focusing more on developmental and structural characteristics.

Strong positive correlations were observed between seed yield and several critical traits, including biomass yield, harvest index, plant height, ear height, thousand kernel weight, and number of kernels per row. These correlations suggest that improvements in these traits could lead to enhanced seed yield. In contrast, days to 50% silking and days to 50% tasseling exhibited strong negative correlations with seed yield (Figure 4.7). This implies that delayed silking and tasseling may adversely affect yield, underscoring the importance of early flowering in optimizing productivity (Figure 4.7).

Regression analysis was performed to examine the relationship between the principal components and seed yield (Figure 4.8). The resulting regression equation was $y = 3.35 + 0.19 \times \text{PC1} + 0.04 \times \text{PC2}$, where y represents seed yield, and PC1 and PC2 are the first two principal components. The intercept value of 3.35 represents the baseline seed yield when both principal components are zero. The positive coefficient for PC1 (0.19) indicates that an increase in PC1 is associated with a significant increase in seed yield, reinforcing the positive contributions of the yield-related traits linked to this component. Similarly, the positive coefficient for PC2 (0.04) suggests that an increase in this component is associated with a slight increase in seed yield, highlighting the minor but positive effects of the traits contributing to PC2. Furthermore, the high R^2 value of 0.911 demonstrates that these two principal components explain 91.1% of the variation in seed yield, emphasizing their strong predictive power.

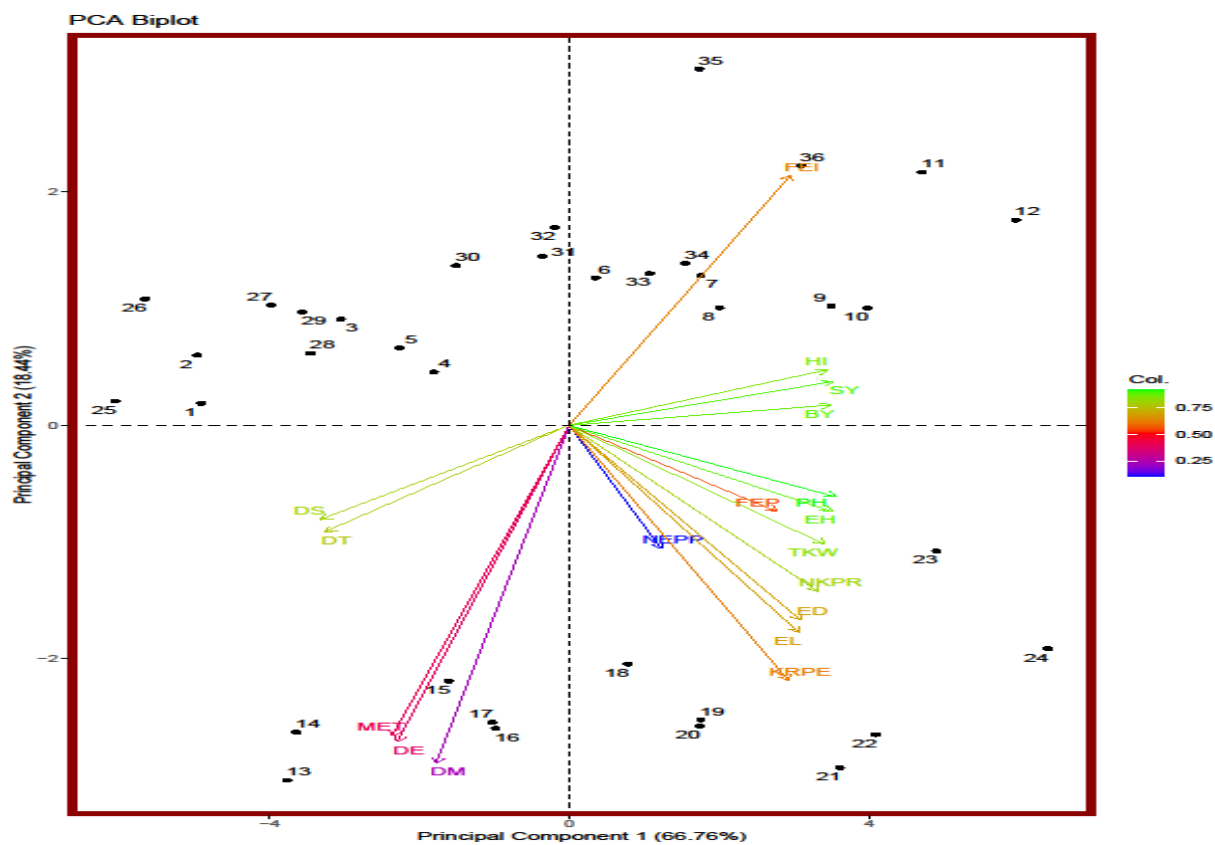


Figure 4.7. Biplot (axes PC1 and PC2) of 18 measured traits of maize inbred line

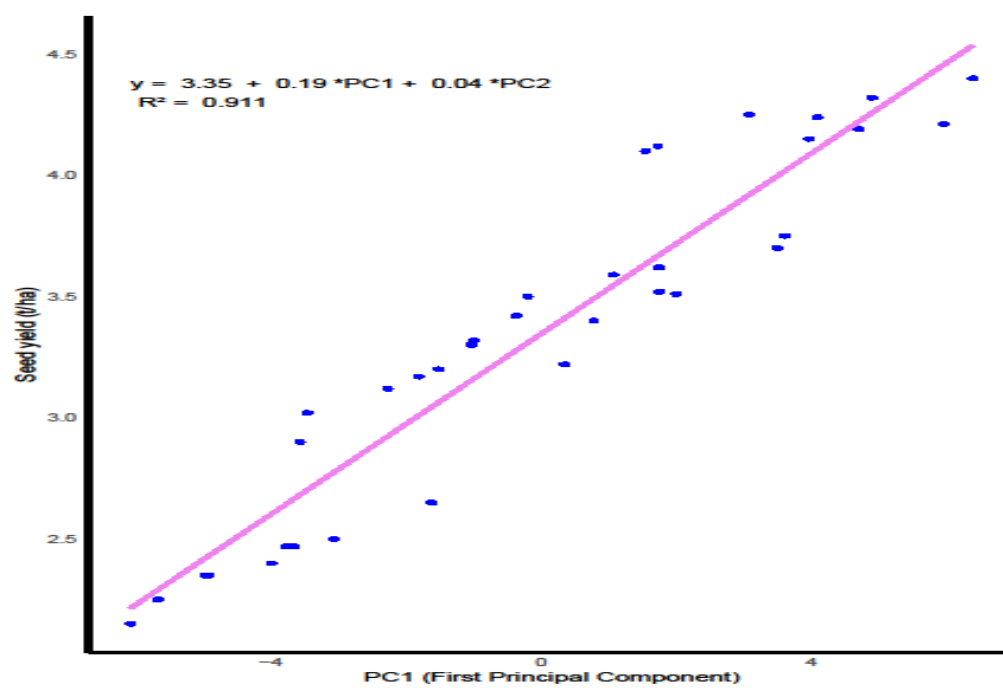


Figure 4.8. The relation between principal components (PCA 1 and PCA2) and seed yield

The relation between seed yield and major contributing traits:

The graphs illustrate the relationships between seed yield (t/ha) and four major traits (Figure 4.9). The analysis showed that biomass yield (BY) and harvest index (HI) had the strongest influence on seed yield. Biomass yield exhibited a very high correlation with seed yield ($R^2=0.963$), indicating that an increase in overall plant biomass had directly contributed to higher yield production. Similarly, the harvest index ($R^2=0.977$) had the highest correlation, suggesting that improving the efficiency of biomass conversion into grain had significantly enhanced seed yield (Figure 4.9). These results highlighted that among the traits studied, BY and HI had been the most critical factors for maximizing crop productivity, making them key targets for past breeding and agronomic improvements.

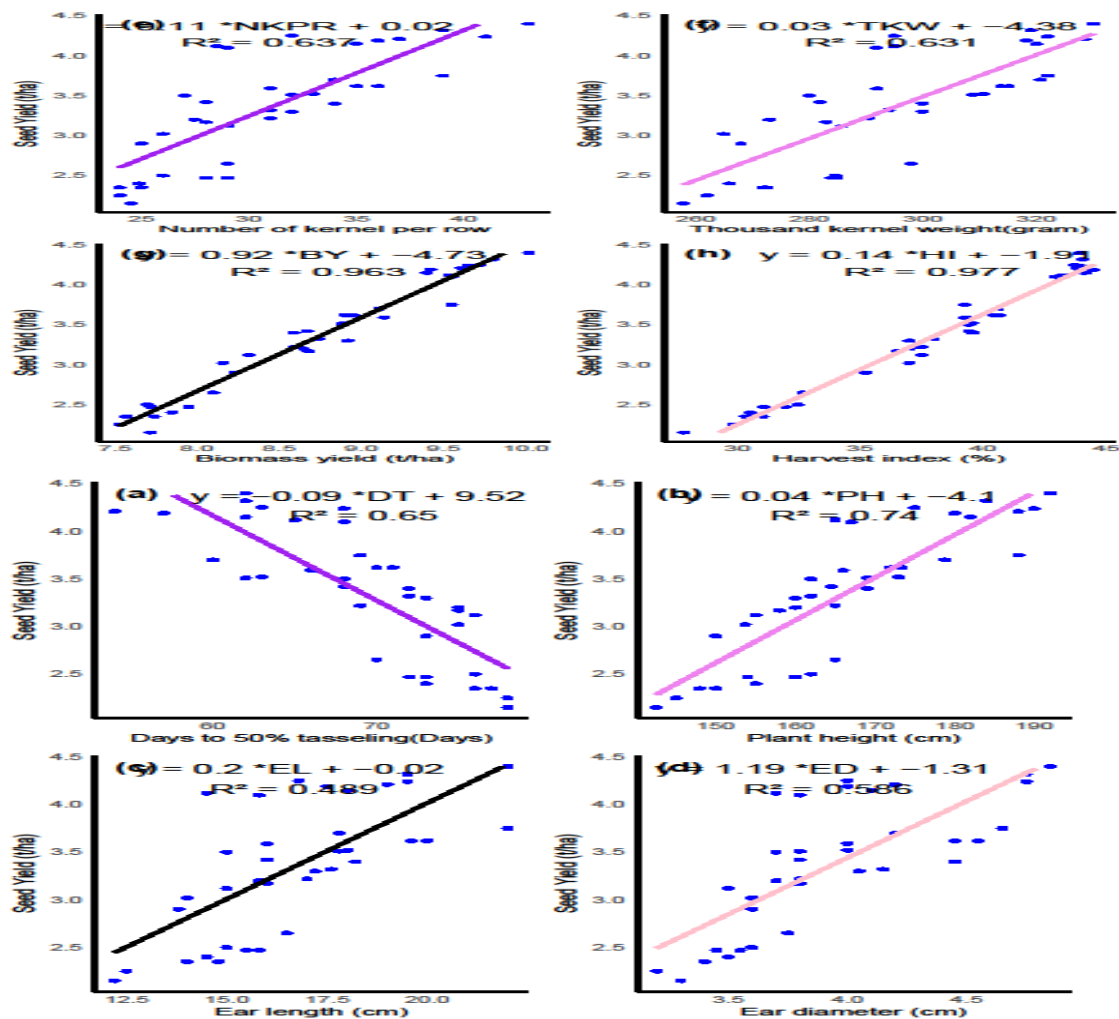


Figure 4.9. The relation between seed yield and major contributing traits of maize inbred line

4.3. Partial Budget Analysis

The partial budget analysis revealed that seeds treated with a 225 ppm GA₃ concentration provided the highest net benefit of 510,293.16 ETB/ha and a marginal rate of return (MRR) of 1,420.06% (Table 4.8). This indicates that the additional investment in GA₃ application resulted in a significant economic gain, as the return on investment far exceeded the costs incurred. The high MRR suggests that the benefits from this treatment substantially outweighed the expenses, making it the most cost-effective option for seed producers. In contrast, seeds soaked solely in distilled water (0 ppm GA₃) resulted in the lowest net benefit of 298,622.40 ETB/ha (Table 4.8).

Similarly, regarding soaking duration, a 24-hour soaking period yielded the highest net benefit of 427,705.44 ETB/ha and the highest marginal rate of return (MRR) at 11,524.76%. In contrast, a 12-hour soaking period resulted in the lowest net benefit of 409,322.79 ETB/ha (Table 4.8).

These findings highlight that both GA₃ concentration and soaking duration significantly influence economic returns. Seed producers who adopt these treatments can expect substantial financial returns, enhanced seed quality, and improved competitiveness in the market. The results demonstrate the economic advantage of investing in improved agricultural practices, particularly the combination of GA₃ application and extended soaking duration.

Table 4.8. Partial budget analysis for the main effect of both GA₃ concentration and soaking duration on seed yield of maize inbred line

GA ₃ Conc.(ppm)	SY (t/ha)	Adjusted SY (t/ha)	GR (ETB/ha)	VC GA ₃ cost (ETB/ha)	Labor cost (ETB/ha)	TVC (ETB/ha)	NB (ETB/ha)	MRR (%)
0 (DW)	2.40	2.16	298,922.40	0	300	300.00	298,622.40	-
75	3.18	2.86	395,795.40	4,944.70	450	5,394.70	390,400.70	1801.45
150	3.58	3.22	445,615.80	9,708.39	600	10,308.39	435,307.41	913.91
225	4.22	3.8	525,882.00	14,838.84	750	15,588.84	510,293.16	1420.06
Soaking duration								
12 hours	3.29	2.96	409,772.79	-	450	450	409,322.79	-
18 hours	3.30	2.97	411,018.30	-	600	600	410,418.30	730.34
24 hours	3.44	3.10	428,455.44	-	750	750	427,705.44	11,524.76

Note: - GA₃= Gibberellic Acid concentration, SY = Seed yield, GR = Gross Revenue, VC = Variable cost, TVC = Total variable cost, NB = Net benefit, MRR = Marginal rate of return, DW = Distilled Water, ETB = Ethiopian birr.

Chapter 5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study found that both Gibberellic Acid (GA_3) concentration and soaking duration significantly affected the seed physiological quality, yield, and yield components of maize inbred lines. However, the interaction between these factors was not significant. On the other hand, field emergence parameters were significantly influenced by both the main effects and their interaction.

Seeds treated with 225 ppm GA_3 and a 24-hour soaking duration independently resulted in the highest seed germination, seedling vigor index, and seed yield, while also reducing the 50% maturity date. In contrast, seeds treated with 255 ppm GA_3 for 24 hours enhanced the field emergence index and reduced the mean emergence time. The partial budget analysis confirmed the feasibility of treating seeds with 225 ppm GA_3 , yielding a net benefit of 510,293.16 ETB/ha and a marginal rate of return of 1,420.06%. Similarly, a 24-hour soaking duration resulted in the highest net benefit (427,705.44 ETB/ha) and marginal rate of return (11,524.76%).

This study highlights the benefits of GA_3 treatment and optimal soaking duration in maize inbred lines, improving seed quality, field emergence, and yield while shortening the maturity period.

5.2. Recommendations

Based on the findings of this study, maize inbred line seeds treated with 225 ppm GA_3 and soaked for 24 hours before planting significantly enhanced seed physiological qualities, field emergence, yield, and yield components. Moreover, since these treatments proved to be the most economically feasible, they present a promising option for maize inbred line production. However, this experiment was conducted in a single location and during a single year. Therefore, further research is needed to confirm the consistency and applicability of these results; specifically, it is necessary to repeat the field experiment over multiple years and across different locations.

Chapter 6. REFERENCES

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Chapter 7. APPENDICES

Appendix Table 1. The mean square value of analysis of variance for seed physiological qualities parameters of maize inbred line

Traits	Source of Variations			
	GA ₃ Conc. (DF=3)	Soaking duration (DF=2)	GA ₃ *SDU (DF=6)	Error (DF=36)
GP	53.021***	8.271*	0.187 ^{ns}	1.576
SPG	8.6501***	0.8020**	0.0837 ^{ns}	0.1242
MGT	2.02692***	0.40816**	0.00828 ^{ns}	0.05056
SL	38.540***	1.871 ^{ns}	0.116 ^{ns}	0.686
RL	41.464***	6.017**	0.304 ^{ns}	0.870
RSR	0.162780***	0.000727 ^{ns}	0.003122 ^{ns}	0.007723
SDW	0.031724***	0.004258***	0.000056 ^{ns}	0.000410
SVI I	1859881***	181130***	5426 ^{ns}	14017
SVI II	324.68***	44.84***	0.55 ^{ns}	3.47

*Significant. codes: '***' 0.001 '**' 0.01 '*' 0.05, GP = Germination Percentage, SPG = Speed of Germination, MGT = Mean Germination Time, SL = Shoot Length, RL = Root Length, SDW = Seedling Dry Weight, VI I = Vigor Index I, VI II = Vigor Index II.*

Appendix Table 2. The mean square value of Analysis of variance for field emergence parameters of maize inbred line

Traits	Source of Variations				
	Replication (DF=2)	GA ₃ Conc. (DF=3)	Soaking duration (DF=2)	GA ₃ *SDU (DF=6)	Error (DF=22)
DE	12.03***	8.11***	1.69***	0.36***	0.03
MET	10.95***	8.43***	1.97***	0.22**	0.04
FEI	0.82***	2.23***	0.41***	0.08**	0.01
FEP	179.32***	206.22***	30.38**	4.66 ^{ns}	2.63

*Significant. codes: '***' 0.001 '**' 0.01 '*' 0.05, DF = Degree of freedom, GA₃ = Gibberellic Acid, SDU = Soaking duration, DE = Days to 50 % emergence, MET = Mean emergence time, FEI = Field emergence index, FEP = Final emergence percentage*

Appendix Table 3. The mean square value of Analysis of variance for phenological parameters of maize inbred line

Traits	Source of Variations				
	Replication (DF=2)	GA ₃ Conc. (DF=3)	Soaking duration (DF=2)	GA ₃ *SDU (DF=6)	Error (DF=22)
DT	39.36*	310.69***	35.19*	4.31 ^{ns}	9.85
DS	60.86*	359.30***	43.36*	2.99 ^{ns}	10.59
DM	135.86***	90.77***	29.86***	0.94 ^{ns}	0.68

*Significant. codes: '***' 0.001 '**' 0.01 '*' 0.05, DF = Degree of freedom, GA₃ = Gibberellic Acid, SDU = Soaking duration, , DT = Days to 50 % tasseling, DS = Days to 50 % silking, DM =Days to 50 % maturity*

Appendix Table 4. The mean square value of Analysis of variance for yield and yield components of maize inbred line

Traits	Source of Variations				
	Replication (DF=2)	GA ₃ Conc. (DF=3)	Soaking duration (DF=2)	GA ₃ *SDU (DF=6)	Error (DF=22)
EH	334.42 ^{***}	672.88 ^{***}	124.76 ^{***}	6.294 ^{ns}	5.63
PH	570.09 ^{***}	1325.694 ^{***}	302.454 ^{***}	9.777 ^{ns}	9.28
EL	570.09 ^{***}	26.13 ^{***}	7.46 ^{***}	0.175 ^{ns}	0.46
ED	1.27 ^{***}	1.08 ^{***}	0.2 [*]	0.0021 ^{ns}	0.02
NEPP	0.02 [*]	0.0011 ^{ns}	0.0023 ^{ns}	0.00326 ^{ns}	0.0019
KRPE	14.38 ^{***}	5.93 ^{***}	0.543 ^{***}	0.059 ^{ns}	0.03
NKPR	163.62 ^{***}	155.78 ^{***}	19.38 [*]	1.03 ^{ns}	2.38
TKW	2851.02 ^{***}	2746.11 ^{***}	267.80 ^{***}	11.14 ^{ns}	15.76
ABY	0.27 ^{***}	5.57 ^{***}	0.21 ^{**}	0.02 ^{ns}	0.02
HI	6.45 ^{***}	264.25 ^{***}	1.69 ^{ns}	0.88 ^{ns}	0.53
SY	0.15 ^{***}	5.23 ^{***}	0.08 ^{***}	0.003 ^{ns}	0.0024

Significant. codes: '***' 0.001 '**' 0.01 '*' 0.05, DF = Degree of freedom, GA₃ = Gibberellic Acid, SDU = Soaking duration, EH = Ear height, PH = Plant height, EL = Ear length, ED = Ear diameter, NEPP= Number of Ear Per Plant, KRPE = Kernel Row Per Ear, NKPR = Number of Kernel Per Row, TKW = Thousand Kernel Weight, ABY = Above Biomass Yield, HI =Harvest Index, SY = Seed Yield



Appendix Figure 1. Laboratory trial during sowing



Appendix Figure 2. The laboratory trial on the tenth day



Appendix Figure 3. Pictures during sampling for measurement



Appendix Figure 4. Pictures during root length and shoot length measurement



Appendix Figure 5. Dried seedlings in the dry oven



Appendix Figure 6. Field trial after planting



Appendix Figure 7. Field trial at the emergence stage



Appendix Figure 8. Field trial at the vegetative stage



Appendix Figure 9. Field trial at the tasseling stage



Appendix Figure 10. Field trial during data recording

AUTHOR'S BIOGRAPHY

The author, Mr. Yemataw Chanie, was born from his father, Ato Chanie Haile, and his mother, W/ro Yeshye Kelkay, on April 21, 1991, in Addis Zemen, Libo Kemkem District, South Gondar Zone, Amhara Regional State. He attended his Junior Class at Addis Zemen Primary School from 1999 to 2006. He then pursued his Secondary and Preparatory Education at Addis Zemen Secondary High School from 2007 to 2010. After completing his Secondary and Preparatory School, he joined Adama Science and Technology University in 2011 and graduated with a B.Sc. Degree in Plant Science (Horticulture) on July 3, 2014.

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